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Information Flow Matters: Improving Productivity Performance in Engineering and Construction

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Engineering, The University of Auckland, 2017
Abstract

This research explores the problem of the relatively poor productivity performance of the engineering and construction sector in New Zealand. The objective is to gain an understanding of the linkages between information flow and productivity and thereby to identify future directions for improving productivity performance.

A mixed methods research approach is used, comprising of semi-structured interviews, surveys, observations and analyses of statistical performance data. A new information flow productivity causality model is proposed which links information flow as an input to productivity outcomes via a number of intermediate stages with productivity identified as a function of efficiency and effectiveness. A quantitative finding is that information flows are of statistical significance for organisational performance with knowledge-based information products giving significant potential for improvement. A comparison is also made between information search strategies undertaken by engineers for decision-making nowadays and those undertaken in the early 1980s, finding some dramatic changes in information flow patterns. However a preference for face to face communications has remained unchanged, with such information flows being important for the understanding and solution processes. Further analyses of information flows in meetings on a major project are also given, leading to numerous findings linking the quality of information to performance outcomes.

In a philosophical discussion a new definition of the semantic value of information is offered. This leads to a fresh understanding of the fundamental nature of informational value and allows for the incorporation of information into multifactor productivity.

Performance of the sector is also addressed at an aggregate level leading to new findings that performance of the wider supply chain in construction is better than previously indicated in other studies. Furthermore the causality of the construction sector productivity performance is identified as being the high volatility of the output demand and low investment rates in capital inputs.

As a contribution to knowledge evidence is presented that information flow matters, that it is a vitally important component to productivity performance. In conclusion fourteen key recommendations are made for productivity performance improvement.

KEYWORDS

Productivity; Information; Communications; Engineering and Construction.
Dedication

Dedicated to:

K – the best,

and to

H & R – who are also the best,

and to

M & D – who likewise are also the best.
Acknowledgements

The following are acknowledged as contributing to this thesis in different ways:

Firstly, to my supervisors, Dr Theunis Henning and Dr Andrea Raith is supervising the project with much wisdom, patience and generosity. Your guidance has been invaluable.

Secondly to BRANZ for funding my scholarship and providing assistance with inviting participants to contribute to the research.

Thirdly to the University of Auckland staff in the Department of Civil and Environmental Engineering who have provided encouragement throughout the years, particularly Prof Suzanne Wilkinson and Prof Pierre Quenneville.

Also, I would like to acknowledge the assistance from the numerous participants, including interviewees, questionnaire participants, the professional bodies and associations for advertising the questionnaires (BRANZ, IPENZ, NZCID and PMINZ) and staff at the Well-Connected Alliance for the industry observations. All your contributions to the primary data have enabled the research to be progressed in this field.

I acknowledge also my advisory committee and contributions of Prof Bruce Melville and Dr Jim Bentley. Also the valuable contributions of the assistants who helped with transcribing the interviews, data entry into database systems and assistance with coding of data. I also acknowledge Academic Consulting Ltd for proof reading to identify typographical errors.

Thank you.
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# Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alliance</td>
<td>A form of collaborative project delivery used in construction</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>BIM</td>
<td>Building information modelling</td>
</tr>
<tr>
<td>BRANZ</td>
<td>Building Research Association New Zealand</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer aided drafting</td>
</tr>
<tr>
<td>CEO</td>
<td>Chief executive officer</td>
</tr>
<tr>
<td>CIC</td>
<td>Construction Industry Council</td>
</tr>
<tr>
<td>CSG</td>
<td>Construction Strategy Group</td>
</tr>
<tr>
<td>DIKW</td>
<td>Data, information, knowledge, wisdom</td>
</tr>
<tr>
<td>FileMaker Pro</td>
<td>A database software tool, produced by FileMaker, a subsidiary of Apple</td>
</tr>
<tr>
<td>GFC</td>
<td>Global financial crisis</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information system</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>HR</td>
<td>Human resource</td>
</tr>
<tr>
<td>HSD</td>
<td>Honestly significant difference</td>
</tr>
<tr>
<td>ICT</td>
<td>Information communication technology</td>
</tr>
<tr>
<td>IPENZ</td>
<td>Institution of Professional Engineers New Zealand</td>
</tr>
<tr>
<td>I-Space</td>
<td>Information space</td>
</tr>
<tr>
<td>JIT</td>
<td>Just in time</td>
</tr>
<tr>
<td>KPI</td>
<td>Key performance indicator</td>
</tr>
<tr>
<td>MFP</td>
<td>Multifactor productivity (for full definition see Appendix A1)</td>
</tr>
<tr>
<td>MTI</td>
<td>Mathematical theory of information</td>
</tr>
<tr>
<td>NPV</td>
<td>Net present value</td>
</tr>
<tr>
<td>NVivo 10</td>
<td>A qualitative data analysis software tool, produced by QSR International</td>
</tr>
<tr>
<td>NZ</td>
<td>New Zealand</td>
</tr>
<tr>
<td>NZCID</td>
<td>New Zealand Centre for Infrastructure Development</td>
</tr>
<tr>
<td>NZS</td>
<td>New Zealand Standards</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>PMBoK</td>
<td>Project Management Body of Knowledge</td>
</tr>
<tr>
<td>PMINZ</td>
<td>Project Management Institute New Zealand</td>
</tr>
<tr>
<td>PPP</td>
<td>Public-private partnership</td>
</tr>
<tr>
<td>PSP</td>
<td>Professional services provider</td>
</tr>
<tr>
<td>RFI</td>
<td>Request for information</td>
</tr>
<tr>
<td>RMA</td>
<td>Resource Management Act</td>
</tr>
<tr>
<td>SME</td>
<td>Small to medium-sized enterprise</td>
</tr>
<tr>
<td>SNZ</td>
<td>Statistics New Zealand</td>
</tr>
<tr>
<td>SPSS</td>
<td>A statistical data analysis software tool, produced by IBM</td>
</tr>
<tr>
<td>TFP</td>
<td>Total factor productivity (for full definition see Appendix A1)</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
</tbody>
</table>
1 Introduction and Research Objectives

1.1 Introduction

This research addresses the problem of the relatively poor productivity performance in the engineering and construction sector of New Zealand (NZ). The particular focus of the research is on information flow. The central proposition is that a flow of information is an imperative to the efficient and effective delivery of projects in a highly fragmented industry such as the NZ engineering and construction sector. Our hypothesis, therefore, is that improvements to the quality of information flow (e.g., accuracy, reliability, timeliness) will deliver performance improvements for all parties involved within the industry. Our research may have applicability to other sectors within the NZ context that have similar problems and are highly reliant on informational inputs into value-creating activities, and to the engineering and construction sectors in other nations similar to NZ.

The issues of information flow and productivity in the construction sector are complex. Some preliminary statements are helpful for setting the context of the rest of this thesis:

- There appears to be some linkage between information flow and productivity. However, the mechanism linking information to performance outcomes is not well understood, either generally or in the particular context of the construction industry.
- The performance track record of the construction sector at the industry aggregate level appears to be poor, based on official statistical measurements of productivity.
- The contextual issues that have an effect upon productivity and performance outcomes in the construction industry are extensive and complex, and furthermore, are constantly in a state of flux, interacting upon each other in ways that make quantitative analysis of causality extremely difficult.
- There is no readily available theory of information flow applicable for investigating the problem statement under consideration. A new theory of information flow is therefore necessary to investigate our research objective.
- The impact of information flow upon productivity has not previously received significant levels of research attention. However, information flow has been identified and generally acknowledged as a relevant factor. The reasons for the lack of research on this topic are not known, but it is speculated that they may be related to the inherent difficulties in researching qualitative information inputs concurrently with quantitative productivity outcomes.
- There is no existing conceptual model linking information flow to productivity.

Our research investigates productivity issues in the NZ engineering and construction industry and seeks to identify possible means of improving productivity. The central challenge is to identify the root enablers and barriers to productivity growth within the sector. Addressing this challenge is important from both a theoretical and a practical point of view.
1.2 Research Objectives

Our objective was therefore defined as:

*To gain an understanding of the linkages between information flow and productivity in the engineering and construction sector; and thereby to identify future directions for improving productivity.*

Within this objective a number of goals were identified:

- **Goal 1:** To investigate the linkages between information flow and productivity within the sector and determine the extent to which productivity outcomes are dependent upon information flow inputs.
- **Goal 2:** To understand the mechanisms by which information flow affects productivity and thereby build a framework or causality model linking information flow with productivity.
- **Goal 3:** To identify the impact of information flow upon the quality of problem-solving and decision-making within the engineering and construction context.
- **Goal 4:** To investigate the relative effectiveness of different information search strategies for decision-makers.
- **Goal 5:** To identify the relative effectiveness of a range of information dissemination and transfer systems, including new and emerging information technology and management solutions.
- **Goal 6:** To provide some directions for productivity improvement for the engineering and construction sector in NZ.

1.3 Scope of Research

1.3.1 Within Scope

The scope of our research is set within the context of the NZ engineering and construction sector. The sector is defined in a broad sense, and covers all aspects of the built environment, including infrastructure, commercial property and housing. It also covers the extended supply chain, including clients, professional service providers, constructors, academia and government. The scope focuses on the NZ context, but where appropriate also includes comparisons with overseas countries.

This research project examines a number of interrelated themes, which include, but are not necessarily limited to, the following:

- information and productivity core bodies of knowledge;
- management theories applied to the engineering and construction sector, including issues relating to strategy, human resource management, organisational behaviour, procurement practices, supply chain management and engineering management decision-making;
• performance improvement theories, including theories associated with lean thinking and systems thinking;
• modern information communication technology (ICT) and management systems.

Within the context of these themes, the particular focus of the research at a fundamental level is on information flow and performance as measured by productivity.

1.3.2 Out of Scope

While this research draws upon a number of intersecting bodies of knowledge, it does not seek to advance knowledge specifically in the related fields. Specifically, out-of-scope items include the following:

• development of new macroeconomic theories of productivity in the field of economics;
• validation (or otherwise) of the existing productivity statistical data published by official sources such as Statistics New Zealand (SNZ);
• development of new ICT solutions;
• implementation of productivity performance improvement directions.

1.4 Thesis Structure

There are 10 chapters, which follow a logical progression of the research, with presentation of findings and development of contributions to knowledge in logical sequence as indicated in Table 1-1.

Table 1-1: Structure of This Thesis

<table>
<thead>
<tr>
<th>Chapter Heading</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction and Research Objectives</td>
<td>Setting of the objectives, goals and broad context for the research</td>
</tr>
<tr>
<td>2 Literature Review</td>
<td>Review of the main existing bodies of knowledge relating to the research</td>
</tr>
</tbody>
</table>
| 3 Research Design | Design of research methodology to suit the objectives and goals
Outline of broad philosophical considerations and development of a progressional research plan using grounded theory |
| 4 Development of a New Framework for Information Flow and Productivity | Phase 1 of primary data collection
Qualitative data collection via semi-structured interviews in order to gain depth of insight
Development of a framework as a causality model linking information flow with productivity |
| 5 Explorations into Information Flow Productivity Performance and Context Factors in Engineering and Construction | Phase 2 of primary data collection
Qualitative and quantitative data collection via industry questionnaire in order to validate and refine the model developed in Chapter 4 |
| 6 Information Search Patterns in Engineering and Construction | Phase 3 of primary data collection
Quantitative data collection via detailed questionnaire on decision-making in order to gain depth of insight into information search patterns for decision-making |
Chapter Heading | Brief Description
--- | ---
7 | Information Flow via Meetings and the Impacts upon Performance Outcomes in Engineering and Construction
Phase 4 of primary data collection
Qualitative and quantitative data collection via industry observations of series of meetings in a detailed case study in order to gain depth of understanding of information flow patterns on decision-making and productivity outcomes

8 | A New Theory of Information: An Information Semantic Theoretical Model
Theoretical development of a new theory of information, drawing on findings and conclusions of previous chapters

9 | Information Flow and Making the Linkage to Industry Productivity Performance at the Macroeconomic Level
Review of the overall findings and overarching development of discussion towards final conclusions

10 | Overarching Conclusions and Recommendations
Final conclusions and recommendations, including identification of contributions to knowledge, and future directions for ongoing research in the subject area

Following the introduction and literature review in Chapters 1 and 2 respectively, a research methodology is developed in Chapter 3. Various research approaches are compared and discussed in relation to the research objectives, and identify grounded theory as appropriate. Chapters 4 to 7 (inclusive) present the findings of the four main stages of primary data collection: Phase 1 comprising semi-structured interviews, Phases 2 and 3 comprising questionnaires, and Phase 4 comprising industry observations. At the start of each of these chapters a brief introduction is provided outlining the specific objectives of the stage of research, before presentation of the findings and analysis. At the end of each chapter there is a discussion and conclusion on the findings. Linkages are made between chapters by making further final conclusions in a progressional manner, in which conclusions are melded with previous conclusions in order to demonstrate the progressional nature of the research in stages. Chapter 8 differs from Chapters 4 to 7 in that it does not introduce any new primary data but rather synthesises the findings and development of conclusions from previous chapters into a new theory of information flow. Chapter 9 comprises some macroleconomic analyses of the NZ construction industry productivity performance in order to make final linkages between information and productivity. Chapter 10 provides an overarching set of conclusions and recommendations that address the objective and goals of the research and draw upon all the previous chapters. It concludes with sections identifying contributions to knowledge and possible future directions for ongoing research in the subject area. Appendices are used to present pertinent material to support the main body of the thesis.

1.5 Planned Contribution to Knowledge

The planned contribution to knowledge is to advance understanding of linkages between information flow as an input and productivity performance as an outcome within the engineering and construction sector. As this field has not been specifically researched to any significant extent, there is scope to contribute to the understanding of productivity causality. Goals 1 to 6
provide direction for the contribution to knowledge in the field. Specific contributions to knowledge planned are a framework for information flow and productivity, development of information theory and a set of recommendations for productivity improvement.
2 Literature Review

2.1 Introduction

The subjects of information and productivity have separately received considerable research interest from diverse fields, including information science, linguistics, philosophy, engineering, economics and social sciences. This chapter attempts to draw on the important themes and theories from these fields, particularly upon the concept of information flow and productivity, but also relevant literature from other related domains.

In this literature review we examine four components, each taken from a major body of knowledge. The knowledge areas have been selected on the basis of their importance to the subject matter, and are summarised in Table 2-1.

Table 2-1: Literature Review Outline

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>The intent of this section is to identify and critically assess the main information theories and conceptualisations of information flow.</td>
</tr>
<tr>
<td>Productivity</td>
<td>This section provides an overview of productivity metrics and a critical analysis of previous studies on productivity performance in the NZ construction sector. Reference is also made to overseas productivity studies. The intent is not an analysis of overseas comparisons; rather, it is to draw on international research on issues relating to productivity performance in the sector.</td>
</tr>
<tr>
<td>Lean Thinking</td>
<td>This section examines lean thinking theories and the application of such theories to construction. Lean is a management system founded on a philosophy of continuous improvement and reduction of the waste in order to improve overall value.</td>
</tr>
<tr>
<td>Decision-Making</td>
<td>Information has to be interpreted by human agents and applied in decision-making. Hence, in the context of improving performance outcomes, information cannot be divorced from decision-making. There is evidence that human agents typically do not use information in objective, rational ways. This section therefore examines theories relating to how human agents use information for decision-making.</td>
</tr>
</tbody>
</table>

2.2 Information

2.2.1 Definition of Information

Shenton (2004) suggested that the researcher’s notion of information as a concept is a critical factor in the study of information behaviour. It is important also to differentiate between information, data and knowledge. This is not straightforward. A study by 57 scholars from 16 countries identified 130 different definitions of the words data, information and knowledge (Zins, 2007b). These definitions are classified on the basis of two domains: the subjective domain and the universal domain. These differentiate between the subjective and the objective. Subjective knowledge exists in the individual’s internal world (e.g., a thought), whereas objective knowledge exists in the external world (e.g., published in books). Objective knowledge is not related necessarily to truthfulness, nor subject to the arbitrariness of the individual. Zins (2007b)
used the term universal knowledge, referring to this domain as the objective and collective realm. The differences between the domains are illustrated in Table 2-2.

**Table 2-2: Data, Information and Knowledge Domains**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Data</th>
<th>Information</th>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective Domain (SD)</td>
<td>The sensory stimuli, which we perceive through our senses Empirical perception</td>
<td>Meaning of the data Empirical knowledge</td>
<td>A thought in the individual’s mind, which is characterised by the individual’s justifiable belief that it is true</td>
</tr>
<tr>
<td>Universal Domain (UD)</td>
<td>Sets of signs that represent empirical stimuli or perceptions</td>
<td>A set of signs, which represent empirical knowledge</td>
<td>A set of signs that represent the meaning (or content) of thoughts that the individual justifiably believes are true</td>
</tr>
</tbody>
</table>

Source: Zins (2007b)

Using these domains, Zins (2007b) identified five alternative models to categorise the different definitions of data, information and knowledge, as summarised in Table 2-3.

**Table 2-3: Alternative Models for Defining Data, Information and Knowledge**

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>UD</td>
<td>SD</td>
<td>UD</td>
<td>SD</td>
<td>UD</td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>K</td>
<td>K</td>
<td>K</td>
<td>K</td>
<td>K</td>
</tr>
</tbody>
</table>

D = Data, I = Information, K = Knowledge, UD = Universal Domain, SD = Subjective Domain

According to Zins (2007b), the most common categorisation is Model 1, and it underlies information science, which focuses on exploring data and information. In Model 1, data and information are external phenomena and knowledge an internal phenomenon. However, a flaw in Model 1 is apparent; different human agents are able to draw different information from the same data, depending upon the agent’s existing knowledge. Therefore, information cannot be entirely objective and universal. It is interesting to note that while all the models classify knowledge in the subjective domain and data in the universal domain (with duality of domains for some models), the classification of information is more equivocal.

### 2.2.2 The Data, Information, Knowledge, Wisdom Hierarchy

One common view of information is within the context of a data–information–knowledge–wisdom (DIKW) hierarchy, referred to variously as the ‘knowledge hierarchy’, the ‘information hierarchy’ and the ‘knowledge pyramid’. It is one of the fundamental, and widely recognised, models in the information and knowledge management literature. The implicit assumptions are that data can be used to create information, information can be used to create knowledge; and knowledge can be used to create wisdom. This is often illustrated in diagrammatic form as illustrated in Figure 2-1.
A number of authors have proposed similar typologies, some adding an additional layer of understanding, as summarised in Table 2-4.

**Table 2-4: Alternative Classifications of Data, Information and Knowledge**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>Symbols</td>
<td>Know nothing</td>
<td>Data is raw. It simply exists and has no significance beyond its existence (in and of itself). It can exist in any form, usable or not. It does not have meaning of itself.</td>
</tr>
<tr>
<td>Information</td>
<td>Data that is processed to be useful; provides answers to who, what, where and when questions</td>
<td>Know what</td>
<td>Data that has been given meaning by way of relational connection. This 'meaning' can be useful, but it does not have to be.</td>
</tr>
<tr>
<td>Knowledge</td>
<td>Application of data and information; answers to how questions</td>
<td>Know how</td>
<td>Knowledge is the appropriate collection of information, such that its intent is to be useful. Knowledge is a deterministic process.</td>
</tr>
<tr>
<td>Understanding</td>
<td>Appreciation of why</td>
<td>-</td>
<td>Understanding supports the transition from each stage to the next. Understanding is not a separate level of its own.</td>
</tr>
</tbody>
</table>
Wisdom

Evaluated understanding

Know why

Wisdom calls upon all the previous levels of consciousness, and upon special types of human programming (moral, ethical codes). It is the essence of philosophical probing. Unlike the previous four levels, it asks questions to which there is no (easily achievable) answer. Wisdom is therefore, the process by which we also discern, or judge, between right and wrong.

Enlightenment

Attaining a sense of truth, the sense of right and wrong, and having it socially accepted, respected and sanctioned

-  


A comprehensive review of the DIKW model was undertaken by Rowley (2007), who identified numerous variations on the theme, but stated that all formulations of the hierarchy share a common view:

- The key elements are data, information, knowledge and wisdom.
- These key elements are virtually always arranged in the same order, although some models offer additional stages.
- The higher levels in the hierarchy can be explained in terms of the lower elements by identifying an appropriate transformation process.
- The implicit challenge is to understand how data is transformed into information, information is transformed into knowledge and knowledge is transformed into wisdom.

The DIKW hierarchy has been criticised by Fricke (2009) as being based on dated and unsatisfactory philosophical positions of operationalism and inductivism. Fricke (2009) argues that the inductivist view of science has been discarded because it is incorrect and replaced by the revolution account of science, mainly due to the works of Popper (1963) and Kuhn (1970):

*The information scientist does not want to be collecting data hoping that it might be promoted to information. A better methodology is more top down and just in time. A good theory of questions may elicit exactly the information needed to answer a particular question; and then the raising of a question will itself direct the search for information, observations or data.* (p. 135)

While Fricke does not differentiate between information dissemination and information-seeking patterns, it is clear that he places a higher value on information obtained from deliberate searches to well-informed questions. Hence, it can be argued that information is something that is pulled by a seeker out of a sea of data, rather than something that is pushed by a sender. A message might be pushed by a sender, but such data only becomes information when it is sought for or recognised by the receiver.
The process of transformation between the states of data, information, knowledge and wisdom is given less consideration than the DIKW hierarchy itself. Bellinger et al. (2004) suggested that understanding supports the transition from each stage to the next. The transformation process was described by Choo (1996) as increasing structure and human agency, via means of physical structuring, cognitive structuring and belief structuring, as illustrated in Figure 2-2.

![Figure 2-2: The Information Transformation Process](source: Choo (1996))

Not only is the definition of information problematical, but there also is no consensus on the fundamental entity of information. Gitt (2006) asserted that information is a fundamental entity, on equal footing with matter and energy, stating that it is “the third fundamental entity alongside matter and energy” (p. 9). By contrast, Stonier (1991) asserted that information is fundamentally physical in nature. The lack of an agreed theory of information was acknowledged by Gitt (2006), who stated, “In regard to the fundamental quantity information, we are still squarely in the process of discovery” (p. 19).

### 2.2.3 Conceptualisations of Information

A number of authors have attempted to develop theories of information. Notable are Shannon and Weaver (1949; 1948), Dretske (1981), Gitt (2006) and Boisot et al. (2007).

The mathematical theory of information (MTI) is concerned with the quantification, coding and transmission of information. Some of the basic ideas were formulated by Nyquist (1924) and Hartley (1928), but the subject was advanced considerably in seminal papers by Shannon and Weaver (1949; 1948), who are widely regarded as the founders of modern mathematical theories of communication and information.
The MTI model of communication includes six elements: a source, an encoder, a message, a channel, a decoder and a receiver, as indicated in Figure 2-3.

![Schematic Diagram of a General Communication System](image)

**Figure 2-3: Schematic Diagram of a General Communication System**  
Source: Shannon and Weaver (1949; 1948)

Examples of such a system include a radio communication system broadcasting music and a lecturer presenting a lecture to students. For the derivation of the formulae, there are a number of texts that present a mathematical rendition, for example, those of Bremer and Cohnitz (2004) and Reza (1994). MTI was not developed as a theory to cover all aspects of information, in the sense of how the term information is understood in ordinary language. Rather, it was developed to deal with certain engineering problems associated with improving the transmission rate of communication devices. The limitations of the theory are widely recognised in the literature. Bremer and Cohnitz (2004) noted that MTI theory deals with the average amount of information produced by a source, and not with the amount of information carried by a single signal. Moreover, the theory does not address the content of information carriers. Dretske (1981) argued that communication theory should be more properly viewed as a theory of signal transmission, a theory about those physical events (signals) that, in some sense, carry information. Fairthorne (1967) identified adverse effects of an attempt to apply Shannon’s theory beyond its valid scope, arguing that MTI is necessary but not sufficient, and that it needs to be set in a framework of information science. It is clear, however, that Shannon and Weaver’s seminal papers have formed the basis of subsequent research. Cornelius (2002) provided an overview of papers that have developed theories based on these original works.

In the context of this research, MTI is useful as a conceptualisation of information flow with respect to having a source, a transmitter, a receiver and a destination. It implies that one possible means of improving information flow between a sender and a receiver is to eliminate or minimise equivocation and noise. It would appear, however, that a basic assumption is one of data dissemination (i.e., information push from sender to receiver), whereas information-seeking (i.e., pull) patterns may be rather different.

Dretske (1981) built on MTI and attempted to develop a philosophically useful theory of information. Dretske conceptualised information as an objective commodity, as something
whose existence (as information) is largely independent of the interpretive activities of conscious agents. Dretske asserted that the common view held by cognitive scientists, who typically regard information as a creation of the mind, rests upon a confusion about the differences between information and meaning. The differentiation between information (as an objective commodity) and meaning (as higher level accomplishments associated with intelligent life) allows the development of a framework for understanding how meaning can evolve. He developed the mathematical theory of information and communication (C. E. Shannon & Weaver, 1949) into an account of how much a particular signal carries about a source. He then applied this theory of information to some traditional problems of epistemology, knowledge, scepticism and perception. In the final part of his theory of information, he advanced an information theoretic analysis of propositional attitudes, particularly the belief held that something is so.

One of the key points to draw from Dretske’s (1981) theory of information is that “Roughly speaking, information is that commodity capable of yielding knowledge, and what information a signal carries is what we can learn from it” (F.I. Dretske, 1981, p. 44). Dretske formulated a definition of the information contained in a signal that can be formally stated as follows:

Informational content: “A signal r carries the information that s is F = The conditional probability of s’s being F, given r (and k), is 1 (but, given k alone, less than 1)” (F.I. Dretske, 1981, p. 65).

Where r = signal, s= source and k is what the receiver already knows about the possibilities that exist at the source.

To illustrate, suppose that there are four tenderers for a project who have submitted prices in sealed envelopes. To determine who has won the tender, Person A opens the first three envelopes. At this point, Person B joins the scene and is not told about the content of the first three envelopes. The fourth envelope is now opened. How much information does Person B receive compared with Person A? Do they both receive the same information? Person A can learn something from the observation of the content of the fourth envelope that Person B cannot: the observation must be more pregnant with information for Person A (i.e., as to which is the most competitive tender price), because of their existing knowledge.

This constitutes a relativisation of the information contained in a signal, because how much information a signal contains, and hence what information it carries, depends on what the potential receiver already knows about the various possibilities that exist at the source. A greater ignorance requires a commensurately greater amount of information to repair. What makes information a relative quantity is not what the receiver knows about the channel over which he or she obtains information, but what the receiver knows about the situation at the source. This is an important point when considering the nature of communication channels.

Gitt (2006) suggested that the concept of information is so complex that it cannot be defined in one statement, and went on to develop a framework consisting of five levels comprising
statistics, syntax, semantics, pragmatics and apobetics, as illustrated in Figure 2-4. Hence, information transferred from a sender to a recipient can comprise information at different levels of meaning, action and result.

![Figure 2-4: The Five Levels of Information](source: Gitt (2006))

Gitt defines pragmatics in terms of its derivation from the Greek word *pragmatike*: the art of doing the right thing; taking action. He argues that information always leads to some action, although it is immaterial (for the purposes of defining information) whether the recipient acts according to the sender’s wishes, responds negatively to it or ignores it.

The highest level of information according to Gitt (2006) is apobetics, which he defines as the teleological aspect, the question of purpose. It is derived from the Greek *apobainon*: result, success, conclusion. He argues that some purpose is pursued whenever information is involved. The sender’s intention can be achieved in various ways by the recipient: completely, partially, not at all or doing exactly the opposite.

Three types of transmitted information are identified, namely, copied, reproduced and creative information.

- **Type 1**: Copied information comprises the identical propagation of existing information. No new information arises during the copying process.
- **Type 2**: Reproduced information makes a distinction between the originator and the subsequent performer. An example in the arts is music composition, which is composed by the composer but subsequently performed by musicians. According to Gitt (2006), computer programs (including artificial intelligence) fall into this category, as they reply upon pre-programming, and the results obtained are hence reproduced information.
• Type 3: The third type of transmitted information is creative information, in which something new is produced. Examples are designing a coding system, designing a language, writing an original scientific paper and writing a book.

Gitt (2006) formulated some quantitative evaluations of semantics, and in doing so, identified six parameters:

• Semantic quality q (a subjective concept, which mainly concerns the recipient) is a measure of the importance of the meaning of information. For inane or nonsensical information $q = 0$, while for the best possible information $q = 1$.

• Relevance $r$ (a subjective concept, which mainly concerns the recipient) reflects individual interests and it includes its relevance for achieving some purpose.

• Timeliness $t$ (a subjective concept, which mainly concerns the recipient) is a measure of the time dependency. $t = 0$ for yesterday’s news, and $t = 1$ for information received at the right moment.

• Accessibility $a$ (a subjective concept, which mainly concerns the recipient) is a measure of the ease of access. $a = 0$ when there is no access, and $a = 1$ when the recipient has full access to the information transmitted by the sender.

• Existence $e$ (an objective concept, which mainly concerns the sender) concerns whether the information exists at all. $e = 0$ for questions that are completely open, and $e = 1$ when something is fully known. This parameter is not well defined, but would appear to be a measure of knowledge.

• Comprehensibility $c$ (a subjective concept, which concerns both the sender and the recipient) describes the intelligibility of information. $c = 0$ when the information cannot be understood, and $c = 1$ when it is completely understood.

Gitt (2006) qualified the above factors in a note stating that they cannot be distinguished sharply and might overlap. The question of the interlinking of the six parameters is not discussed. However, it is apparent that these parameters could form the basis of some further research towards quantification of information.

In our research study, we are mostly interested in semantics and pragmatics. Statistics and syntax levels are of interest only so far as they enable the higher levels. The potential for information flow to improve productivity in the construction industry is likely to be at the level of pragmatics, but this needs a sound definition of the semantic value of information. Also, we are primarily interested in constructional or creative information. The operational information for running a site is considered too context specific (organisational, project or site specific) to analyse. In addition, this study is interested in reproduced and creative information, not copied information.

Boisot et al. (2007) presented a collection of papers that provide theories relating to information and knowledge and proposed a number of ways of linking such theories to the real world. The theories were developed into a conceptual framework called Information Space, or I-Space, which was used to explore how knowledge first emerges, and is subsequently articulated,
diffused and absorbed by a population of agents. The authors recast Polanyi’s distinction between tacit and explicit knowledge (Polanyi, 1958). The I-Space framework exploits the idea that knowledge that can be articulated will diffuse more speedily and extensively within a given population of agents than knowledge that cannot be so articulated.

The speed and extent to which information diffuses within a population of agents is a function of how far that information has been structured. The structuring of information facilitates both information processing and information transformation. It is achieved through the joint activities of codification and abstraction. Codification establishes discernible differences among phenomena, and among the categories to which these are to be assigned. The idea is to make the process of categorisation as speedy and as unproblematic as possible. Abstraction, by contrast, minimises the use of categories by only drawing on those that are relevant for a given purpose.

According to Boisot et al. (2007), the effective transmission of knowledge does not depend solely on whether information can reach the recipient. Information only becomes knowledge if it is internalised and becomes part of the recipient’s expectation structure, taken as a disposition to act. Agents are free to extract different patterns from the same data: for some, the patterns are banal and carry little information; for others, they lead to discontinuous insights and are highly informative. This concurs with work by Szulanski (1996) who found that best practice is hard to transfer between groups within organisations due to causal ambiguity but can be overcome by addressing motivational barriers.

An agent, according to Boisot et al. (2007), is “any system that receives, processes, and transmits data with sufficient intelligence to allow learning to take place” (p. 9) (italics in original). A population of agents is defined as scalable, and therefore the I-Space framework is not limited to any single level, such as that of the firm. The authors claim that the conceptual framework can find applications at different levels, from an individual through to a whole society. Information is identified as an extraction from data that, by modifying relevant probability distributions, has a capacity to perform useful work on an agent’s knowledge base. The essential relationships between data, information and knowledge are depicted in Figure 2-5.
The diagram indicates that agents operate two kinds of filters in converting stimuli into information. Firstly, perceptual filters orient the senses to certain types of stimuli. Stimuli passing through this initial filter are registered as data. Conceptual filters then extract information-bearing data from what has been registered. According to the authors, both filters are ‘tuned’ by the agents’ cognitive and effective expectations, shaped as these are by prior knowledge, to act selectively on both stimuli and data (Boisot et al., 2007). An interpretation of data and information was offered by Boisot et al. (2007) on the principle of least action. A production function is conceptualised as a schedule optimising the amount of output that can be produced from any specified set of inputs. In neoclassical production functions, capital and labour are identified as inputs, and information and knowledge are not explicitly represented as factors of production in their own right. The authors offered an abstract model, illustrated in Figure 2-6, which brings together two different classes of productive factors:

- physical factors such as capital, labour, space, time and energy;
- data factors, being discernible differences in the states of representation of the physical factors (measured in bits).
According to earlier arguments, information constitutes an extraction from data, which results in economising on that factor, and hence is a move towards the origin. In the diagram, there are two types of movement, one along isoquants and another across them. A move to the left along an isoquant represents a progressive substitution of physical factors by data, which happens when systems ‘learn-by-doing’. Such learning by doing can only work for systems that can store past states, that is, for systems that have memory. By implication, a move to the right along an isoquant is interpreted as either forgetting or an erosion of memory. A downward vertical movement across isoquants and towards the origin in the diagram, by contrast, represents the generation of insight, the extraction of information from data to create new, more abstract knowledge concerning the underlying phenomena. In addition to having memory, a system that has capacity for insight must be intelligent.

In a discussion of the model the authors identified an interesting insight: that while purely physical factors are naturally subject to scarcity and hence are appropriable, data factors are not. While data factors may not be immediately accessible, once they are secured they typically can be replicated and distributed at very low marginal cost. Data in the right physical substrate propagates rapidly and extensively, and thus scarcities appear in the form of a system’s capacity to receive, store, process and transmit data (not in the data factors themselves). For this reason, data factors are much more difficult to appropriate and to subject to traditional forms of economic exchange than physical factors.

In the context of construction, this model is useful in identifying issues of improving performance (productivity) from learning and innovation. The nature of projects is such that the industry often fails to capture lessons learned from one project and pass them on to the next in any codified or
structured manner. Hence, learning by doing is slow and embedded primarily through experience gained by individuals, and typically not transferred between individuals, groups or firms. One of the main reasons why the construction industry does not improve is that the nature of one-of-a-kind projects makes capturing lessons learned difficult. Furthermore, movement across isoquants is limited because of the relatively low levels of research and innovation in construction and the conservative, risk-adverse nature of the industry. A possible means of achieving such knowledge transfer is via use of templates as a simple means of replicating best practice and organisational routines (Szulanski & Jensen, 2004).

2.2.4 Conceptualisations of Information Flow

A number of attempts have been made to develop a theory conceptualising information flow. These include metaphors of fluid dynamics (Fyall, 2002; Krovi, Chandra, & Rajagopalan, 2003), the flow of products in manufacturing (Womack & Jones, 1996), electrical current (Ostergaard & Summers, 2007) and the automotive power train (Caldwell, Palmer, & Cuevas, 2008).

Fluid Mechanics

Fyall (2002) attempted to model informational flow in organisations in an analogous way to fluids. The motivation was to predict when the demands on a project team are approaching critical levels, leading to organisational failure. An analogy was made to fluids transitioning from smooth and stable to turbulent and chaotic flow, and simulation analysis was used to identify an organisational Reynolds number. The organisation was conceptualised as an information-processing machine, with a capacity to process information. A metric was identified called ‘indirect work’, which is a measure of rework, communication and wait times, and was used to plot performance against an exception rate. A project with a zero exception rate would be completed on time, in accordance with a deterministic planned schedule (such as a Gantt chart). The modelling indicated that information flow has a point of inflection, where the flow moves from a laminar stable region, through a transition zone, into a turbulent zone.

A number of such models were run for different organisational hierarchical structures. The models indicated that organisations with a low degree of centralisation have greater capacity for teams to operate under stressful scenarios, extending the turbulent region to a higher error rate, but at the cost of a sharper transition point of inflection. By contrast, highly centralised organisations have a lower point of transition, but the slope of change is not as drastic, the argument being that exceptions are controlled to a larger degree by management.

The analogy has some potentially interesting aspects and may be useful for informing organisational design and project team structure; however, there was no validation of the results. In addition, while the report refers to ongoing research, it would appear that the line of research has not been progressed.

Krovi et al. (2003) also made an analogy between information and fluid flow. However, the analogy was made purely in descriptive terms. Also, the fluid analogy is somewhat flawed on the basis that information flow involves discrete pieces of information for decision-making. Furthermore, the fluid analogy is not able to address qualitative aspects of information. One
particle of a fluid is the same as any other, whereas information has multiple characteristics and is not homogeneous. The fluid flow analogy was also critiqued by Tribelsky and Sacks (2010) on the basis that information is not continuously streamed, its quantity is not fixed and so cannot be replicated to flow to multiple paths with the full initial quantity, and information flow paths cannot be predetermined in their routes and capacities.

**Electric Current**

Ostergaard and Summers (2007) presented a model for collaborative design that is analogous to electrical circuits with current (rate of design artefact synthesis and analysis), voltage (knowledge that drives the design process) and resistance (barriers to the exchange of design information). The electric analogy was used to capture the flow of information throughout the design process, and resistances were identified from collaborative design taxonomy. Although some empirical results were obtained from a simulated environment with student actors, the proposed model has not been applied to real-world design cases, and values of resistance have not been determined for the taxonomy factors.

The electric current analogy is also somewhat flawed, for similar reasons to those of the fluid analogy. It is apparent from even a fairly rudimentary consideration of electrical circuits that information is very different from a stream of electrons being transmitted through a conducting material, such as a wire. Information has a certain granularity and lumpiness, which is exchanged between a giver and a receiver. It does not flow through a predetermined circuit, and knowledge is not necessarily the voltage providing the driving force for the flow. Information flow is not unidirectional; it can be either seeking (e.g., request for information or research) or informative (e.g., instructions).

**Product Flow**

Huovila et al. (1997) extended the analogy of product flows to information, based on Koskela’s (2000) transformation–flow–value theory of production in the construction sector. In this analogy, information is transferred in discrete packages between designers. Such information packages may be copied without limitation, stored, aggregated or divided as needed. Features of flow found in the production process such as bottlenecks, batching and cycle time are observed in the design process.

Hicks (2007) applied the concepts of lean thinking to information management, based on a case study of 10 small to medium-sized organisations. Information management was conceptualised as a process of adding value to information by virtue of how it is organised, visualised and represented, and enabling information to flow to the end user through exchange, sharing and collaboration. Furthermore, Hicks argued that it is desirable that the process is performed with the minimum of waste. The five key principles of lean thinking identified by Womack and Jones (1996) (namely, value, value stream, flow, pull and continuous improvement) were also applied by Hicks (2007) to information management. Hicks (2007) suggested that the conceptual framework provides a generic framework for supporting improvement processes and systems that manage information. He acknowledged, however, that the framework does not represent an
explicit strategy for improving information management. It should be noted that the framework has not been applied and no evidence of delivering performance improvements was provided to validate the framework. Hicks (2007) did not differentiate between data, information and knowledge, nor between different uses of information. It is not clear whether there is any correlation between a lean information flow and a lean manufacturing flow, although by implication perhaps, a leaner information flow produces a more efficient production function.

In conclusion, none of the conceptualisations of information flow based upon analogous thinking are particularly compelling. While they give insights that may be useful in different contexts such as design process or manufacturing, there is no generally accepted model of information flow. In some ways this is not surprising given the difficulties previously identified in defining information in the first place, as discussed earlier in Section 2.2.1.

2.2.5 Information Flow and Productivity

Researchers at the Massachusetts Institute of Technology Sloan School of Management and Boston University investigated the relationships between ICT use, patterns of information flows and individual worker productivity for a mid-sized executive recruiting firm (Aral, Brynjolfsson, & Van Alstyne, 2006). The study analysed project-level and individual-worker-level performance using accounting data on revenues for 1300 projects over five years, observation of over 125,000 emails over a 10-month period and data on workers’ self-reported ICT skills, ICT usage and information sharing. Information flow via email was captured using capture software developed specifically for the project, and content was masked using cryptographic techniques to preserve individual privacy. The detailed data was analysed using egocentric social network techniques and regression analysis.

A number of significant findings were reported from this study, namely:

- ICT use and skills are positively correlated with increased revenues and project completion. This concurs with findings from a separate study by Chien and Barthorpe (2010).
- The structure and size of workers’ communication networks are highly correlated with performance.
- An inverted U-shaped relationship exists between multitasking and productivity such that, beyond an optimum, more multitasking is associated with declining project completion rates and revenue generation.
- Asynchronous information seeking such as email and database use promotes multitasking, while synchronous information seeking, such as using the phone, shows a negative correlation.

Overall, the results demonstrate significant relationships among technology use, social networks, completed projects, revenues and productivity for project-based information workers (Aral et al., 2006). These relationships are illustrated in Figure 2-7.
While this research has not been applied within the context of the construction industry, it does provide significant insight into the relationships between information flow and productivity. The applicability of these findings to construction are arguably more relevant to the design office than construction, as designers work in teams processing multiple design jobs at any point in time, whereas construction teams are spatiotemporally constrained to one site at a time. It would be useful to replicate the approach adopted by Aral et al. (2006) in the design office to investigate design task efficiency. However, a limitation of this approach is the focus on task-level productivity, and in construction the greater challenge is on improving multiple tasks into co-coordinated projects.

2.2.6 Discussion

As identified previously, information is a highly complex concept, so much so that it cannot be defined in one statement (Gitt, 2006; Johnson & Clayton, 1998). Suffice to say that information flow is a significant component of engineering and construction activity for the purposes of delivering infrastructure and other outcomes. Hence, having good-quality information is a critical part of productivity and is widely accepted to be a key mechanism in which performance and operating efficiency can be improved (Hicks, Culley, & McMahon, 2006). Information allows the company as a whole, as well as individual human agents, to manage labour, capital and day-to-day tasks to achieve the desired goals (Collins & Shuter, 1982).

The quality and reliability of information not only affects and determines the quality and the accuracy of the design, but can also influence the amount of rework necessary during later stages in the implementation of decisions. Another consequence is an initial delay due to late information being carried further down the chain. Both Josephson (1999) and Hammerlund (1999) agree that design errors and omissions are the major contributing cause of waste in the construction phase. A further problem arising from poor information flow, attributable to the project manager’s failure to realise the importance of information among teams, is late decision-
making and poor coordination of effort, resulting in cost overruns and project delays (Chan & Kumaraswamy, 1997).

The technology behind information being disseminated and being received has made dramatic advancements since the 1980s (Hicks et al., 2006). One of the most significant advancements is the internet, and receiving mail in electronic form has dramatically changed work patterns. Rapid and easy sharing of information should lead to the reduction of time delays and facilitate more rapid decision-making. However, this is not necessarily a straightforward issue, as human agents have limited capacity to process information, and information overload is a recognised issue (Edmunds & Morris, 2000). Also, despite the advances in technology, information can be lost to the degree that often it has to be re-entered or converted into hard copy (e.g., drawings) in order to continue with design tasks (Zou & Seo, 2006).

It is recognised that information technology has made the production, manipulation and dissemination of information inexpensive (Johnson & Clayton, 1998). However, the enhancement of technology does not necessarily result in improved quality of decision-making or improved outcomes, but rather speeds up the data exchange. In essence, the rate of information exchange does not distinguish the quality of the information (Parfitt, Syal, Khalvati, & Bhatia, 1993). Also, despite advances in information technologies, the proliferation of options and lack of embedded intelligence within tools, often makes it hard for decision-makers to source the right information. Hence, there is a need to train and educate staff in the use of information technologies, so that end users can access their sources effectively (Bibby, Austin, & Bouchlaghem, 2006).

Although organisations have invested to a degree in ICT to aid the design process, the process continues to remain inefficient as projects in construction are still fragmented and highly dependent on information exchange in traditional paper form (Moreau & Back, 2000). Barriers also include the lack of ICT standards and inertia of traditional practices (Barthorpe & Chien, 2003). The advent and uptake of three-dimensional parametric design tools such as Building Information Modelling (BIM) over the recent decade has assisted to a significant degree in this regard (Eastman, Teicholz, Sacks, & Liston, 2008; Love, Edwards, Han, & Goh, 2011; Sacks, Koskela, Dave, & Owen, 2010). However, counteracting this is the double impact of increasing complexity of projects and fragmentation of specialisations, which increase the complexities for information flow between project participants. Ultimately, the imperative for co-ordination, if not addressed in the appropriate manner, can lead to slow and interrupted information flows resulting in significant waste (Tribelsky & Sacks, 2010).

2.2.7 Conclusions to Information Literature Review

This section of the literature review does not claim to be a comprehensive review of the literature on information. Others have attempted to do so, the most recent of whom appear to be Cornelius (2002) and Capurro and Hjorland (2003). However, it is clear from a review of the literature that there is no generally accepted theory of information. In order to progress research on the relationships between information flow and productivity, it is important to have a clear
understanding of the concept of information. Capurro and Hjorland (2003) made this point, stating that:

There are many concepts of information, and they are embedded in more or less explicit theoretical structures. In studying information it is easy to lose one’s orientation. Therefore, it is important to state the pragmatic question: ‘what difference does it make if we use one or another theory, or concept, of information?’ (p. 396)

To answer this pragmatic question: yes, it does make a difference for this research project if we adopt one theory or concept rather than another. For example, if we adopt Shannon and Weaver’s theories, it will lead us to consider information in terms of the signal content, whereas adoption of Dretske’s theories will lead us to consider more philosophical issues relating to information flow and knowledge.

Unfortunately, the literature review has not identified an existing theory of information that links with the concepts of productivity. The closest fit is the application of lean thinking to information by Hicks (2007), but it is somewhat limited because of its roots in manufacturing. A new theory, or hypothesis, is therefore needed in order to investigate the effect of information flow upon productivity. It is clear that information flow is a factor that fundamentally determines productivity outcomes, even if the causality mechanisms are not yet fully understood.

2.3 Productivity

Productivity is commonly defined as a ratio of a volume of output (such as physical products and services) to a volume of input (such as labour and capital) (Organisation for Economic Co-operation and Development, 2001). Productivity relates to how efficiently resources are used in the production of goods and services (Holzer & Nagel, 1984). It is an indicator of value delivered. Productivity performance in the economy is important, as it the main driver for improving standards of living and increases in welfare (Davis, 2007; Heap, 1992; Huang, Chapman, & Butry, 2009; Organisation for Economic Co-operation and Development, 2001).

Productivity performance has implications at all levels of the economy. The benefits of higher productivity include a better-performing economy, which generates improvements in average incomes, greater opportunities for people and increased wellbeing. A strong economy can also make countries more resilient to inevitable shocks and adversities. For employees, productivity is important because of its link to wages and the subsequent consumption these wages can finance (Janssen & McLoughlin, 2008). At the level of an organisation, improving productivity is fundamental to survival as a means of meeting obligations to staff, shareholders and governments, while remaining competitive in the market place (Huang et al., 2009). At an industry-wide level, productivity improvement is essential for the health of the sector as a means of improving standards, practices and industry systems (Heap, 1992). In the context of the construction industry, productivity is vital because inadequate increases in productivity will mean sharper rises in construction costs, with significant knock-on adverse social implications for a nation generally and a possible subsequent decline in work for the industry (Ganesan, 1984).
It has been acknowledged that productivity, especially in the construction industry, has always been very difficult to measure (Ganesan, 1984; Huang et al., 2009; Motwani, Kumar, & Novakoski, 1995). Construction tasks are generally complex and interdependent and thus they are hard to quantify when assessing and measuring productivity. This technical difficulty is compounded further by the fact that the sector is influenced to a significant degree by external factors such as economic cycles, political interference, changes in government commitments and periodic legislative amendments. Therefore, it is important that productivity measures are interpreted with care (Heap, 1992).

2.3.1 Overview of Productivity Measures

There are a number of methods for measuring productivity. The choice between them depends upon the purposes of measurement and, in many instances, upon the availability of data (Organisation for Economic Co-operation and Development, 2001). Generally, productivity measures can be divided into single-factor productivity measures (which relate a measure of output to a single measure of input) or multifactor productivity (MFP) measures (which relate a measure of output to a bundle of inputs). Another distinction is made between productivity measures that relate to gross output and those that use a value-added concept of output. A summary of the main productivity measures is provided in Table 2-5.

Table 2-5: Overview of Productivity Measures

<table>
<thead>
<tr>
<th>Type of Output Measure</th>
<th>Type of Input Measure</th>
<th>Type of Productivity Measure</th>
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<td>Single-Factor</td>
<td>Multifactor</td>
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<td></td>
<td>Productivity Measures</td>
<td>Productivity Measures</td>
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<td>Labour</td>
<td>Capital and Labour</td>
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<td>Intermediate Inputs</td>
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<td>Gross Output</td>
<td>Labour Productivity</td>
<td>Capital-Labour</td>
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<td></td>
<td>(based on gross output)</td>
<td>Multifactor Productivity</td>
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<td></td>
<td></td>
<td>(based on gross output)</td>
</tr>
<tr>
<td>Value-Added Output</td>
<td>Labour Productivity</td>
<td>Capital-Labour</td>
</tr>
<tr>
<td></td>
<td>(based on value added)</td>
<td>Multifactor Productivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(based on value added)</td>
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Partial productivity is the ratio of output to one class of input (i.e., labour or capital), which gives labour and capital productivity respectively. Other partial factor productivity measures are theoretically possible (e.g., material or energy) but are rarely used. Both labour and capital partial productivity measures can be based on either a gross output basis or the value-added concept of output.

Caution is required when using partial productivity measures as changes in input proportions (e.g., the ratio of capital to labour) can influence these partial measures (Davis, 2007). Therefore, they can be misleading indications of growth, as the apparent growth may be attributed simply to changes in the mix of labour and capital.
MFP is the ratio of output to the sum of associated labour and capital inputs. MFP indices show the time profile of how productively combined labour and capital inputs are used to generate value. This method serves as a method of analysis of micro-macro links, such as the contribution of an industry to the economy-wide MFP growth (OECD, 2002). The main advantage of the MFP measure is the ease of aggregation across industries and that the data required is directly available from national accounts. However, a limitation is that the MFP metrics are not a good measure of technology shifts at the industry level.

Increases in labour productivity may reflect increases in the capital–labour ratio, rather than increases in labour quality and efforts. A unit of production may achieve high levels of labour productivity, but the overall productivity may be compromised because the underlying capital–labour ratio may not be optimal. Similarly, low labour productivity might be efficient in the sense that low wages induce producers to adopt more labour-intensive practices and save on capital costs. Hence, labour productivity measures are limited in the sense that they do not reveal a complete picture and are prone to misinterpretation. While labour productivity is often a less preferred measure of productivity compared with MFP, it is calculated with much more precision and with fewer assumptions. The data requirement for labour productivity calculation is significantly lower compared with MFP calculation.

Gross output refers to goods or services that are produced within a producer unit and that become available for use outside the unit. It is a gross measure in that it represents the value of sales without allowing for purchases of intermediate inputs. Conversely, the value-added measure deducts purchases of intermediate inputs from the gross output. In this sense, value added is a net measure. However, it should be noted that it is not a net measure, in the sense that it includes the value of depreciation or consumption of fixed capital (Organisation for Economic Co-operation and Development, 2001).

In 2002, the Organisation for Economic Co-operation and Development (OECD) ranked the most commonly used methods in constructing productivity series in its publication Measuring Productivity — OECD Manual (OECD, 2002). Among them, the most frequently computed productivity statistic is the value-added-based labour productivity, which is followed by the value-added MFP. In NZ, value-added MFP is recommended as the preferred method of measurement for the construction industry by Davis (2007), and endorsed by Page (2010) as the most appropriate metric.

Theoretically, the level of total factor productivity (TFP) can be measured by dividing total output by total inputs. This requires aggregation of all inputs, but in practice not all inputs are included; for example, land is often excluded (Davis, 2007). Theoretically, when all inputs in the production process are accounted for and properly measured, TFP growth can be thought of as the amount of growth in real output that is not explained by growth in inputs. Because of the problems inherent in accounting for all inputs and measuring those inputs, the TFP residual has been referred to as “a measure of our ignorance” (Abramovitz, 1956, p. 11).
Productivity levels in absolute units of measurement are rarely of primary interest, because of their sensitivity to the units of measurement of inputs and outputs. Rather, the focus of productivity measurement is on growth rates and relative comparisons. A growth rate shows how fast an indicator has risen (or declined) over a period of time. Absolute productivity levels are of interest to managers at the level of the firm; however, the more pressing concern is whether efficiency is improving or declining (Davis, 2007).

Productivity is usually measured as a quantity index of output over a quantity index of inputs. An important distinction between index numbers draws on whether they establish chained or direct comparisons. In a time series context, whenever indices of two non-adjacent periods have to be compared, the question arises as to which period should be chosen as a basis for the comparison. Options include choosing the first or the last observation as the base, or using the chain principle. The chain principle makes use of the natural order provided by the march of time. Some of the most common index formulae are Laspeyres, Paasche, Fisher and Tornqvist. The choice of index appears to be of little empirical consequence (Organisation for Economic Co-operation and Development, 2001), and therefore is not discussed further here.

2.3.2 Purposes of Productivity Measurement
The objectives of productivity measurement include the following.

Efficiency
Full efficiency in an engineering sense means that a production process has achieved the maximum amount of output that is physically achievable, with current technology and a fixed amount of inputs (Diewert & Lawrence, 1999). Efficiency gains are thus a move towards ‘best practice’ or the elimination of technical or organisational inefficiencies. Gains can be due to improved efficiency in individual organisations that make up the industry or a shift of production towards more efficient organisations.

Real Cost Savings
Productivity is typically measured residually and this residual captures not only technical and efficiency gains, but also changes in capacity utilisation, learning by doing and a myriad of other sources behind productivity growth. Harberger (1998) labelled these real cost savings.

Technology Change
Productivity is often used as a measure of technological change. However, it is important to note that not all technical change translates into productivity growth (Organisation for Economic Co-operation and Development, 2001). It is important to distinguish between embodied and disembodied technological change. Embodied technological change represents advances in the design and quality of new capital and intermediate inputs. Its effects are attributed to the productivity factor as long as the factor is remunerated accordingly. Disembodied technical change, by contrast, comes without cost. Examples of such disembodied technology change are general knowledge, blueprints, network effects or spillovers from other factors of production, including better management and organisational change.
Living Standards
Measurement of productivity is a common approach for assessing standards of living.

Benchmarking Production Processes
Comparisons of production measures for specific production processes can help to identify inefficiencies. These are typically measured in physical units and tend to be highly specific.

2.3.3 Construction Productivity: Task, Project and Industry Metrics
Huang et al. (2009) contend that the nature of the construction process points to a need for measures of construction productivity at three levels: task, project and industry. Tasks refer to specific construction activities such as concrete placement or structural steel erection. Projects are the collection of tasks required for the construction of a facility or renovation of an existing facility. Industry measures are based on sector statistics, and represent the total portfolio of projects.

Task-Level Productivity
Task-level metrics are widely used within the construction industry. Most task-level metrics are single-factor measures and focus on labour productivity. For example, RSMeans in the United States of America (USA), Spons in the United Kingdom (UK) and Rawlinsons in NZ have published task-level metrics for many years. Typical task-level metrics estimate how much a given output is produced by a designated crew in a normal eight-hour day. For some tasks, equipment may be involved, and can be considered multifactorial. Generally, such metrics are easy to understand and are widely used within the construction industry as estimating tools. Guides and databases in the public domain are usually supplemented by contractors' own historical productivity data to estimate future projects.

Project-Level Productivity
Since a project is a collection of tasks, project-level metrics are more complicated. The inputs and outputs for a given task, say, concrete placement, differ from those of another task, say, structural steel erection. Thus, it is not possible to aggregate the individual raw task productivity metrics into a project productivity metric unless adjustments are made. One way to make these adjustments is to use a reference data set to calculate baseline values for each task. Information is still needed, however, to calculate a meaningful project-level productivity metric. For instance, information yielding the task weight is required (i.e., the share that it represents to the overall project), as is an understanding of the task flows. Because some tasks are completed in parallel and others in series, the composition of the task flows affects the overall project productivity.

The project-level productivity metric previously described is useful in measuring how an individual project compares with the overall average in the reference data set. In addition, data from all projects can be compiled into a distribution. Further analyses can then be conducted to identify characteristics associated with the best-performing or worst-performing projects. A
project-level productivity index can also be used to track changes in project productivity over time.

Publicly available project-level productivity estimates tend to be rare. Compilation of a data set requires considerable data collection and is ultimately limited by contributing organisations’ projects and not of the industry as a whole. It should be noted that changes in productivity might reflect changes in the composition of projects, in addition to changes in productivity. Each construction project is unique, and the mix of projects in each year is different. Hence, there is an intrinsic challenge in construction industry productivity analysis (Huang et al., 2009).

**Industry-Level Productivity**

At the industry level, the amount (or value) of output produced per unit of input provides a productivity measure that is indicative of industrial efficiency.

**Relationships between Task, Project and Industry Levels Productivity**

Construction projects tend to be unique and are increasingly more complex. Task-level productivity does not capture project-level uniqueness and complexity. The trend of increasing project complexity could partly explain the productivity decline at the industry level observed in most industrialised nations, including NZ. High productivity at the task level also does not necessarily translate into high productivity at the project level. Project-level success depends on managerial coordination and planning, which task-level productivity does not capture. For instance, idle time is not included in task-level productivity measurement, but it certainly can impede progress and adversely affect productivity at the project level. Likewise, project-level productivity does not necessarily transfer directly to industry-level productivity. There are significant levels of waste in inefficiencies inherent in the projectisation of the industry. These inter-actions are typical of complex systems (Kurtz & Snowden, 2003), which cannot be predicted and hence are unlikely to be responsive to traditional management techniques and require new forms of leadership and business models to address route causes (Snowden & Boone, 2007).

It is worth noting that the relationships between task-, project- and industry-level productivity in the construction industry do not appear to have been the subject of research, either in NZ or internationally. This may be due to the difficulty in obtaining sufficient data to undertake meaningful empirical studies. Mullaly (2014) identifies that improvements in performance are not to be derived from a simplistic project maturity curve, but rather issues need to be addressed from a contingent and contextual perspective.

### 2.3.4 International Literature on Construction Productivity

A number of studies have sought to identify the factors that affect construction productivity, the majority of which originate from the USA. A common model referred to in the literature is the factor model of construction labour productivity (Thomas & Sakarcan, 1994), and it is reproduced in Figure 2-8.
Figure 2-8: Factor Model of Construction Labour Productivity

Source: Thomas and Sakarcan (1994)

This model splits the common factors into two categories: the work environment and work to be done. These factors have been subjected to varying degrees of research, from none to sizeable empirical studies.

A summary of some of the international research on factors affecting construction is provided in the following sections.

**Skilled Labour Availability**

Skilled labour shortage is attributed to a shrinking skilled workforce rather than increasing demand (Huang et al., 2009). Statistical analysis provides evidence that the workforce is ageing, and a reducing proportion of the workforce comprises new employees. In the USA, the percentage of the construction workforce aged below 45 decreased from 72% in 1994 to 61% in 2008 (Huang et al., 2009). There is anecdotal evidence that the same issue applies in NZ; however, there does not appear to be any empirical research on this matter in NZ.

**Technology Utilisation**

Goodrum and Haas (2002) examined the impact of equipment technology and tools on partial labour productivity for 200 activities over a 22-year period. They identified that activities experiencing significant change in technology witnessed a substantially greater long-term improvement than those that did not experience technology change. Furthermore, this research indicates that, despite an increase in task-level measures in construction productivity in the USA over the period of the study, at an aggregate industry level the productivity trend has been in decline over the same period. The reasons for this disparity were not identified, and the research recommended that "reasons for this apparent contradiction need to be further explored" (Goodrum & Haas, 2002, p. 471).
BIM is currently an emerging technology that is receiving considerable amounts of interest, from both academics and practitioners (Eastman et al., 2008). BIM is described as a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format (Eastman et al., 2008). It is identified as an activity that could lead to breakthrough improvements in construction productivity in the USA (National Research Council, 2009). However, while the proponents of BIM advocate the advantages of the technology, there is no published research that investigates the impact of BIM upon productivity, perhaps because the technology is still new. A case study of the building projects of the architect Frank O. Gehry identified that digital three-dimensional representations produced diverse innovations across multiple, heterogeneous firms in those projects, each of which created a wake of innovation (Boland, Lyytinin, & Yoo, 2007). Although the benefits of BIM are unproven in NZ, it is likely that BIM will be a technological driving force of change in the construction industry in the future.

**Off-Site Fabrication and Modularisation**

Prefabrication, pre-assembly, modularisation and off-site fabrication offer potential benefits, including the potential to increase productivity in the more controlled off-site environment. Costs can be reduced because moving part of the on-site construction work to a controlled off-site environment can reduce the adverse impact of weather and other site conditions. It also has the potential to enhance safety.

Eastman and Sacks (2008) compared the relative productivity of construction industry sectors with significant off-site fabrication with more traditional on-site sectors. The off-site sectors, such as curtain wall, structural steel and pre-cast concrete fabrication, were shown to have consistently higher levels of productivity growth than on-site sectors. Furthermore, the value-added content of the off-site sectors is increasing faster than that of the on-site sectors. They went on to note that the off-site sectors are not traditionally considered part of the construction industry by the US Economic Census, but rather as part of the manufacturing sector. Ignoring the off-site segments of construction has led to significant underestimation of construction productivity. There does not appear to have been a similar study in NZ; however, literature regarding the NZ construction sector does recognise off-site fabrication as an issue (e.g., Davis, 2007).

**Scheduled Overtime**

A number of studies have identified that scheduled overtime has a negative impact on productivity. The Construction Industry Institute in the USA investigated productivity loss caused by scheduled overtime and showed that the use of overtime is a cause of productivity loss averaging at 15% (Thomas & Raynar, 1997).

**Change Orders**

Change orders have a significant impact not only on cost and schedule performance but also on construction productivity (Park, 2006). Research commissioned by the Construction Industry Institute in the USA studied 522 workdays over a period from 1989 to 1992 and identified that
the average effect of all changes was a 30% loss of efficiency (Thomas & Napolitan, 1995). However, the impact of changes is far from uniform, and it is possible to implement changes without negatively impacting labour productivity, provided that change is implemented early; the key variable affecting efficiency is the time of the change.

**Materials Management**
A number of material management issues, such as waiting for material deliveries, tools or equipment, have been identified as having a negative impact on productivity (Park, 2006).

Labour inefficiencies ranging from 5% to 56% were identified by Thomas and Sanvido (2000), attributable to materials management problems. These included late or out-of-sequence deliveries and fabrication or construction errors.

**Weather**
Thomas and Ellis (2009) reviewed literature and data from multiple projects to estimate the average loss of efficiency resulting from extremes of temperatures and from precipitation. They found significant efficiency losses when the temperature falls below 20 °F (7 °C) or rises above 85 °F (29 °C). Rain and snow are very detrimental to labour productivity, with loss in efficiency in the range of 50% to 60%.

**Human Factors**
Motivation has received considerable attention as a means to improve productivity, including Maslow’s theory based on human needs, Herzberg’s theory based on job enrichment and hygiene factors, McGregor’s theory based on ways of perceiving people, Vroom’s and Porter-Lawler’s theories based on expectancy, and Skinner’s theory based on recognition and punishment. A review of all these theories from general literature is beyond the scope of this literature review. However, some of the main motivation theories were reviewed for applicability to the construction industry in a study by Khan (1993), and found to be applicable, with examples presented in which an intentional or unintentional use of motivation theories has led to improvement in productivity.

Lemna et al. (1986) identified productive foremen and determined their characteristics. Factors found to increase productivity included delegating tasks, forward planning, communication and equipment management.

**Discussion**
It is clear that the factors affecting productivity in construction are multidimensional and complex. The international research literature does not address performance at the programme level (portfolio of projects). A large portion of the construction industry is procured by a relatively small number of major clients, who hold large amounts of capital assets (e.g., utility companies) and therefore are procurers of programmes of work.

Data collection for measuring productivity is difficult and the metrics are reliant on the collection of high-quality data. In addition to the challenges of data collection, there is an intrinsic difficulty in construction productivity measurement. Much of this difficulty lies in the heterogeneous
nature of the industry. Construction building or infrastructure types are heterogeneous. Within each building or infrastructure type, there is also heterogeneity as each project is unique. Finally, there is heterogeneity in the composition of construction firms, with large operators taking advantage of economies of scale and scope.

The heterogeneity that exists in these multiple dimensions means that productivity may be improving or deteriorating for a particular segment of the industry, at a particular level of analysis. Changes in productivity at an aggregated level may simply be caused by changes in the composition of projects or firms involved, rather than reflecting productivity change per se.

It is notable that very little research has been undertaken on information flow with respect to productivity within the construction sector, despite it being identified by Thomas and Sakarcan (1994) in their seminal work. Some work has been undertaken with respect to communications, for example Doloi (2009), who identified communications as being the most influential factor impacting upon partnering success. However Wikforss and Löfgren (2007) lament the focus on technical aspects of information handling in construction, and argue that the perspective must be widened to include ICT from an organisational and management perspective. A possible reason for lack of research in this direction could be the difficulty in observing information flows, as information exchanges using informal communications do not reflect the formal structures typically adopted in engineering projects (De Blois, Herazo-Cueto, Latunova, & Lizarralde, 2011).

2.3.5 New Zealand Construction Industry Productivity

Over the past decade, a number of studies have been undertaken to analyse the construction sector productivity performance in NZ. A list of the main reports is provided in Table 2-6.

Table 2-6: Significant Productivity Studies Undertaken in New Zealand

<table>
<thead>
<tr>
<th>Author</th>
<th>Date</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black, Guy and McLellan</td>
<td>2003</td>
<td>Productivity in New Zealand 1988 to 2002</td>
</tr>
<tr>
<td>Davis</td>
<td>2007</td>
<td>Construction Sector Productivity Scoping Report</td>
</tr>
<tr>
<td>Janssen and McLoughlin</td>
<td>2008</td>
<td>New Zealand Productivity Performance</td>
</tr>
<tr>
<td>Davis</td>
<td>2007</td>
<td>Construction Sector Productivity Scoping Report</td>
</tr>
<tr>
<td>Allan, Yin and Scheepbouwer</td>
<td>2008</td>
<td>A Study into the Cyclical Performance of the New Zealand Construction Industry</td>
</tr>
<tr>
<td>Cunningham</td>
<td>2010</td>
<td>International Building and Construction Industry Productivity Reform Programmes</td>
</tr>
<tr>
<td>Page</td>
<td>2010</td>
<td>Construction Industry Productivity</td>
</tr>
<tr>
<td>New Zealand Contractors’ Federation</td>
<td>2011</td>
<td>Productivity in Civil Construction: A Contracting Industry Perspective</td>
</tr>
<tr>
<td>Construction Strategy Group</td>
<td>2011</td>
<td>Valuing the Role of Construction in the New Zealand Economy, PWC report</td>
</tr>
<tr>
<td>Conway and Meehan</td>
<td>2013</td>
<td>Productivity by the Numbers: The New Zealand</td>
</tr>
</tbody>
</table>
Black et al.'s (2003) paper is the first of a series published over the past 10–15 years investigating productivity, and is typically the starting point for literature reviews in subsequent papers. The aims of this paper were to provide aggregate and industry productivity series for the market sector of the NZ economy, to give an initial analysis of these series and to compare the productivity performance of Australia and NZ. Industry series were produced for nine sectors in order to undertake a cross-sectional performance comparison between sectors, and construction was identified as the worst performing of the sectors considered.

The purpose of the Janssen and McLoughlin (2008) study was to examine NZ's long-term productivity performance and the factors that may be inhibiting NZ from reaching its potential. The authors made particular reference to the performance of the construction industry, noting that the industry experienced high employment growth but labour productivity below the average (and falling over the period). Accordingly, the sector has the largest negative impact nationally on overall labour productivity. The authors went on to identify the reasons for the expansion of employment in the sector, citing factors such as high net migration inflows, low interest rates, declining household sizes and infrastructure investment. They stated that "The growth in construction, a labour-intensive industry, has likely had a negative influence on overall productivity growth. However, without a long span of data we are unable to test if this pattern is present in past cycles" (Janssen & McLoughlin, 2008, p. 21).

The Davis Report (2007) was commissioned by the Department of Building and Housing because of concerns that low productivity growth may be adversely affecting the affordability of housing. The author reviewed a number of previous studies, and concluded that "there does appear to be a problem of low productivity in the construction sector" (p. 1). The report also identifies a number of possible reasons for the poor productivity, such as regulation and skills availability, and presented a model differentiating between industry, firm and site productivity issues. While these factors appear intuitively to be relevant, there is no evidence or data offered to support the contributing factors.

Allan, Yin and Scheepbouwer (2008) adopted a methodology that differed from that of the previous research. While previous studies adopted a macroeconomics approach of industry-level productivity based on statistical data collected from SNZ, this study investigated the boom–bust nature of the industry via a series of qualitative interviews with industry leaders and developed a framework using systems thinking. The objective of this study was to establish and
communicate a shared understanding of the key drivers in the boom–bust cycles of the construction industry. The study also aimed to identify what the industry needs to know in terms of quantitative or qualitative data that would help further explain the interplay and interactions between the industry players, the environment, other industries and government. System dynamic models were provided for the three main sectors, namely, private house building, infrastructure and public building, and commercial sectors. Within the infrastructure sector, a grouping of key concepts was identified: reducing the lead time of construction, shortening cycles, sharing information and smooth workflows. A further grouping was also identified: exchanging workforces, collaborating in terms of sharing information and joint action. Within the commercial sector, a grouping of concepts is improved communication between industry and clients leading to smarter procurement, improved margin and mutually beneficial efficiencies for both sides of a contract. This concurs with findings elsewhere, for example Egan (1998) and Walker & Lloyd-Walker (2015).

Partly in response to the increasing body of evidence highlighting the comparably poor productivity performance of the sector, the Department of Building and Housing established a Sector Productivity Taskforce in 2008. The taskforce comprised senior members of industry, government and academia, who were tasked with the objectives of developing a construction-sector-wide skills strategy and an improved approach to the procurement of construction projects. The Building and Construction Productivity Taskforce Report (2009) made no new findings but rather used existing reports to make 39 detailed recommendations with the aim of improving productivity by 20% by 2020. The Productivity Partnership Roadmap (2012) defined what increasing productivity would mean for the industry in terms of more outputs for fewer or the same inputs, better value for customers at a competitive price, more efficient procurement of resources, increased standardisation, design and build for whole of life, the right type and level of skills, and greater use of technology and innovation. The Productivity Partnership Roadmap asserted that the key to transforming the industry is to provide the tools it needs to transform itself.

The Cunningham (2010) report was commissioned by Building Research Association New Zealand (BRANZ) to investigate construction industry reform programmes in a number of OECD countries. It is a cross-sectional study comparing NZ productivity improvement programmes with seven other nations. Countries studied were NZ, the UK, the USA, Australia, Singapore, Denmark, Sweden and Japan. The study explored published research and current initiatives that have been introduced to address falling productivity in the building and construction industry in these countries, and then identified common themes and actions that have enabled progress to be made. The author identified that all countries studied have undergone a significant reform programme within their construction industries, with the exception of Japan. The issues addressed in each country were very similar, leading to a conclusion that there is a common model for change in the industry. A central recommendation was to adopt a productivity improvement programme in NZ and a model based on the international comparisons was proposed.
The objective of the Page (2010) study was to examine existing research on productivity, including productivity measurement and the reasons for poor productivity, and thereafter to identify some actions that the industry could undertake to improve its performance. The author identified that labour productivity in the whole industry had been declining by about 0.1% per year since 1988, and MFP had declined by about 1% per year since 1988. In addition to addressing issues of productivity measurement, the author went on to examine factors influencing productivity. This was done via a literature review and industry survey, and identified the following themes as being particularly relevant for NZ:

- poor skills and low levels of training, particularly site management, and management of multi-projects at the firm level;
- lack of modularisation and excessive use of one-off designs;
- a lack of benchmarking at the firm level to encourage improvements;
- poor levels of capturing and disseminating lessons learned from innovative and efficient firms in the industry;
- lack of economies of scale because of small average firm size;
- poor industry-government liaison for programming of government works to mitigate the boom–bust cycle;
- poor streamlining of regulations.

The survey of factors affecting the building industry productivity solicited views from approximately 190 new house builders and 80 non-residential builders. The results indicated that skills, project organisation and design detailing were the most important factors. Workload levels, procurement, innovation and multi-project organisation were also rated as being important.

The Construction Strategy Group (CSG) report (2011) suggested that the NZ construction industry was characterised by high volatility and low labour productivity, and had seen a decline in productivity over the previous 10 years. The report pointed to the small business elements of the industry making it hard to invest in people and capital as a partial reason for low productivity. The report argued that construction’s labour productivity was one of the lowest. This report identified the boom–bust characteristics of the construction sector as a problem, suggesting that the industry was volatile and suffered poor skills retention and poor productivity growth.

The objective of the New Zealand Contractors’ Federation (2011) study was to raise issues within the civil construction industry, contributing to the ongoing debate on productivity by providing some perspectives from industry. In particular, it addressed four themes, namely:

- reviews the productivity of the sector;
- questions whether civil works are procured in the most effective way;
- reviews the effectiveness of the legal environment for supporting civil infrastructure projects;
- assesses the means of developing and maintaining the skills base.
Interestingly, within the first of these themes, the report questioned some of the productivity metrics, citing challenges of collecting relevant data for the civil sector and making meaningful interpretations. If read between the lines, the report brings into question the validity of previous evidence of declining productivity, with the chief executive officer’s (CEO’s) covering letter claiming that such evidence is counter-intuitive. Nevertheless, the review identified that “there are significant benefits to be gained from a more robust approach to defining and quantifying civil construction productivity” (New Zealand Contractors’ Federation, 2011, p. 2).

The objective of the Conway and Meehan (2013) study was to review NZ’s productivity performance at the level of the whole economy, sectors and individual industries. It compared performance through time and also in comparison with other OECD countries, particularly Australia. The report identified that sectors that use information and communications technologies intensively have helped to improve NZ’s productivity performance, but identified construction and a number of labour-intensive, low-skilled service industries as having negative impacts upon the aggregate growth performance of the nation. Interestingly, construction was identified as the sector with the greatest impact upon the nation’s productivity performance. Conway and Meehan suggested that, in principle, the productivity performance of a low-productivity country such as NZ should converge with other economies as capital and ideas flow across borders. They argued that it should be easier to learn from others than to push the productivity frontier, and therefore, catch-up countries should see greater productivity growth than those at the frontier. Such catch-up is dependent upon the extent to which new technologies and ideas diffuse via mechanisms such as foreign direct investment and mobility of high-skilled workers. However, the authors presented evidence that NZ shows no evidence of such catch-up. This indicates that the NZ industry needs to be much more open to new ideas and technology, which may require significant changes in business attitudes, culture, standard practices and so on, which may be a deep-rooted challenge for New Zealanders.

The Ministry of Business, Innovation and Employment sector report on construction (2013) provided an assessment of the performance of the construction sector against a number of indicators, including productivity. It identified that construction is a high-impact sector, with demand from construction driving a wide range of other activities in the economy. It recognised the cyclical nature of the sector and challenges of responding to the Christchurch rebuild, but critiqued the productivity performance, drawing on the evidence given in previous reports referenced above.

A group comprising BRANZ, the Construction Industry Council (CIC), the CSG and the Ministry of Business Innovation and Employment (MBIE), representing different sectors of the construction industry, published the document Building a Better New Zealand (2013). The aim of the document was to improve the built environment, with a focus on using research and innovation to lift performance. The report covers broad areas of construction research such as materials performance, sustainability and productivity. Involved in developing the document were two key industry groups: the CSG and the CIC, who aim to influence government policy
and practice. The CSG is a self-appointed group of leaders in the national construction industry who seek to provide leadership and strategic direction to grow a productive professional construction industry. The CIC is a meeting of the chief executives of numerous groups of the NZ construction industry that aims, among other things, to promote the interests of the broader construction industry to central government and create conditions in which the sector can prosper. The extent to which the CSG and CIC actually influence government policy and practice is unknown. However, such lobby groups serve to raise the profile of the industry and strengthen the messages to the government regarding strategic policy directions necessary to improve productivity in the sector.

2.3.6 Productivity: Efficiency vs. Effectiveness

Before concluding on productivity, it is worth pausing to ask, “Are we measuring the right thing?” It is apparent that the paradigm of productivity performance is efficiency. However, should we be more concerned about effectiveness than efficiency? We can accept a decline in efficiency of an intermediate output, if in doing so we increase the effectiveness of deliverables to achieve better outcomes at a higher aggregate level within a system. The problem with productivity measures is the focus on outputs rather than outcomes. An examination of the model provided by Ramanathan (1985) illustrates this point:

\[
\frac{B}{C} = \frac{B}{OC} \times \frac{OC}{O} \times \frac{O}{I} \times \frac{I}{C}
\]

Where:

- \( B \) = Benefit,
- \( C \) = Cost,
- \( OC \) = Outcomes,
- \( O \) = Outputs,
- \( I \) = Inputs

![Figure 2-9: The Three E's: Efficiency, Effectiveness and Economy](image)

While efficiency is important, an even more important consideration is economy, which is a measure of outcomes over inputs. An improvement in economy can be achieved by leveraging the effectiveness of outputs to achieve the desired outcomes. So, for example, if the outcome of
a highway project is to reduce congestion in a city network, then it may be appropriate to deliver the project in a way that has a negative effect on the productivity of the construction project output (i.e., design and building of physical infrastructure) if it is done in a way that optimises (or improves) the congestion outcomes for the roading network. Similar arguments can be found for other construction sectors. In this respect, it is important to recognise that the construction industry is not an end in itself in any typical supply chain, but rather it is an intermediate input into other sectors. For example, the infrastructure for a hospital is an output for the construction sector, but the ultimate outcome is improved patient healthcare.

Many nations around the world have found similar trends to those of NZ with construction productivity over the past 20–30 years. Could this trend simply be a reflection that we are improving the ‘effectiveness’ and ‘economy’, at the expense of some reduction in ‘efficiency’? If so, this would in fact be a good thing. None of the studies reviewed in this literature review give cognisance to the relative weightings of effectiveness and efficiency.

2.3.7 Discussion

The body of evidence indicates that productivity in the NZ construction sector is poor compared with other sectors and with other nations. However, the literature has not answered the reasons for the performance emphatically, as there are no accurate industry-level measures of productivity for either the construction industry as a whole or its components (i.e., commercial, infrastructure and residential). The causes for the poor performance are not understood in detail, although a number of possible reasons are offered, including factors such as skills, training and business cycles.

There is an observable trend, however, in the productivity research over the past 10–15 years. The earlier reports are biased towards aggregate-level studies comparing different sectors with the NZ economy as a whole (e.g., Black et al., (2003)), which serve to identify the relatively poor performance of the construction industry. However, the early studies provide little or no analysis of the reasons for the apparently poor performance. More recent studies have a different focus towards analysis and discussion of the contributing factors (e.g., Allan et al., (2008)). However, these studies still lack a depth of analysis of the root causes, and there is a significant lack of research from an engineering perspective, and at the levels of the project and task. This is particularly apparent in comparison with the research outputs into construction productivity overseas, most notably from the USA.

It is clear from the literature that driving improvements in construction industry productivity is difficult. Other OECD nations have attempted to address construction sector productivity issues through major industry reform programmes. The factors influencing productivity in construction are complex, and it would appear that improvement is dependent upon many factors, including governmental engagement and industry participation.

None of the research provides a comprehensive framework for productivity improvement in the NZ context, with the possible exception of the Cunningham (2010) report. While the reported poor performance prevails in the reports, it should be noted that all studies are based on the
same data source, namely, SNZ data, and hence may simply be serving to reconfirm systemic measurement errors. This is alluded to in the New Zealand Contractors’ Federation (2011) study and warrants further investigation. Productivity is only one indicator, and any single indicator should be treated with care; it would be much more useful to have a series of indicators. None of the reports identify suitable metrics for measuring productivity at the task, project or programme (portfolio) levels. The paradigm of all of the reports is performance in terms of efficiency. This could be too narrow a focus and the issue of performance should be broadened to include effectiveness.

2.3.8 Conclusions to Productivity Literature Review

While productivity is a simple concept, actual measurement is difficult, and causality of performance is complex. It appears to be particularly difficult for the construction sector because of the heterogeneous nature of projects. However, some conclusions are as follows:

- Productivity performance of the NZ construction industry at an industry-wide level is comparatively poor compared with other sectors and other nations.
- There is no single measure of productivity, and the metric selected needs to be chosen carefully and the results interpreted properly. Different metrics are suitable for measuring performance at task levels, project levels and industry levels.
- There is a dearth of research into understanding productivity causality at task and project levels in NZ. There is a reasonable amount of research at the aggregate industry level.
- Productivity is only one metric of performance, and the results need to be understood in light of other performance metrics such as effectiveness.
- There appears to be conflicting evidence in productivity growth at an industry level compared with at an individual task level. The international research indicates that task-level productivity has improved, while industry-level performance has declined over the same period. There is a lack of understanding of the reasons for these opposing trends at different levels of measurement and analysis.
- The impact of off-site production upon productivity of the industry at an aggregate level is not well understood, and may not be adequately captured in the productivity statistics because of the classification of industry sectors.

2.4 Lean Thinking

The term ‘lean production’ was first used by researchers at the International Motor Vehicle Project (Womack, Jones, & Roos, 1991). They used the term ‘lean’ to distinguish a novel production system, pioneered primarily by the Toyota Motor Corporation, from both traditional mass-production and craft-production systems used in motor vehicle manufacturing. While the origins of lean can be traced back to earlier writings of Taylor, Ford, Deming, Goldratt, Chandler and Ohno, among others (Crowley, 1998), the two seminal books entitled The Machine that Changed the World (Womack et al., 1991) and Lean Thinking (Womack & Jones, 1996) are commonly referenced as the origins of lean.
Lean is a management system and philosophy that combines several tools and techniques, including (but not limited to) just in time (JIT) manufacturing, total quality management, total preventative maintenance, Kaizen (continuous improvement), design for manufacturing and assembly, and supplier management, with human resource management practices (Treville & Antonakis, 2006).

The term ‘lean thinking’ was introduced by Womack and Jones as a generic term to describe application beyond manufacturing (Womack & Jones, 1996). Lean thinking comprises a complex bundle of ideas including continuous improvement, flattened organisational structures, the elimination of waste, teamwork, the efficient use of resources and cooperative supply chain management (Green & May, 2005).

Koskela (1992) was the first to explicitly assess the application of lean production systems to the construction industry. He argued that the conceptual foundation of construction management and engineering, being based on the concept of conversion only, is obsolete, and challenged the construction industry to adopt the new lean production philosophy, opening a fruitful field of research, which continues to the present day.

The discourse of lean became central to the quest for industry improvement among practitioners with the publication in the UK of the Rethinking Construction report (Egan, 1998). The report identified examples of lean production systems being applied to construction firms in the USA, and recommended that the UK construction industry adopt lean thinking as a means of sustaining performance improvement.

2.4.1 Theoretical Basis of Lean Production

According to Womack and Jones, lean production is a production philosophy that focuses on adding value to the steps of the production process, from raw materials to finished goods. Lean thinking is described as lean because it “provides a way to do more and more with less and less – less human effort, less equipment, less time, and less space, while coming closer and closer to providing customers with exactly what they want” (Womack & Jones, 1996, p. 15). Lean production promotes the elimination or reduction of waste to optimise the performance of a production system as a whole.

Taichi Ohno (1988), a Toyota executive, was the first to identify and control waste in manufacturing systems. He identified seven types of waste, namely, defects (in products), overproduction of goods not needed, inventories of goods awaiting further processing or consumption, unnecessary processing, unnecessary movement (of people), unnecessary transport (of goods) and waiting by employees for process equipment to finish its work or on an upstream activity. Womack and Jones (1996) added an eighth type of waste: the design of goods and services that do not meet users’ needs.

Five lean principles are identified as follows (Womack & Jones, 1996):
• Value: Definition of the product value from the customer’s point of view. Value is only meaningful when expressed in terms of a specific product (or good or service) that meets the customer’s needs at a specific price at a specific time.

• Value stream: The entire set of activities running from raw material to finished product.

• Flow: Making the value-creating steps flow in a continuous process, removing all waste and impediments. The implementation of work practices that eliminate backflows, scrap and stoppages so that the design and production of products can proceed continuously.

• Pull: A production system in which no goods or services are produced until the customer downstream asks for them. More simply, an approach in which nothing is made until it is needed, and then it is produced very quickly. Implementation involves an approach called level scheduling, which is a system that attempts to avoid surges in demand. The shipping system and takt time become the pacemaker for the entire operation. Takt time synchronises the rate of production to the rate of sales to customers. Kanban systems regulate the pull in the production system by signalling upstream production and delivery.

• Perfection: Continuous, radical and incremental improvement.

2.4.2 Lean Production and Information Flow

While emphasis is given to production flow in lean thinking, less emphasis is given to information flow. Womack and Jones give explicit reference to information management only in a few instances. Rather, they focus on the lean production system in its entirety, arguing that benefits can only be achieved when all components of lean are implemented. However, aspects where use of information is made are as follows:

• Benchmarking: Reporting on performance metrics and benchmarking against competitors as a tool for driving performance improvement. However, it should be noted that Womack and Jones (1996) revised their view on the value of benchmarking between 1990 and 1996, going so far as to describe benchmarking as a waste of time for managers who understand lean thinking.

• Transparency and visual control: Use of visual displays is emphasised. These are clearly visible to all, so that everybody can see where production stands at every moment. They are used to alert teams in real time to the need to react, and are described as having particular importance to the management of the takt time.

• Constant verbal communications: In a lean enterprise the workspace is designed to enable workers to talk constantly. Professional support staff are placed right beside production staff. Reference is made to machines being quiet in a lean enterprise to avoid the need for ear protection.

• Goal setting: Goal setting is a top-down approach for policy deployment, incorporating simple goals with improvement targets.

• Kanban: Kanban is a system using small information cards that regulate pull in the lean system by signalling upstream production and delivery. Kanban formalises the system
to make information flow smoothly backwards through the supply system at the same rate that products flow forward. This system is central to the Toyota JIT approach across a vast group of suppliers converting them into one large machine.

- Lean learning: A lean learning approach is implemented that is carefully synchronised such that knowledge is supplied just in time and in a way that reinforces the commitment of managers and all employees to doing the right thing.

- Sharing of information: Exchange of detailed information with suppliers is emphasised, based on relationships of trust and long-term commercial arrangements. A feature of lean is that suppliers share only a single piece of information with the assembler: the bid price per part. By contrast, in a lean supply chain arrangement, there is complete transparency of information on designs and costs. A rational framework for analysing costs, establishing prices and sharing of profits facilitates the sharing of such sensitive information.

- Employee knowledge sharing: Employee knowledge sharing is facilitated via a set of mechanisms for continuous, horizontal information flow among manufacturing, supply systems, product development, technology acquisition and distribution. This is achieved primarily via ‘shusa’-led, multidisciplinary teams working together on product development. Team members are rotated through development teams, often in different specialties. The mechanism of information flow is the employees themselves as they travel among technical specialties and across the regions of a company. The result is a broad network of horizontal information channels across a company.

While lean thinking is multifaceted, and incorporates philosophies, management theories, and implementation tools and techniques (a comprehensive review of which is beyond the scope here), the way information is used is implicitly central to the lean approach. This is perhaps best summarised by the following quote:

> A simple but comprehensive information display system makes it possible for everyone in the plant to respond quickly to problems and to understand the plant’s overall situation. In old-fashioned mass-production plants, managers jealously guard information about conditions of the plant, thinking this knowledge is the key to their power. In a lean plant, such as Takaoka, all information – daily production targets, cars produced so far that day, equipment breakdowns, personnel shortages, overtime requirements, and so forth – are displayed on ‘andon’ boards (lighted electronic displays) that are visible from every work station. Every time anything goes wrong anywhere in the plant, any employee who knows how to help runs to lend a hand. So in the end, it is a dynamic work team that emerges as the heart of the lean factory. (Womack et al., 1991, p. 99)

It is apparent from the above that the foundation of the dynamic work team is attributable to the transparent information-sharing systems. In a theoretical sense, transparency means a separation of the network of information and the hierarchical structure of order giving (Greif, 1991). In classical organisation theory, information flow follows a hierarchical structure, whereas the goal in lean thinking is the substitution of formal control with self-control via sharing of information.
While lean has attracted considerable research interest as a production system, there is surprisingly little research within the arena of lean thinking that addresses matters of information flow. It would appear that nobody has considered what the underlying communication patterns are within lean that enable the advanced lean management systems such as JIT. For example, the classic text *Factory Physics* (Hopp & Spearman, 2008) makes no explicit reference to information flow. This is perhaps due to the lack of any specific chapter, conclusions or recommendation relating to information flow or communication systems by Womack et al. in their seminal writings. However, it could be argued that information flow and sharing is the tacit building block for lean, as none of the five principles of lean thinking can be applied without information flow.

### 2.4.3 Lean Construction

Lean construction is a production approach for construction based on lean production (Koskela, 1992). Koskela argues that parts of the lean production philosophy are applicable to the construction industry. He claims that the conceptualisation of production in construction is based on the conversion process model, as it once was in manufacturing, and can be extended therefore to construction. His proposal is to view a construction project as consisting of three basic flows, namely, design process, material process and work process, with supporting flows. For most organisations these processes repeat from project to project with a moderate quantum of variation (Koskela, 1992).

Koskela argues that traditional managerial concepts in construction, based on the conversion concept, have often ignored flows, and as a consequence, construction projects are characterised by a high proportion of non-value-adding activities and low productivity. He proposed a new production model defined as a flow of material and/or information from raw material to the end product (Koskela, 1992).

Koskela also argues that because of the one-of-a-kind project character of construction, it is necessary to have two time frames for analysis: a project time frame and a longer time frame. From the viewpoint of a particular one-of-a-kind project, the goal is to attain the level of cost and value of the best existing practice. For the project, flows from different companies are combined, often only for one run. Hence, it is important for organisations to coordinate flow processes on any particular project, and this implies that the role of the project manager needs to encompass information flow. This in turn implies that good project managers are those that are able to use their skills to optimise flow of information, via defining dissemination channels and removing bottlenecks.

From the viewpoint of a particular organisation, the goal is to attain a way of doing things that enables the firm to compete in the market in a way that satisfies the needs of the various stakeholders, including profit for owners and job satisfaction for employees. For the organisation, flows need to be sufficiently standardised to industry general practice, yet sufficiently flexible to enable the organisation to collaborate with other organisations across the supply chain. Hence, it is important for the organisation to coordinate information flow
processes in multiple ways that are adaptable and sufficiently agile to suit the needs of different projects.

2.4.4 Lean Construction Research

There are at least 300 peer reviewed journal papers on lean construction (Bertelsen & Koskela, 2004), which makes a comprehensive literature review challenging. Suffice it to say that lean construction has been a ripe area for research in the past decade, and there are plenty of case studies, critical analyses, and recommendations for application. An overview of a portion of the lean literature indicates there are a number of trends in the research, with principal authors taking leads in different areas. An attempt to assess these trends is provided in Table 2-7.

Table 2-7: Overview of Main Research Authors and Themes in Lean Construction

<table>
<thead>
<tr>
<th>Principal Author</th>
<th>Lean Construction Research Theme</th>
<th>Example Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballard</td>
<td>A range of issues, including tools (e.g., Last Planner™), and project delivery systems</td>
<td>(Ballard, 2000a, 2000b; Ballard, Arbulu, &amp; Elfving, 2006; Ballard, Harper, &amp; Zabelle, 2003; Ballard &amp; Howell, 1998, 2003a, 2003b, 2005; Ballard et al., 2005; Ballard &amp; Rybkowski, 2009)</td>
</tr>
<tr>
<td>Howell</td>
<td>Research on practical issues relating to application of lean thinking</td>
<td>(G. A. Howell et al., 2004; G. Howell, Llaufer, &amp; Ballard, 1993)</td>
</tr>
<tr>
<td>Sacks</td>
<td>Visualisation, information technology and building information management</td>
<td>(Sacks, Eastman, &amp; Lee, 2004a, 2004b; Sacks, Esquenazi, &amp; Goldin, 2007; Sacks &amp; Goldin, 2007; Sacks et al., 2010; Sacks &amp; Partouche, 2009; Sacks, Treckmann, &amp; Rozenfeld, 2009)</td>
</tr>
<tr>
<td>Horman</td>
<td>Buffer management, and application of lean principles to issues of construction sustainability</td>
<td>(Horman &amp; Thomas, 2005; Lapinski, Horman, &amp; Riley, 2006)</td>
</tr>
<tr>
<td>Alarcon</td>
<td>Implementation issues</td>
<td>(Alarcon, Diethelm, Rojo, &amp; Calderon, 2005; Alarcon &amp; Mourgues, 2002)</td>
</tr>
<tr>
<td>Tommelein</td>
<td>Simulation of work flow</td>
<td>(Tommelein, 1998; Tommelein, Riley, &amp; Howell, 1999)</td>
</tr>
</tbody>
</table>

All of the authors listed in the table are generally advocates for lean thinking in construction.

2.4.5 Discussion

Lean thinking is offered as a way of improving performance for the construction industry. However, in reviewing the literature it is apparent that the paradigm is of transferring manufacturing processes and philosophies to construction, with a positivistic view on the benefits to be gained. The case for lean construction is in general compelling, with numerous case studies showing the reduction in waste, greater profitability, improved customer satisfaction and so on. However, there are some dissenting voices. Winch (2003) is critical of lean construction for having a unitary view of value, lacking in theory about uncertainty and risk, and being deficient in issues relating to concepts of the firm. Green and May (2003, 2005) are
also critical of lean as being overwhelmingly prescriptive, with little recognition of the social and politicised nature of the construction industry. Koskela and Vrijhoef (2001) also acknowledged that lean thinking application to construction has been limited, stating, “Direct application of this production template to construction has been limited due to the different context of construction in comparison with manufacturing” (p. 197). The reasons why lean has not revolutionised construction have not been the direct subject of research; however, they are likely to include the following challenges, which are generally well recognised in the literature:

- Construction is characterised by one-of-a-kind production.
- Construction outputs are delivered via temporary organisations, which are inherent in the nature of one-of-a-kind projects.
- Complexity exists in construction and site-based production.

### 2.4.6 Conclusions to Lean Thinking Literature Review

Lean thinking appears to have a number of merits and applications to construction, which are generally supported in the literature, but not without criticism. Lean thinking has not transformed the construction industry, despite being firmly on the agenda of industry reform. Lean thinking was the central proposition of Sir John Egan’s report Rethinking Construction (1998), but has failed to drive radical improvements (Wolstenholme, 2009).

However, some of the lean principles and performance improvement approaches do appear to have merit. In particular, the identification of value-adding and wasteful (non-value-adding) activities is useful in considering ways of improving productivity. Also, some of the pragmatic approaches to information sharing adopted in lean organisations are worthy of further investigation.

### 2.5 Decision-Making

#### 2.5.1 Information for Decision-Making

There has been a significant research output over the past half century in human decision-making. We have not attempted to provide a comprehensive literature review of this output, but rather aimed to identify some of the main themes relating to how information is used in human agent decision-making. Information is used by human agents for decision-making leading to action (which in some cases may be a decision not to act). Our research needs to recognise and understand this vital stage in the process in order to address the linkages between information flow and productivity. Classical decision theory is based on the rational economic model of maximisation of subjective expected utility, with human agents following a rational process as indicated in Figure 2-10.
Classical decision theory states that the rational course of action in decisions made under uncertainty is to select the option that maximises subjective expected utility. In such a normative account, human actors are seen as adopting rational behaviour, with people choosing the course of action that is ‘best’ for them. Decision-makers are assumed to be perfectly informed about alternatives available to them, and assured of their own beliefs and values, from which they determine what is best.

2.5.2 Limitations of Human Decision-Making

The classical theory is now accepted as not providing an accurate account of how people typically make decisions (Huczynski & Buchanan, 2010). The body of knowledge on human decision-making recognises that human decision-making has various limitations within three broad areas of decision-making, as summarised in Table 2-8.

Table 2-8: Theories of Human Decision-Making and Associated Limitations

<table>
<thead>
<tr>
<th>Level of Analysis</th>
<th>Key Issues</th>
<th>Theoretical Perspectives</th>
</tr>
</thead>
</table>
| Individual        | Limits to information-processing ability  
Biases (heuristics) | Information-processing theories  
Cognitive psychology |
| Group             | Effects of group dynamics on individuals’ perceptions, attitudes and behaviours | Groupthink, group polarisation and group cohesiveness |
| Organisational    | Effects of conflicts, power and politics | Theories of organisational conflict, power, politics and decision-making |

Source: Based on Huczynski & Buchanan (2010)

There are a number of alternative descriptive theories. These descriptive theories are concerned with explaining what people actually do, rather than what they ought to do. Some of the main ones are outlined in the following sections.

Behaviour theory recognises and attempts to explain how people actually behave under conditions of uncertainty. Simon (1960) and March (1962, 1987, 1988) showed that people
make decisions within the limits of ‘bounded rationality’, recognising that information and the
definition of any problem and generation of alternatives will be incomplete. This leads to the
concept of ‘satisficing’, in which people evaluate one option at a time and accept the first option
that meets certain minimum requirements. Consequently, satisficing may lead to acceptance of
non-optimal options.

Prospect theory describes how people make choices in situations of uncertainty, and identifies a
framing effect (Kahneman & Tversky, 1979). Trivial changes to the way information is
presented, emphasising either potential gains or potential losses, lead to reversals of
preference. Prospect theory states that decision-making is a two-stage process comprising:

- Editing, which involves the building of a mental model as a reference frame. Once
  formed, this reference frame is perceived as the neutral point.
- Evaluation, which is made on relative terms and not absolute terms (i.e., against the
  perceived neutral point identified in the first stage of the process).

The implications of prospect theory are dramatic: the authors claim that the theory accounts for
observed systematic biases in decision-making and that the way problems are framed in
informational terms matters. These implications were summarised by Bazerman (2002) as
follows:

- Human decision-makers are risk seeking when information is framed in the domain of
  losses (i.e., when losses are highlighted).
- Decision-makers are risk averse when information is framed in the domain of gains (i.e.,
  when gains are highlighted).
- Responses in the domain of losses are more extreme than those in the domain of
  gains.

Groupthink is a phenomenon in which groups or teams develop high degrees of cohesiveness
(Janis, 1972). While cohesiveness is generally a positive thing, it can lead to negative
consequences from faulty decision-making. This occurs in groups when members’ strivings for
unanimity override a realistic appraisal of information and choices, or override expression of
contradictory views. An example of groupthink is the Challenger Space Shuttle disaster, which
was attributed in a presidential commission to flawed decision-making and the negative
symptoms of groupthink (Esser and Lindoefer, 1989).

The judgement heuristic model is based on the concept that people use judgement shortcuts, or
rules-of-thumb called heuristics, to reduce the information-processing demands of decision-
making. Heuristics help people deal with complexity; however, they have been shown to result
in a number of biases in situations when individuals inappropriately apply a heuristic. A large
number of heuristics were identified in a series of papers by Kahneman and Tversky (1972,
Table 2-9: Summary of Different Heuristics and Associated Inherent Biases Typically Inherent in Each Heuristic

<table>
<thead>
<tr>
<th>Heuristic</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>A predisposition to base judgements on probability on the basis of information that is readily available. Hence, an event that is vividly remembered is considered more likely to occur than a bland memory.</td>
</tr>
<tr>
<td>Representativeness</td>
<td>A predisposition to base judgements of probability on the basis of things that are familiar, and to ignore other relevant information.</td>
</tr>
<tr>
<td>Anchorage and adjustment</td>
<td>A predisposition to make a judgement by starting from an initial value (anchor) and then making insufficient adjustments from that anchor to reflect other significant factors. Different starting points yield different answers.</td>
</tr>
<tr>
<td>Overconfidence</td>
<td>A predisposition to be overly confident in judgements when answering moderately to extremely difficult questions.</td>
</tr>
<tr>
<td>Escalation of commitment</td>
<td>A predisposition to continue in a commitment to a course of action, and to ignore evidence indicating failings in the chosen course.</td>
</tr>
</tbody>
</table>

Each of these heuristics needs to be recognised in any research relating to information, and ultimately will have some bearing on outcomes such as the productivity and performance of organisations, projects, teams and individual performance.

2.5.3 Decision-Making in Engineering and Construction

In the engineering and construction sector some research has been undertaken, primarily relating to decision-making in design. Mullaly (2014) identifies human agency coupled with rule effectiveness leads to effective decision-making in a project context, and goes on to conclude that agency can compensate for organisational inadequacies. Tenah (1984) asserted that the proper utilisation of information allows designers and management to make sound decisions, and information flow facilitates all individuals working on a project to be on the same page. Wallace and Burgess (1995) found that because of the amount of inevitable revisions made during the design process, the adjustments of each revision increase information, which yields better decisions with the accumulated information. However, there is a balance, as decision-makers become indecisive and ineffective when information becomes overloading (Galbraith, 1974). Also, the skilful use of information in the design management process is dependent on the level of experience, training and expertise of the design manager (Bibby et al., 2006).

A study by Patterson and Farrant (1982) succeeded in gaining insight into the information search and dissemination strategies of decision-makers in engineering in the NZ construction sector, by undertaking a detailed set of questions and answers based on a recent decision taken by a research participant. In their study they asked participants, taken from a sample of practitioners, to identify a recent decision and then, through a comprehensive set of questions, to identify the various information sources, including people and documentary sources. They concluded that the information search strategy is multifaceted. Typically, the sources used by decision-makers comprise a mix of personal experience, information from other people and written materials, in a ratio of 3–2–1 parts respectively. They also found that the decision-maker’s choice of information sources depends upon the role and position of the decision-
maker, and the context of the decision. They found that decision-making in design is preceded by three typical phases: awareness, acquisition of information and confirmation. This line of research does not appear to have been followed further in the NZ research outputs.

Decision-making and communications behaviour during construction co-ordination meetings were studied by Gorse and Emmitt (2003), who found that decision-making was primarily task based but with occasional outbursts of emotional interaction. In a subsequent study of management and design meetings the same authors found similar high levels of task-based interaction, with low levels of socio-emotional interaction, leading to a concern that problems may be left unchallenged (Gorse & Emmitt, 2007). These findings were somewhat contradictory to the stereotypical view of engineering and construction being aggressive and adversarial.

2.5.4 Conclusions to Decision-Making Literature Review

Decision-making is hard to quantify, as the human brain is able to make judgements using a range of heuristics, and make subjective considerations, which can be difficult to state explicitly. Although some of the heuristics research has been criticised (Gigerenzer, 2003), there is strong evidence that human decision-making is often not rational and may be less than ideal. This has important implications for information flow in the construction industry for the following reasons:

- Trivial changes in the way information is framed can affect risk seeking or avoidance behaviour. Excessive risk seeking or avoidance behaviours may affect productivity.
- The way that information is presented may lead to biases as a result of decisions made on the basis of heuristics. In particular, availability, representativeness and anchorage and adjustment heuristics are likely to be prevalent in the construction sector. Decision-making based on information presented is therefore likely to be biased, which may have an impact upon productivity.
- Information requirements and processing by teams is likely to be different from those of individuals. Much of the construction industry works in teams. Some teams may be predisposed to the negative effects of groupthink, and may ignore available information in order to maintain group cohesiveness. Accordingly, some teams may exhibit counter-productive behaviours, which in turn may adversely affect productivity.
- Decisions may be based on information that is readily available following ‘satisficing’ behaviour (rather than seeking more complete information), which may affect productivity.

These normative theories have been found to describe behaviours of people at all levels of education, and apply equally to professionals (Bazerman, 2002). Therefore, these issues may apply equally to designers, contractor management staff and tradespeople at all levels of organisational hierarchies. It may not be possible, however, to directly observe the heuristics being deployed, but the possible biases arising should be acknowledged.
2.6 Literature Review Overall Summary and Conclusions

Although our literature review is not a comprehensive review of all literature on the subjects considered, it is possible to identify a number of areas where there are substantial levels of existing knowledge and areas where there are knowledge gaps. These are offered in Table 2-10.

Table 2-10: Summary of the Pertinent Known and Unknown Issues Identified from the Literature Review

<table>
<thead>
<tr>
<th>Known</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>There are a number of theories of information. It is generally accepted that there are a number of different levels of information, e.g., statistics, syntax, semantics, pragmatics. Mathematical theories of information at the levels of statistics and syntax are well understood.</td>
</tr>
<tr>
<td>Information</td>
<td>Information is closely associated with data and knowledge, and is also linked with wisdom and understanding.</td>
</tr>
<tr>
<td>Recent research from other sectors investigates information flow and productivity, which shows that there is a positive correlation at the task level.</td>
<td>There is no research linking information flow to productivity in the construction sector.</td>
</tr>
<tr>
<td>Productivity performance for the NZ construction industry at the aggregate level is poor.</td>
<td>Causality for productivity performance in the NZ construction sector is not well understood in detail.</td>
</tr>
<tr>
<td>Productivity</td>
<td>There is no single measure of productivity. The metric selected needs to be chosen carefully and the results interpreted properly. Different metrics are suitable for measuring performance at task, project and industry levels.</td>
</tr>
<tr>
<td>Productivity</td>
<td>Productivity is only one metric of performance, and the results need to be understood in light of other performance metrics such as effectiveness. Effectiveness may be more important than efficiency.</td>
</tr>
<tr>
<td>There appears to be conflicting evidence relating to productivity growth at an industry level compared with an individual task level.</td>
<td>There is a lack of understanding of the reasons for these opposing trends at different levels of measurement and analysis.</td>
</tr>
<tr>
<td>International research indicates causality for productivity loss in construction and includes rework, weather conditions, human factors such as motivation, change orders, materials management and other wastes generally.</td>
<td>The linkage between information flow and productivity has not previously been the subject of research (although the matter of information flow is identified as a factor affecting productivity).</td>
</tr>
<tr>
<td>Known</td>
<td>Unknown</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Lean is a well-developed theory of production that has been widely</td>
<td>Lean thinking has not transformed the construction industry, despite</td>
</tr>
<tr>
<td>applied in the manufacturing industry. It is generally accepted that</td>
<td>being firmly on the agenda of industry reform. Lean thinking was the</td>
</tr>
<tr>
<td>lean thinking has revolutionised manufacturing on a global basis. The</td>
<td>central proposition of Sir John Egan’s report Rethinking Construction</td>
</tr>
<tr>
<td>theory and practical application of lean to production systems lifts</td>
<td>(1998), but has failed to drive radical improvements (Wolstenholme, 2009).</td>
</tr>
<tr>
<td>performance and generates productivity improvements.</td>
<td>The reasons why lean has failed to transform construction are not well</td>
</tr>
<tr>
<td></td>
<td>understood.</td>
</tr>
<tr>
<td>There is a distinction between value-adding activities and waste.</td>
<td>While information flow within the lean production system is recognised,</td>
</tr>
<tr>
<td>Aspects of lean production have been thoroughly researched.</td>
<td>the relationships between information flow and production are not as</td>
</tr>
<tr>
<td></td>
<td>well understood.</td>
</tr>
<tr>
<td>Lean thinking has attracted significant levels of research interest</td>
<td>Lean is a management philosophy borrowed from manufacturing, and it is</td>
</tr>
<tr>
<td>in construction, and has developed a body of knowledge called lean</td>
<td>not clear that it is directly applicable to the context of construction.</td>
</tr>
<tr>
<td>construction.</td>
<td>There is a lack of an adequate theory of construction that has been</td>
</tr>
<tr>
<td></td>
<td>conceptualised from within the construction industry. There is no</td>
</tr>
<tr>
<td></td>
<td>competing paradigm to lean construction.</td>
</tr>
<tr>
<td>Human decision-making is often not rational and may be less than ideal.</td>
<td>Excessive risk seeking or avoidance behaviours may affect productivity</td>
</tr>
<tr>
<td>Prospect theory (Kahneman &amp; Tversky, 1979) states that trivial</td>
<td>outcomes, but the linkage is unknown. Also, the heuristics of availability,</td>
</tr>
<tr>
<td>changes in the way information is framed can affect risk-seeking or</td>
<td>representativeness, anchorage and adjustment are likely to be prevalent</td>
</tr>
<tr>
<td>avoidance behaviour. Also, the way that information is presented may</td>
<td>in the construction sector. This may have a detrimental effect upon</td>
</tr>
<tr>
<td>lead to biases as a result of decisions made on the basis of</td>
<td>productivity in construction, but this is unproven.</td>
</tr>
<tr>
<td>heuristics.</td>
<td></td>
</tr>
<tr>
<td>Information requirements and processing by teams is likely to be</td>
<td>Some teams in construction may be predisposed to the negative effects</td>
</tr>
<tr>
<td>different for individuals. Groupthink can lead to faulty group</td>
<td>of groupthink, and may ignore available information in order to maintain</td>
</tr>
<tr>
<td>decision-making. Much of the construction industry works in teams.</td>
<td>group cohesiveness. Therefore, some teams may exhibit counter-productive</td>
</tr>
<tr>
<td></td>
<td>behaviours, which in turn may adversely affect productivity, but this</td>
</tr>
<tr>
<td></td>
<td>is unproven.</td>
</tr>
<tr>
<td>Decisions may be based on information that is readily available</td>
<td>The extent to which satisficing occurs in decision-making in engineering</td>
</tr>
<tr>
<td>following ‘satisficing’ behaviour (rather than seeking more</td>
<td>and construction is unknown.</td>
</tr>
<tr>
<td>complete information) which may affect productivity.</td>
<td></td>
</tr>
</tbody>
</table>

In summary, there is no known research that addresses the four subject matters considered above in a coherent manner. The synthesis of these bodies of knowledge presents opportunity to develop a new line of research to address information flow and productivity in the engineering and construction sector.
3 Research Design

3.1 Introduction
This chapter develops a detailed research approach for investigations into the linkages between information flow as inputs to a process and productivity performance as an outcome of the process. Generally speaking, information is used in human endeavours as an input for decisions, leading to actions that ultimately affect productivity outcomes. Information is by nature an abstract concept that is hard to define, whereas productivity is a much more objective construct that is quantifiable with specific metrics. We therefore propose a research design suitable for undertaking investigations into abstract causal factors with more objective outcomes.

3.2 Development of the Research Methodology
Rajasekar et al. (2006) define research as “a logical and systematic search for new and useful information on a particular topic” (p. 1). Research often involves several interconnected activities such as study, experiment, observation, analysis, comparison and reasoning. These activities are usually done sequentially, with preceding tasks serving to guide subsequent tasks. Therefore, in order to draw these activities into a systematic and coherent whole approach, a philosophy needs to be deployed and allied with appropriately selected tools and techniques. This combination of philosophy and applied techniques is referred to as the methodology of the study (Easterby-Smith, 2008).

Research methodology is concerned essentially with why data should be collected, what data should be collected, where the data should be collected from, when the data should be collected, how the data should be collected and how the data is to be analysed (Saunders, Lewis, & Thornhill, 2009). Research methodology should not be confused with research methods per se, which are rather the "various procedures, schemes, algorithms, etc. used in research" (Rajasekar et al., 2006, p. 2).

The development of our research methodology followed the research process framework provided by Saunders et al. (2009), which is illustrated in Figure 3-1, supplemented by other materials where pertinent. Development started from the outside of the onion by considering the fundamentals of research philosophy, and moves progressively inwards towards the details of data collection methods.
In the following sections we discuss each layer in turn and conclude with a fully developed research plan. A brief overview of each layer is provided in Table 3-1.

Table 3-1: Overview of the Research Process Onion Outlining the Different Layers

<table>
<thead>
<tr>
<th>Layer</th>
<th>Domain</th>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Philosophy</td>
<td>Epistemological considerations and assumptions</td>
<td>Deeply held beliefs about the nature of knowledge and how we know</td>
</tr>
<tr>
<td>Research Approaches</td>
<td>Research purpose</td>
<td>High-level considerations of deductive vs. inductive approach to generation of knowledge Consideration of research purpose as exploratory vs. descriptive, vs. explanatory</td>
</tr>
<tr>
<td>Research Strategies</td>
<td>Development of strategies to fit research purpose</td>
<td>Matching approaches to address the request question</td>
</tr>
<tr>
<td>Timing Horizons</td>
<td>Time considerations</td>
<td>Research methods at point in time (cross-sectional ‘snap shot’) or across time horizons (change and trends across time)</td>
</tr>
<tr>
<td>Data Collection Methods</td>
<td>Practical considerations</td>
<td>Selection of the data collection methods. Consideration of qualitative and quantitative data collection, or combination in mixed method approach</td>
</tr>
</tbody>
</table>

3.2.1 Research Philosophy

Epistemology is defined as “the philosophical theory of knowledge” (Chambers, 2014). There are two generally accepted epistemological approaches, namely, positivism and interpretivism. The difference between positivism and interpretivism is rooted in the approach to knowledge. In the positivist approach, people and processes are seen as constructions, whereas in the
interpretive approach, people are the constructors. This philosophical difference between the two strands ultimately influences the way that research is carried out.

In the positivist approach, knowledge is scientifically and systematically established through the accrual of validated data. Proponents of positivism would advocate that knowledge is deductive and must be carried out in an objective way. Therefore, in the positivist's view, the role of research is primarily to test theories and create laws. This approach gives the researcher the view that phenomena can be subjected to hypotheses and thereafter tested. This approach is termed the hypothetico-deductive model (Whewell, 1840), being a description of the scientific method of research: observing a phenomenon, constructing theories, postulating hypotheses to test, developing rigorous tests, and then either accepting or rejecting hypotheses on the basis of the test results.

Interpretivism, by contrast, maintains that events (and facts) are not independent of their interpretation. Our reality is determined by the observer's interpretation of matters. Accordingly, in the interpretivist view, objective analyses are impossible on the basis that the researcher is also part of the system being analysed, and therefore by definition is not independent. Hence, proponents of the interpretivist philosophical view hold that knowledge is a social construction and that the researcher's role is to present an interpretation of complex (and often incomplete) sets of data and information.

Saunders et al. (2009) identified realism as a third research philosophy, which is based on the belief that a reality exists independent of human thoughts and beliefs. In social sciences this is seen as indicating that there are universal powers and rules that affect events, without people necessarily being aware of the existence of such influences, and hence events are not subject to observers' interpretations. Saunders et al. (2009) stated that while “realism shares some philosophical aspects with positivism, it also recognises that people themselves are not objects to be studied in the style of natural science”.

Boisot and MacMillan (2004) identified four intersecting worlds: possible, plausible, probable and actual worlds. Possible worlds encapsulate the entire spectrum of what can be taken as knowledge, which they defined as beliefs that individuals are willing to act upon to some degree. Plausible and possible worlds constitute the more limited sets of knowledge that meet either the truth or the justified condition. The fourth, actual world is found in the area given by the intersection of plausible and probable, which comprises Plato’s definition of knowledge, that is, justified true belief (Plato, 360BC). Boisot and MacMillan (2004) argued that people have two distinct paths for navigating from possible to actual worlds and therefore plausibility and probability constitute alternative yet complementary bases for research. An approach via the plausible world starts by enlarging coherence into beliefs, and then seeks congruity of the plausible with the real world by a process of verification of these coherent beliefs. In the alternative approach, via probable worlds, a researcher initially investigates the phenomena in the real world and then constructs a coherent and plausible interpretation. The first of these
approaches fits more readily with the interpretative philosophy, and the second with the positivist philosophy.

The aim of this research is to understand the relationship between an abstract construct (information) as an input to a process and an objective outcome (productivity) from the process. We contend that the complex issues relating to information flow and information-related concepts of knowledge, thoughts and belief fall into the interpretivist domain. However, the productivity problem that we are addressing needs to be based in a reality that exists independently of human thoughts and beliefs. Therefore, the research should be oriented towards a realist view rather than a strictly positivist or interpretivist view. Such a view follows the reasoning identified by Walsham (2001), who noted the growing acceptance of interpretivism within the domain of information research, and also concurred with Saunders et al. (2009) who noted that management research is “often a mixture between positivist and interpretivist, perhaps reflecting the stance of realism” (p. 85).

Meredith et al. (1989) researched alternative paradigms for operational research, and provided a useful framework for selecting research options. In addition to the positivist and interpretivist approaches outlined previously they included an axiomatic perspective, and critical theory, which are mapped against three views of reality comprising direct observation, people’s perception and artificial reconstruction. Using this framework, we applied a process of elimination of options to narrow the field and provide some direction to our research, with suitable approaches highlighted in shaded fields in Table 3-2.

Table 3-2: A Framework for Research Methods

<table>
<thead>
<tr>
<th>Approach to Knowledge Generation</th>
<th>Direct Observation of Reality</th>
<th>People’s Perception of Reality</th>
<th>Artificial Reconstruction of Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axiomatic (a theorem-proof approach in which a high degree of knowledge is assumed, a priori)</td>
<td>-</td>
<td>-</td>
<td>Reason/logic/ theorems Normative modelling Descriptive modelling</td>
</tr>
<tr>
<td>Logical Positivist / Empiricist</td>
<td>Field studies Field experiments</td>
<td>Structured interviewing Survey research</td>
<td>Prototyping Physical modelling Laboratory experiments Simulation</td>
</tr>
<tr>
<td>Interpretive</td>
<td>Action research Case studies</td>
<td>Historical analysis Delphi Expert panel Intensive interviewing Introspective reflection</td>
<td>Conceptual modelling Hermeneutics</td>
</tr>
<tr>
<td>Critical Theory (a post-positivist perspective)</td>
<td>-</td>
<td>Introspective reflection</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Meredith et al. (1989) (annotated for this research)
In consideration of this framework we identified that:

- Axiomatic approaches are not appropriate, on the basis that we are seeking practical solutions to a complex management and engineering issue. A low degree of knowledge is assumed, \textit{a priori}, about the issues.
- Approaches adopting artificial reconstructions of reality, such as physical modelling, laboratory experiments and simulation, are not applicable for our objective, which relates to real life management issues that cannot be reconstructed in a laboratory.
- The development of critical theory using introspective reflection should be part of the research, as the intent of the project as a whole needs to address philosophical debate and development of theories of information.

It was apparent that in order to embrace a research philosophy of realism, a programme of research was necessary to understand the problem from both an interpretative and a positivist point of view. Recognition of this fact indicated that mixed research methods were appropriate, and should be applied in the progressive manner. Also, in seeking to address the research problem through the different worlds of plausibilities and probabilities, we were encouraged by Popper (1959, 1963) and Kuhn (1970), who have already made the case for tolerance of high degrees of uncertainty and who spurred us to hypothesise with boldness.

3.2.2 Research Approaches

\textbf{Deductive vs. Inductive Logic}

There are two broad methods of reasoning in the field of logic: deduction and induction. Informally, they may be referred to as ‘top-down’ and ‘bottom-up’ approaches respectively.

Deductive reasoning starts from the more general and works towards the more specific. A theory is proposed, which is subsequently narrowed down to a more specific hypothesis. The hypothesis is subsequently subjected to experimental testing and observations, leading to verification or otherwise of the theory (Trochim, 2006). Conversely, inductive reasoning works from specific observations towards broader generalisations and theories. The researcher begins with specific observations or measures and seeks to identify patterns and regularities. Tentative hypotheses are formulated based on the accumulation of such observations and are finally used for the development of some general conclusions or theories.

Inductive reasoning by nature is typically more tentative, exploratory and elastic than deductive (especially in early stages), whereas deductive reasoning is more attenuated, being concerned with testing and confirming hypotheses (De Vaus, 2001). However, even though a particular study may look like it is purely deductive, most research involves both inductive and deductive reasoning processes at some time in the project (Trochim, 2006). Saunders et al. (2009) noted that in relation to research philosophies, “the deductive approach owes more to positivism and the inductive approach to interpretivism” (p. 85).

In this research, because of the lack of a well-established theory of information flow in construction, an approach that is more inductive than deductive was identified as being be appropriate.
**Research Approach in Relation to Purpose**

A research design provides an operational plan, within which valuable outputs can be obtained through collecting, processing and analysing raw data to enable answers to the initial question as unambiguously as possible (De Vaus, 2001). Essentially, there are three types of design frameworks that most research projects are based upon: exploratory, descriptive and explanatory research.

Exploratory studies are a valuable means of finding out “what is happening; to seek new insights; to ask questions and to assess phenomena in new light” (Robson, 2002, p. 59). It is particularly useful for clarifying a problem (Saunders et al., 2009). The inherent flexibility in exploratory research does not mean an absence of direction, but rather that the focus is initially broad and becomes progressively narrow as the research progresses.

Descriptive research is a research design in which the major emphasis is on describing data and the characteristics of the phenomenon being studied. It seeks answers to the questions of who, what, where, when and how. This method finds its application in disciplines such as social science or psychology, where a profile of problems is created and analysed by researchers so that a general overview of the subject can be obtained. It is also useful in situations in which it is not possible to test and measure the large number of samples needed for more quantitative experimentation (Cooper & Schindler, 2003). Although the data description is factual, accurate and systematic, descriptive research does not explain interactions or relations between factors and therefore cannot be used to create a causal relationship, in which one variable affects another. Rather, the objective of descriptive research is “to portray an accurate profile of persons, events or situations” (Robson, 2002, p. 59).

Explanatory research (sometimes called causal) studies a situation or a problem in order to explain the relationship between variables. Such studies seek to establish causal relationships (Saunders et al., 2009). Typically, they involve subjecting data to statistical tests such as correlation, in order to obtain a clear view of the relationship.

This research required a progression from exploratory, through descriptive, to explanatory (causal) research. As the ultimate objective was to identify ways of improving productivity, causal relationships needed to be understood. This led to the conclusion that a staged research plan was necessary, with a progressional approach.

### 3.2.3 Research Strategies

Saunders et al. (2009) identified six main research strategies: experiment, survey, case study, grounded theory, ethnography and action research.

Experiment is a classical form of research that owes much to the natural sciences. It typically involves definition of a theoretical hypothesis, selection of samples, allocation of samples to experimental conditions, introduction of a planned change, and measurement. The survey strategy is usually associated with the deductive approach. It allows the collection of large amounts of data from a sizeable population in a highly economical way (Saunders et al., 2009).
Case study is defined by Robson (2002) as “a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence” (p. 178). It is particularly useful for gaining a rich understanding of the context of the research and has considerable ability to generate answers to the why question (Saunders et al., 2009). Grounded theory is a methodology that emphasises the generation of theory from data in the process of conducting research (Glaser & Strauss, 2009). A combination of induction and deduction are used to develop theory, in which data is initially collected without the formation of a theoretical framework; rather, theory is developed from the data collected via a series of observations. Ethnography emanates from the field of anthropology. The purpose is to interpret the social world that the research subjects inhabit, in the way in which they interpret it. Action research is an applied form of research that has a particular focus on generating change. As noted by Coghlan and Brannick (2010), the purpose of action research is not to describe, understand and explain the world but also to change it.

This research required a mixed approach, combining surveys and case studies within grounded theory. The lack of an existing theoretical model for information flow and productivity meant that new theories and models were required, which needed to be developed from the data while in the process of collecting data. This was best done in a staged progression manner.

### 3.2.4 Research Time Horizons

Saunders et al. (2009) identified two main types of study with respect to issues of time horizons: the cross-sectional and the longitudinal approaches. Time horizons of the research are independent of the research strategy, but should be selected to suit the research question. The cross-sectional study provides a snapshot taken at a particular point in time. Such studies often seek to describe the incidence of a phenomenon or to compare factors in different sections of the subject matter. Surveys are often undertaken in cross-sectional studies, but other qualitative methods may also be used. The longitudinal approach, by contrast, studies change and development over time. One benefit of the longitudinal approach is that the researcher may instigate some controls over the variables being researched.

In this research, we were seeking first to understand the problem of productivity and then to find ways of improving productivity performance. Thus, an initial cross-sectional study was appropriate, followed by some longitudinal research in order to study trends of productivity performance over a period of time.

### 3.2.5 Research Methods: Quantitative vs. Qualitative

Many authors draw a distinction between quantitative and qualitative research, for example, Creswell (2008), Easterby-Smith (2008) and Saunders et al. (2009).

Quantitative research comprises an empirical investigation of quantitative phenomena, undertaken in a systematic way to establish properties and causal relationships. It provides means of establishing and verifying correspondence between empirical observations and mathematical expressions. Quantitative research techniques are useful for analysing and
interpreting data at various levels of sophistication. Quantitative approaches range from simple tables or diagrams through to establishing statistical relationships between variables, or complex statistical modelling. Saunders at al. (2009) noted that virtually all research involves some numerical data, which should be quantified to help answer the research question.

Qualitative research is exploratory in nature. Qualitative methods were defined by Miles and Huberman (1994) as a set of data collection and analysis techniques that emphasise the fine grained, the process oriented and the experimental, and that provide a means for developing an understanding of complex phenomena from the perspectives of those who are living it. Such methods allow the researcher to discover new variables as well as linkages between them; and also importantly to identify contextual issues (Barr, 2004). Qualitative research is particularly useful for discerning complex issues and for identifying the influence of a range of individuals’ perspectives (Lee, 1999).

Qualitative methods are most often utilised for building theory, when, for example, an existing phenomenon is poorly understood and relevant variables and/or linkages cannot be readily identified. They provide the researcher with an opportunity to develop detailed understandings and descriptions of the phenomenon of interest (Barr, 2004). Qualitative research encompasses a number of data collection techniques including observations, interviews and analysis of archival information such as documents. The differences between qualitative and quantitative methods as summarised by De Vaus (2001) are presented in Table 3-3.

**Table 3-3: Qualitative and Quantitative Methods Compared**

<table>
<thead>
<tr>
<th></th>
<th>Quantitative Mode</th>
<th>Qualitative Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assumptions</strong></td>
<td>Social facts have an objective reality</td>
<td>Reality is socially constructed</td>
</tr>
<tr>
<td></td>
<td>Primacy of method</td>
<td>Primacy of subject matter</td>
</tr>
<tr>
<td></td>
<td>Variables can be identified and relationships measured</td>
<td>Variables are complex, interwoven and difficult to measure</td>
</tr>
<tr>
<td></td>
<td>Etic (outsider’s point of view)</td>
<td>Emic (insider’s point of view)</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Generalisability</td>
<td>Contextualization</td>
</tr>
<tr>
<td></td>
<td>Prediction</td>
<td>Interpretation</td>
</tr>
<tr>
<td></td>
<td>Causal explanations</td>
<td>Understanding actors’ perspectives</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td>Begins with hypotheses and theories</td>
<td>Ends with hypotheses and grounded theory</td>
</tr>
<tr>
<td></td>
<td>Manipulation and control</td>
<td>Emergence and portrayal</td>
</tr>
<tr>
<td></td>
<td>Uses formal instruments</td>
<td>Researcher as instrument</td>
</tr>
<tr>
<td></td>
<td>Experimentation</td>
<td>Naturalistic</td>
</tr>
<tr>
<td></td>
<td>Deductive</td>
<td>Inductive</td>
</tr>
<tr>
<td></td>
<td>Component analysis</td>
<td>Searches for patterns</td>
</tr>
<tr>
<td></td>
<td>Seeks consensus, the norm</td>
<td>Seeks pluralism, complexity</td>
</tr>
<tr>
<td></td>
<td>Reduces data to numerical indices</td>
<td>Makes minor use of numerical indices</td>
</tr>
<tr>
<td></td>
<td>Abstract language in write-up</td>
<td>Descriptive write-up</td>
</tr>
<tr>
<td><strong>Role</strong></td>
<td>Detachment and impartiality</td>
<td>Personal involvement and partiality</td>
</tr>
<tr>
<td></td>
<td>Objective portrayal</td>
<td>Empathic understanding</td>
</tr>
</tbody>
</table>

Source: De Vaus (2001)
The approach of this research needed to be rooted in the qualitative approach in order to investigate how information is used in the context of the construction industry, but also quantitative in order to investigate the impact of information flows upon productivity. Hence, our research needed to adopt methods combining both qualitative and quantitative elements. A manifold approach, combining different approaches, strategies and data collection methods, is supported as appropriate in the field of construction management by Fellows and Liu (2015).

3.2.6 Research Methodology Summary

A mixed research approach, undertaken in planned stages (i.e., progressional) was the most appropriate for our research objective. This allowed for the development of theory following a grounded theory approach such that each stage was used to inform the focus of research in subsequent phases. A summary is provided in Table 3-4.

Table 3-4: Summary of Research Methodology Considerations for This Research Project

<table>
<thead>
<tr>
<th>Research Layer</th>
<th>Summary of Selected Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research philosophy</td>
<td>Realism</td>
</tr>
<tr>
<td>Research approach</td>
<td>Predominantly inductive, and moving through the stages from exploratory through descriptive to explanatory research</td>
</tr>
<tr>
<td>Research strategy</td>
<td>Mixed approach comprising interviews, surveys, case study, introspective reflection</td>
</tr>
<tr>
<td>Time horizon</td>
<td>Both cross-sectional and longitudinal</td>
</tr>
<tr>
<td>Qualitative/quantitative</td>
<td>An approach combining both qualitative and quantitative elements</td>
</tr>
</tbody>
</table>

3.3 Research Design Mapping

3.3.1 Development of New Research Design Mapping Technique

Having developed the research methodology approach at each level of the research onion (Saunders et al. 2009), we needed to identify the most appropriate data collection methods. In addition to considerations of research philosophy, approaches, strategies, time horizons and methods, we needed to consider the existing knowledge domains and find ways of making linkages between different research paradigms and multiple existing knowledge domains. For this we developed a new graphical technique for research design, which assists in the identification of appropriate data collection options by mapping graphically between paradigms and knowledge domains, as illustrated in Figure 3-2.
In this mapping technique we illustrate three different generic approaches. The first generic approach seeks to address contrasting views across paradigms (horizontal arrow). An example could be selection of data using action research approaches, including both qualitative and quantitative perspectives, to a research problem. The second seeks to collect data that makes linkages between existing subject areas (vertical arrow). Examples could include traditional qualitative or quantitative methods that make linkages between existing knowledge domains, but staying within the interpretivist paradigm or positivist paradigm. The third example seeks to make specific linkages across paradigms and knowledge domains by means of collecting data through two lenses (indicated by ovals in the diagram linked with a diagonal arrow). An example could include the selection of data collection methodologies incorporating case studies and observations within the philosophy of realism, combining interpretivist and positivist paradigms, following a grounded research approach.

### 3.3.2 Application of Our New Research Design Mapping Technique for this Research

Our literature review identified four main bodies of knowledge as being pertinent to the research objective, namely, information, productivity, lean thinking and human decision-making. We applied our new research mapping design technique by plotting these knowledge domains against the qualitative-inductive and quantitative-deductive paradigms and identified relevant data collection methods, with a number of key stages, as provided in Figure 3-3.
The mixed approach identified as appropriate was developed using a matrix as presented in Table 3-5. A staged approach became apparent, commencing with interviews and progressing through survey, observations, case studies and, finally, statistical data analysis.

Table 3-5: Developed Research Methodology Plan

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Chapter</th>
<th>Research Approaches</th>
<th>Research Purpose</th>
<th>Time Horizons</th>
<th>Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interviews</td>
<td>4</td>
<td>Inductive</td>
<td>Exploratory &amp; Descriptive</td>
<td>Cross-sectional</td>
<td>Interviews (semi-structured)</td>
</tr>
<tr>
<td>2</td>
<td>Industry Survey Questionnaire</td>
<td>5</td>
<td>Mixture of Inductive and Deductive</td>
<td>Descriptive &amp; Explanatory</td>
<td>Cross-sectional</td>
<td>Questionnaire (anonymous)</td>
</tr>
<tr>
<td>3</td>
<td>Decision Survey Questionnaire</td>
<td>6</td>
<td>Mixture of Inductive and Deductive</td>
<td>Descriptive &amp; Explanatory</td>
<td>Cross-sectional</td>
<td>Questionnaire (anonymous)</td>
</tr>
<tr>
<td>4</td>
<td>Industry Case Study Observations</td>
<td>7</td>
<td>Inductive</td>
<td>Exploratory, Descriptive &amp; Explanatory</td>
<td>Longitudinal</td>
<td>Direct observations</td>
</tr>
<tr>
<td>5</td>
<td>Introspective Thinking</td>
<td>8</td>
<td>Inductive</td>
<td>Exploratory, &amp; Explanatory</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>Productivity Statistical Data Analysis</td>
<td>9</td>
<td>Deductive</td>
<td>Descriptive &amp; Explanatory</td>
<td>Cross-sectional and Longitudinal</td>
<td>Secondary sources (Statistics NZ)</td>
</tr>
</tbody>
</table>

Each of the stages relate to one of the chapters in this thesis, and taken together form a mixed research approach implemented in a progressional manner in order to address the central
research objective. Detailed implementation plans were prepared for each stage with specific task-level actions for each component. These were used to develop research ethics applications, which are described in more detail within each chapter.

3.4 Conclusions to Research Design

In conclusion, we have proposed a means of researching topics that seek to identify linkages between information and productivity. We have provided an approach that both draws upon the existing literature and adopts a new research design mapping technique. In particular, we have advocated the need to consider contrasting paradigms using multiple data collection methods, and have postulated the need to deliberately select data collection methods that provide contrasting views across paradigms while also identifying linkages between existing knowledge areas.

We contend that our progressional approach comprising a staged sequence of research studies, using a variety of methods crossing different philosophical viewpoints, was appropriate for researching the complex issue at hand. In order to gain real insight into the linkages between the abstract concept of information and the more objective construct of productivity, we deliberately adopted multiple viewpoints. To this end, breaking the problem into a number of stages was necessary. We see this as an emergent outcome of our research design and detailed development of our research methodology that could be a useful model for other researchers in similar fields.
4 Development of a New Framework for Information Flow and Productivity

4.1 Introduction
In this chapter we present the findings of 24 semi-structured interviews, together with analysis and discussion. The purpose of the interviews was to gain a deep understanding of the broad issues relating to the use of information in engineering and construction with respect to the impact upon productivity issues. The findings of the interviews were used to develop a new framework for information flow and productivity.

4.2 Objectives and Goals of this Research Stage
As outlined in Chapter 1, the overall objective of this research was defined as:

*To gain an understanding of the linkages between information flow and productivity in the engineering and construction sector; and thereby to identify future directions for improving productivity.*

Within this objective, a number of goals were identified and are addressed in this part of the research as summarised in Table 4-1.

<table>
<thead>
<tr>
<th>#</th>
<th>Overall Research Goals</th>
<th>More Specific Goals for This Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To investigate the linkages between information flow and productivity within the sector and determine the extent to which productivity outcomes are dependent upon information flow inputs.</td>
<td>To obtain views from senior managers on the linkages and causal factors for productivity. To seek to identify a broad range of causal factors such as macroeconomic and industry structural issues.</td>
</tr>
<tr>
<td>2</td>
<td>To understand the mechanisms by which information flow affects productivity and thereby build a framework or causality model linking information flow with productivity.</td>
<td>To identify the issues arising from information flow and how they relate to productivity, from experienced people in the industry. To gain perspectives from clients, constructors and professional service providers alike. To develop a qualitative model.</td>
</tr>
<tr>
<td>3</td>
<td>To identify the impact of information flow upon the quality of problem-solving and decision-making within the engineering and construction context.</td>
<td>To gain an in-depth insight into how information is used by people in a range of different roles and subsectors within the industry.</td>
</tr>
<tr>
<td>4</td>
<td>To investigate the relative effectiveness of different information search strategies for decision-makers.</td>
<td>To identify qualitatively the ways in which relevant information is sourced.</td>
</tr>
<tr>
<td>5</td>
<td>To identify the relative effectiveness of a range of information dissemination and transfer systems, including new and emerging information technology and management solutions.</td>
<td>To identify qualitatively the issues, challenges and opportunities on improving productivity performance via technology solutions.</td>
</tr>
<tr>
<td>6</td>
<td>To provide some directions for productivity improvement for the engineering and construction sector in NZ.</td>
<td>To obtain a range of views and suggestions on routes for improving productivity performance.</td>
</tr>
</tbody>
</table>
The overall objective of this stage of the research was to develop a framework explaining the linkages between information flow and productivity from a qualitative perspective.

4.3 Data Collection Methods for this Research Stage: Semi-Structured Interviews

The research method for this phase comprised semi-structured interviews. Considerations of research philosophy, design and approaches were discussed in Chapter 3. A set of 19 questions was developed for the semi-structured interviews. The questions and objectives for each question are given in Table 4-2.

<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Please confirm your industry sector, role and type of organisation.</td>
<td>To ensure a mix of views from different sectors.</td>
</tr>
<tr>
<td>2</td>
<td>What forms of information does your organisation use?</td>
<td>To gain insight into the breadth of different types of information used in engineering and construction.</td>
</tr>
<tr>
<td>3</td>
<td>What information do you receive from people outside your organisation?</td>
<td>To understand information flow from an input, processing, output model. To understand differences of information inputs extraneous to the organisation.</td>
</tr>
<tr>
<td>4</td>
<td>What information do you receive from people inside your organisation?</td>
<td>Similar to Question 3 but differentiating information inputs from within the organisation.</td>
</tr>
<tr>
<td>5</td>
<td>What information do you give to others outside your organisation?</td>
<td>Similar to Question 3 but differentiating outputs extraneous to the organisation.</td>
</tr>
<tr>
<td>6</td>
<td>What information do you give to others inside your organisation?</td>
<td>Similar to Question 5 but differentiating outputs internal to others within the organisation.</td>
</tr>
<tr>
<td>7</td>
<td>How does what you receive match what you need to do your job?</td>
<td>To gain insight into how well the information meets the needs of the information user, leading to deeper insight into issues of worker productivity.</td>
</tr>
<tr>
<td>8</td>
<td>Please describe the primary modes of contact.</td>
<td>To gain insight into the different forms of communication and formats of information flow.</td>
</tr>
<tr>
<td>9</td>
<td>Please outline the qualities of information that are most important.</td>
<td>To identify the attributes of information that are deemed to be important.</td>
</tr>
<tr>
<td>10</td>
<td>Please describe how you use information for decision-making.</td>
<td>To identify how information is used for decision-making.</td>
</tr>
<tr>
<td>11</td>
<td>Are there information guardians in your organisation?</td>
<td>To identify any possible issues of guardians protecting or hindering information flow.</td>
</tr>
<tr>
<td>12</td>
<td>To what extent is technology used to facilitate information flow?</td>
<td>To understand the trends in technology application to facilitate and improve information flow.</td>
</tr>
<tr>
<td>13</td>
<td>Why is information important?</td>
<td>To gain depth of insight into why information is important in engineering and construction.</td>
</tr>
<tr>
<td>14</td>
<td>In your view is there a link between information flow and performance?</td>
<td>A closed question seeking specific commitment to whether participants see a linkage.</td>
</tr>
<tr>
<td>15</td>
<td>In what ways do you currently use information to optimise productivity?</td>
<td>To identify ways in which industry proactively use information with respect to performance.</td>
</tr>
<tr>
<td>16</td>
<td>In your view what are the differences between efficiency and effectiveness?</td>
<td>To differentiate productivity matters in terms of efficiency and effectiveness.</td>
</tr>
<tr>
<td>17</td>
<td>In what ways are data, information and knowledge possibly wasted in your organisation?</td>
<td>To explore issues relating to waste.</td>
</tr>
</tbody>
</table>
In your view how could your organisation use information and knowledge to improve performance?

To explore potential options to improve organisation performance.

Are there any important issues that we have not discussed?

Opportunity for the participant to make pertinent comment on anything relating to the overall discussion.

4.3.1 Research Ethics

A detailed research ethics proposal was submitted to the University of Auckland Human Ethics Committee and approved, copies of which are included in the appendices. Following research ethics approval, participants were approached, and upon acceptance of the invitation to participate an interview was arranged at the participants’ place of work. Interviews were conducted by the researcher and recorded using a digital voice recorder, which were later transcribed verbatim by a third-party transcriber. The third-party transcriber entered a confidentiality agreement to not disclose the content of the interviews to anybody other than the researcher and supervisors. Interviewees were offered the option to receive and review the transcript of their interview should they wish, and any edits accepted prior to commencement of the content analysis.

Because of the nature of the interview questions some implicit ethical issues and risks were identified, namely, commercial sensitivity and participant confidentiality. The research addresses the topic of productivity, and it is recognised that organisational productivity performance is an indicator of organisational competitive position. Therefore, provision of confidentiality and anonymity was deemed necessary to ensure collection of meaningful data, and to protect participating organisations’ competitive positions. In order to address these issues the research methodology adopted the following:

- Agreement was obtained from the CEO (or an executive officer) of participating organisations.
- Procedures were followed to ensure participants had the opportunity to review draft interview transcripts and questionnaire answers, and to withdraw any data.
- While anonymity could not be guaranteed, no report makes reference to individuals or organisations, either by name, innuendo or by inference.
- Interviewees had the right to withdraw at any time without any reason, and to withdraw data traceable to them up to one month after the interview date.

Protection of individual participants was ensured by requiring that their CEOs (or an executive officer) formally acknowledged that participation or non-participation would not influence the individuals’ employment status in their organisations.

4.3.2 Data Collection and Interview Description

The researcher conducted interviews over a period from August 2011 to September 2014. An elite sample of experts from industry was selected as appropriate for gaining depth of insight on issues relating to the research questions. A total of 24 interviews were completed. The average
length of time of the interviews was 54 minutes; the maximum time was 77 minutes and the minimum was 36 minutes. Transcribing of the interviews took approximately four hours for every hour of interview. After being transcribed, the transcripts were reviewed and edited for grammar by the researcher, which took approximately two hours for every hour of interview.

4.3.3 Analysis Methodology

The interview transcripts were analysed with the aid of NVivo 10, a qualitative data analysis software tool. A thematic content analysis was undertaken, with participants’ comments assigned via a coding process to pertinent issues called codes. The thematic coding and analysis approach adopted is illustrated in Figure 4-1.

![Figure 4-1: Thematic Analysis Methodology Adopted Using NVivo 10](image)

Coding is the term used to indicate the process of structuring the data into nodes for further exploration and for identification of meaning of participants’ comments. Nodes, in this context of qualitative data analysis using NVivo, are simply containers that allow for categorisation and location of materials within a node heading for themes, people organisations and so on. The coding was a labour-intensive process, as NVivo 10 software does not have intelligence to interpret the semantic meanings of the comments made by participants. The coding process enabled the subsequent meaningful analyses and interpretation of the qualitative data via the running of comparisons, the running of test queries, and the searches for patterns via a range of classification criteria.

Content analysis was undertaken by the researcher and also in parallel by an independent second data analyst. An iterative parallel process of content analysis and sense making of the results was undertaken as illustrated in Figure 4-2. The process follows a similar parallel process undertaken by Hicks et al. (2006).

---

1 The independent data analyst was a fourth year undergraduate student, working under the supervision of the researcher for a summer project. The summer project was not part of the student’s degree, but the student did receive a summer research project scholarship. The purpose of the summer research scholarship scheme is to give students an opportunity to undertake a small research project to encourage undergraduates to consider taking high degrees after graduating.
Figure 4-2: Schematic Representation of the Research Methodology and Analysis Process
The purpose of the parallel analysis process was to help reduce possible inadvertent biases entering results through the interpretative coding and content analysis of the interviews. Phases 1 and 2 were undertaken working in parallel starting from the transcripts. Initial coding of the transcripts to identify issues was undertaken without any prior conditioning, with each researcher building a database of findings separately using NVivo10 software. The findings and results were compared at key stages, and comparison of the analysis results showed a gradual improvement from a poor to generally good level of comparison, as outlined in Table 4-3.

<table>
<thead>
<tr>
<th>Phase 2</th>
<th>Workshop 1</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The level of agreement between the researcher and the assistant for the coding of issues at codes was poor.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase 2</th>
<th>Workshop 2</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor level of consistency between coding of issues and moderate–good level of agreement on affinity groupings. Following Workshop 2 a coding comparison query was run using a function in NVivo 10 to compare the consistency of coding between the two different coders. This indicated mixed results, with some nodes having very high levels of coding consistency, but others having only poor–moderate levels of compatibility.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase 2</th>
<th>Workshop 3</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Further rationalisation to reduce the number of nodes improved the level of consistency. However, following Workshop 3 it became apparent that complete agreement between coding of nodes was not realistically achievable because of the subjective nature of the materials and therefore the two researchers independently undertook deeper interpretive analysis to identify three key findings for each affinity group.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase 2</th>
<th>Workshop 4</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A good level of agreement was found on the key findings for each affinity group.²</td>
<td></td>
</tr>
</tbody>
</table>

The parallel coding, with iterations and workshops ensured that a robust process was undertaken and reduced the risk of possible interpretative bias by the researcher.

4.4 Results

The results of the interviews were a series of transcripts of the interviews. While a full transcript was produced for each interview they are not reproduced in the thesis; rather, a series of key quotes are given for each question and presented in tabular format in Appendix A2.

The split of participants by role and type of organisation is shown in Figure 4-3.

---

² By the end of Phase 2 the research assistant had finished his summer research scholarship, and Phase 3 was completed by the researcher.
The research objective of obtaining views from a broad spectrum of the industry was achieved with a mix of clients, professional service providers and contractors, and with a range of roles. The roles are all executive level or senior staff grades and hence it should be noted that the research does not identify views from junior- to middle-grade staff. All the interviewees worked in either the infrastructure or commercial building sectors; none of them worked in the residential building sector.

4.5 Analysis and Discussion
Because of the qualitative nature of this research stage, the analysis and discussion are presented concurrently, and structured around the key themes identified from the content analysis.

4.5.1 Affinity Groupings into Key Themes
Affinity grouping of the nodes identified from the content analysis was undertaken. After a number of iterations, as previously identified in Figure 4-2, a node map was created with affinity groups and each individual node was grouped into one of the groups as illustrated in Figure 4-4.
Figure 4-4: Affinity Groups of Issues Identified from Content Analysis

Three key factors were identified independently by the researcher and research assistant for each affinity group, and subsequently compared. A summary comparison of the key findings is given in Table 4-4, and expanded in the following sections.

Table 4-4: Summary of Key Qualitative Findings for Each Group

<table>
<thead>
<tr>
<th>#</th>
<th>Channels</th>
<th>Researcher</th>
<th>Research Assistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preference for face-to-face communications.</td>
<td>Preference for personal communication channels.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Multiplicity of channels making it complex to manage and difficult to adopt alternatives.</td>
<td>Slow adoption of alternative channels.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Challenges of using email as a channel.</td>
<td>Importance of emails.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Engineering drawings are particularly important and require a high degree of fidelity of information.</td>
<td>Issues with communicating drawings and specifications during project construction.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Diversity of different types of documents, all of which serve different purposes.</td>
<td>Range of types of documents used to convey ‘high level’ and ‘low level’ information.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Preferences and relative merits of ‘hard’ and ‘soft’ copies of documents and transition to digital media.</td>
<td>The transition from hard copy documents to BIM modelling, and its effects on the flow of technical project information.</td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>Researcher</td>
<td>Research Assistant</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>While there is a range of different repositories there is a consensus that the most fundamentally useful function of any information system is the ability to search for and effortlessly find the information needed for decision-making purposes.</td>
<td>The need for information-seeking functions in information databases.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>There are a plethora of specifications and technical standards that need to be streamlined.</td>
<td>Multithreaded nature of project information.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Corporate information systems are vital for efficient running of the company and can be the source of competitive advantage.</td>
<td>Trickle-down mechanism of disseminating corporate information.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Accuracy is critically important, but has to be combined with other qualities such as form, consistency and coordination in the design and construction process.</td>
<td>Redundancy in information.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Timeliness of information is just as important as accuracy and time equates to money.</td>
<td>The speed of information flow required increases as project complexity increases.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Information has an intangible and illusive nature. Coupled with this people have a wide range of personal preferences on how they like to receive information.</td>
<td>Information needs to suit the user to avoid communication errors and disputes.</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Information enables knowledge transfer and is the basis for learning.</td>
<td>Importance of the lessons learned process.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Information is the primary ingredient for decision-making.</td>
<td>Primary purpose of information is for decision-making.</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>There is a range of other purposes, including empowerment, influencing, promoting, confirmation, accountability and assumption busting.</td>
<td>Information for empowerment.</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>BIM (3D modelling in general) is a major transforming technology for the sector.</td>
<td>Information systems do improve coordination and collaboration.</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Adoption of enabling information technologies is slow and challenging in the sector due to multiplicity of systems and the fragmented nature of the industry.</td>
<td>Difficulty in achieving industry-wide adoption of novel technologies.</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>There needs to be a greater level of consistency of systems for the construction industry to leverage the benefits.</td>
<td>The high information demands of information systems.</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Dissemination of information poses a particular challenge.</td>
<td>The impact of inadequate briefing information.</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Speed and timing of information flow is important.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Information currency is critical to ensure everybody in the team has the most up-to-date information.</td>
<td>The high level of networking within the industry.</td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>Researcher</td>
<td>Research Assistant</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>---------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Information flow is of prime importance, firstly for coordination, integration and collaboration, and secondly for gaining a shared understanding.</td>
<td>Industry performance suffers from lack of competence in planning and coordination, which is a problem rooted in poor information flow.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>A very high level of importance is placed upon having well-established relationships as information flows more readily in a relationship of mutual trust.</td>
<td>The importance of establishing client trust and honesty.</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Knowing what you want is a significant issue from an efficiency perspective.</td>
<td>The difficulty with communicating what you want.</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Procurement is important but no consensus of opinion on a preferred method. However, consensus that procurement model selected should reflect not only project risk but also completeness of information.</td>
<td>Disagreement on best procurement approach.</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Utilisation of resources is of prime importance for improving productivity, which requires transparency of information that is timely, accurate and robust.</td>
<td>Poor employee retention and development.</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>There are a number of structural issues relating to the construction industry that make it inefficient, which relate to utilisation of capacity, long-term skills development, adoption of new technology, supply chain structure.</td>
<td>Political influences on the construction industry.</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Effectiveness is more important than efficiency in the value creation process.</td>
<td>Issues with project value creation.</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Minimisation of waste and implementation of production processes are key to driving efficiency gains.</td>
<td>Waste due to compliance.</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Risk perceptions, shared understanding and creativity all influence the value creation process turning information into valuable outcomes.</td>
<td>Long-term partnerships and co-creation of value.</td>
<td></td>
</tr>
</tbody>
</table>

Each of the affinity groups is discussed in turn in the following sections. For each group we present a histogram of the nodes, which illustrate the issues and the relative amounts of discussion on each of the pertinent points at the nodes. It should be noted that the presentation using histograms helps illustrate the breadth and frequency of the issues identified by participants, but does not necessarily indicate the importance or significance, and is certainly not to be taken as indicating any statistical significance. Also, it should be noted that this histogram is simply a count of the frequency with which issues were discussed and does not indicate the extent to which there was agreement or otherwise on the related matters. Nevertheless, they are helpful for illustrating the issues. We follow each histogram with a discussion and qualitative analyses of the main issues identified from the content analyses, drawing on relevant comments and quotations from the participants to illustrate matters as appropriate. Further examples of comments and quotes from participants are given in Appendix A2.
4.5.2 Channels Used for Information Transfer

A histogram of the various channels used for information transfer is given in Figure 4-5.

![Histogram of Channels Used for Information Transfer](image)

These results show that people use a wide range of channels, selecting the means most appropriate for the situation. Emails are used as the predominant mode to send and receive information. However, there are three other channels that are closely related, namely, meetings, face to face and verbal, which all infer direct human interaction. If these three channels are taken as meaning essentially the same channel, then the total number of such references exceeds that of emails.

**Key Finding 1:** Many of the interviewees prefer to meet and talk to people personally as opposed to using technologies such as video conferencing, phone or email to communicate remotely. Building long-term business relationships with others, as well as establishing a rapport of trust, was identified by many as being very helpful for facilitating information flow and establishing mutual understanding. Within organisations, small meetings between managerial staff and their subordinates seem to be the most effective method of disseminating information. There is a particular importance placed on having human presence, which means that technologies are unlikely to be a preferred substitute for face-to-face communication. Meetings and face to face are often referred to as the most effective way of communicating semantics and meaning, and have a strong emphasis, especially in the early stages of a project, in design, and in coordination of resources. Meetings warrant further more detailed study.

**Key Finding 2:** There are multiplicities of potential channels from which to select and use, ranging from personal face to face to impersonal data transfer channels. Each channel has particular benefits and drawbacks, which users appear to appreciate and understand in general. While the issues arising in using any one particular channel (e.g., telephone) are relatively
straightforward, the overall management of communications and information flow in the context of multiple channels is complex. It requires that users select the most appropriate channel for the intended receiver and audience, and it would appear that people have a range of personal preferences, making the selection challenging and sometimes necessitating simultaneous use of multiple channels to disseminate to wide audiences.

**Key Finding 3:** Email is a dominant channel for transfer of documents, often in the form of attachments (e.g., drawings, PDF documents, etc.). It has the advantages of being easy, instantaneous and ubiquitous. However, it is open to abuse, examples being unnecessary use of the CC field in messages, ill-considered drafting and misinterpretation. In the domain of design it is not ideal as it is hard to track and coordinate the content of emails (e.g., drawing issues), and in construction it is not ideal for communicating with a workforce in the field because of access issues and possible illiteracy (or an unwillingness to read). Texting is a useful alternative to emails for informing the construction site workforce. It is difficult for alternatives to email to gain industry-wide acceptance because lower-tech communication channels are generally preferred. This phenomenon is mostly due to the large variation in computer skills in the industry supply chain. This endemic lack of ICT education results in a very slow adoption rate for new, and potentially more productive, technologies.

### 4.5.3 Types of Information

A range of different types of information and documents were referred to during the semi-structured interviews, and are given in Figure 4-6.

![Histogram of Types of Information (Informational Document Types)](image)

**Figure 4-6: Histogram of Types of Information (Informational Document Types)**

**Key Finding 4:** While there is a wide range of document types, including reports, diagrams, timesheets and photographs, by far the most commonly cited document type used for information flow in engineering and construction is drawings. From the design perspective,
issues around drawing management are about co-ordination of the informational content between the various contributors and disciplines (there needs to be a high degree of fidelity of the informational content, e.g., between structural, architectural and building services to avoid clashes, etc.). From the construction perspective, the main issue about drawings relates to completeness, as summarised in the following quote:

_The classic is in a contractual situation where you get issued construction drawings and there is not enough information to build it. And you've got to go back to the consultant and ask for more information…. (Participant 4)_

A closely related issue cited by interviewees, regarding the communication of drawings and specifications, is poor version control of documents. Document management systems and adoption of appropriate quality control and assurance procedures help to manage this challenge.

**Key Finding 5:** There is a wide diversity of document types, ranging from reports to cartoons, photographs to physical samples, as-builds to sketches. Each of these serves different specific purposes, but all are a means of communication and must address the needs of the user. Whereas the selected channel appears to address efficiency of information flow, the way in which it is communicated via the appropriate documentation addresses effectiveness.

**Key Finding 6:** There is a range of views regarding soft versus hard copy documents. Some interviewees appeared to have a strong preference for hard copy documents, which may be dependent upon age (but not proven). Hard copy documents are preferred for contractual agreements within the construction industry. Also, in some parts of the industry hard copy is preferred because of legacy issues and lack of access to appropriate ICT infrastructure (e.g., use of hard copy documents in a pre-cast concrete yard). However, from an efficiency perspective, soft copy has the advantage of ease of transmissibility for wide distribution.

### 4.5.4 Repositories for Data, Information and Knowledge

A histogram of the issues related to repositories for data, information and knowledge is given in Figure 4-7.
Key Finding 7: It would appear that there is a range of different repositories for retaining information (knowledge), ranging from obvious traditional sources such as technical standards and specifications, through to more vague concepts such as precedence. While interviewees commonly made references to specifications and technical standards, which was to be expected, it is interesting to note that interviewees did not often refer to trade literature, manuals or guidelines, or research publications. Another surprising finding was that interviewees from client-based organisations readily identified their consultants as being their prime informational source. Despite the range of different types of repositories, there was a consensus view by interviewees that the most fundamentally useful function of any information system is the ability to search for and effortlessly find the information needed for decision-making purposes. At the same time, information should be in a well-organised state.

Key Finding 8 Specifications and technical standards were the most cited issue, and factors mentioned related to the plethora of different standards (e.g., 75 codes for concrete), consultants’ failure to reference the most up-to-date standards, variance in technical specifications between clients (e.g., between adjacent local authorities in water and roading infrastructure), and excessive amounts of bespoke technical requirements. All participants who spoke to this issue identified a need (and major opportunity) for more standardisation across the industry, and streamlining of the standards. There does not appear to be a problem accessing standards; however, participants did refer to a need for increased streamlining. It would appear that the proliferation of numbers of standards, variance from standards, and failure to keep up to date with them is defeating the benefit of having standards in the first place (i.e., that of standardisation). Without exception, all interviewees who referred to technical standards and specifications called for better standardisation.
**Key Finding 9:** Corporate information was commonly cited, which typically related to financial systems, but also human resource, health and safety, legal and other operational management information for decision-making. Challenges with corporate information systems referred to by participants relate mainly to making the information available to the right people at the right time to inform decision-making. There are challenges in making sure such information is reliable (e.g., accurate reporting in time sheets) and participants referred to corporate information being very dynamic, and thus the need for it to be timely and informed. Many of the interviewees mentioned that corporate information is usually collected from the bottom and reported upwards, and then decisions are made that are subsequently disseminated from the top down. A number of interviewees referred to use of informational database systems to help manage corporate information such as finance, customer relationship and human resource systems. It would appear that a wide range of such systems exist, and some of the larger organisations have developed in-house bespoke systems. Some interviewees identified such systems as being part of their competitive advantage, implying that they somehow make the organisation more effective in the competitive market.

Corporate information contrasts with project information, with project information typically being identified by consultants in terms of previous exemplars and design precedence and for contractors in terms of schedule. A commonly mentioned solution was the introduction of daily dashboards.

**4.5.5 Attributes of Information**

A histogram of the various attributes of information identified by participants is given in Figure 4-8.

![Histogram of Attributes of Information](image-url)

**Figure 4-8: Histogram of Attributes of Information**
**Key Finding 10:** Accuracy of information is commonly cited as important for decision-making and subsequently for efficiency and performance. Typically, references to the need for accuracy refer to what happens if information is not accurate, leading to wasted use of resources:

*Accurate information of course will impact on your efficiency with which you do the job. If you rely on inaccurate information, you get out on site, you have a major problem because you haven’t picked up something critical.* (Participant 15)

*Nothing frustrates people more than inaccurate information that causes time lost.* (Participant 5)

These two quotes indicate a linkage between information effectiveness (picking up critical matters) and efficiency (lost time).

It is important to note that while accuracy was often mentioned by the participants, it was also typically linked to other qualities such as timeliness, format or coordination. The following quote illustrates the matter perfectly:

*Accuracy is of course important, and fundamentally as you get closer and closer to people building things from what you are documenting. Sometimes the speed in which something is delivered is a very important quality, I think that is a fair quality to attach to information; sometimes it is required very urgently. Programmes are usually very challenging. They are usually not timely and idle things are often required very quickly so the speed in which things can be turned around is very important. In the general process of working with other consultants, coordination is key, and that is something that is probably quite hard to describe, because coordination is a factor of how much everyone’s information is aligned with everyone else’s. One set of information in that set doesn’t possess any coordination because it is a factor of when you put it alongside another thing. But that is a key quality: that all of the outputs, that all the consultants on the team are actually working towards, a consistency and a coordination with one another.* (Participant 12)

The design and construction process is hence a gradual process of developing from a small amount of coordination (in which completeness and hence accuracy is low) and moving via a series of iterations to a high level of accuracy in the sense of consistency with everybody else’s information.

**Key Finding 11:** Timeliness of information is a significant factor from a productivity perspective:

*So accuracy of information is very important, timeliness is just as important. The old adage time is money is still true, and if we can have the information in advance of when we need it then our life as a contractor is a lot easier.* (Participant 3)

Generally, such linkage was recognised, and one participant stated:

*There is definitely a link between information flow and productivity. The two aspects of that – one is timeliness as always, and the other is the quality of the information.* (Participant 10)

While participants generally acknowledged such linkage, the deeper reasons for the linkage were harder to articulate. However, one interviewee illustrated the matter with reference to the engineering design process very succinctly:

*It’s less of a problem I believe than it used to be because the queries about what you are requesting and whether or not it meets what you need are so much faster now than they used to be. Because packaging up information and exchanging it used to be a much more onerous task, if someone fires you a set of drawings, minutes later you are able to say, “okay, I haven’t reviewed this in full, but I can see that say, these are*
two areas of things that we want to understand more", and you print something out your extract of your 3D model, and you draw a circle around it and you show where you want it cut and reviewed, and you fire it back, and usually the response comes back fairly quickly as well. So I suppose that is only treating the symptoms if the information doesn’t match what you need, but the corollary is that it is very easy now to help make it match what you need, because we all communicate much more quickly now. (Participant 21)

In general, the demands on the rates of information flow are becoming increasingly rapid because of pressures by stakeholders to fast-track projects. In conjunction, projects are in general becoming more complex. The ever-increasing project complexity results in more information created per project, so the rapidity of exchange of such information is a significant consideration to maintain currency and prevent wasteful effort. Quick and easy-to-use information flow channels such as emails and technology can help expedite matters.

**Key Finding 12:** Information has an intangible and illusive nature. Coupled with this, people have a wide range of personal preferences on how they like to receive information, in terms of format and attributes, ranging from completeness to summarised, and transparency to fitness for purpose. This is illustrated by the wide range of aspects of information mentioned by participants, resulting in the identification of 34 different attributes. Most participants identified two or more attributes of information when describing issues. The following example illustrates the point:

> Clarity and understanding: one of the most important things is about getting understanding of what is required, so that’s about clarity of whether people have received the information and understand it. You have to be able to understand that somebody else, you have to be assured that somebody else is understanding what you want and that they are happy to give it to you. But the information has to be accessible and understandable, so it has to be sent in a form that we can deal with: so it’s got to match our requirements, it’s got to be easily importable into the systems that we use. We usually use Microsoft-based systems so we are able to transpose information quite quickly. Also it’s got to be readable, and searchable, i.e., you can find the bit of information that you need out of the mass of information that’s provided. (Participant 19)

It would appear that the important factor is that the information received suits the needs of the user. While such a statement is self-evident, it is not easy to achieve in practice because of the wide range in personal preferences, and furthermore, such preferences may change depending upon context and circumstances. The fact that human intelligence enables us to anticipate what others may be expecting when they receive information helps us to achieve effective communication, which leads to cooperation and then to teamwork and coordinated effort to achieve value-adding outcomes.

> I think probably two things, one is how the information is organised, and also how well it is adapted to its intended user. If you looked at an example of, say writing a procedure for something, the first thing you should do is think about the people who will be using it. What they already know about the subject, what their educational background is, etc. You can tailor the way you present the information so that it is actually suited to their needs. (Participant 22)

Also noted is that a lot of information is lost because people prefer to communicate verbally on decisions made, leading to wasted effort. There are two problems with this. Firstly, verbal
information that is not formally recorded will be lost when employees leave the organisation. Secondly, the lack of records makes it hard to establish responsibility and liability, and many disputes in engineering and construction are routed in verbal instructions that are not recorded in writing.

### 4.5.6 Ways in Which Information Is Used

A simple histogram of the various different uses of information is given in Figure 4-9.

![Figure 4-9: Histogram of Ways in Which Information Is Used](image)

Based on the number of references and sources, the majority of interviewees referred to the uses of information in terms of creating knowledge and for decision-making, and thereafter for a range of other factors, such as empowerment of staff. Some of the other factors such as documenting decisions could arguably be reclassified as part of decision-making, but were left as separate nodes for the purposes of displaying the range of ways information is used in engineering and construction.

**Key Finding 13:** Information enables knowledge transfer and is the basis for learning. It is fundamental for capturing lessons learned. The most commonly cited node refers to information being used for knowledge and lessons learned. The following key quote captures the issue:

> It enables knowledge transfer, and upwards, downwards, sideways. And it enables generation of ideas, so, one doesn’t have a mortgage on knowledge, but information flow allows you to quickly test your own thoughts with others, receive inputs from others and have a higher level of confidence in what your end advice or product is. (Participant 14)

Lessons learned are very important for firms to increase their institutional knowledge, and to continuously develop their staff. Lessons learned are typically disseminated through meetings and staff interactions; some organisations even have dedicated lessons learned meetings with their suppliers to improve the quality of their wider supply chain. The lessons learned process is
recognised as vitally important by many of the interviewees. However, a major weakness of the process is that lessons learned are not formally recorded typically, and as a result, there is a continual loss of lessons learned when employees leave or retire.

**Key Finding 14:** Information is also the primary ingredient for decision-making: without information, it is not possible to make effective decisions. Information for decision-making is inescapable, universal and ubiquitous, as illustrated by the following quote:

> It's what information is for, it's all for decision-making, so to discuss how you use information.... A general comment here is that I'm using information the whole time in regards to making decisions from looking at our finances to say how much forward work have we got, are we hiring or are we firing? Looking at project performance against budget, and saying why is it where it is? What's happened to change it? Everything is based on information. (Participant 8)

Furthermore, information is used to document decisions made, and to keep a record for possible future reference in case of possible audit or legal action. With complex projects with vague requirements, the risk of errors, and subsequent risk of rework, is high. This would appear to be a necessary use of information in the engineering and construction commercial world, but it is not clear such use for record-keeping is value adding.

**Key Finding 15:** While information is primarily used for creating knowledge and for decision-making, there is a range of other uses that are perhaps secondary, but still important. Information can be used to empower others, for influencing, for promotion and marketing, for confirmation, for ensuring accountability and responsibility and for assumption busting.

All the uses of information relate to human agency and are ‘value creating’. Information for decision-making is an immediate application of information. Information for creating knowledge and lessons learned has an element of future promise. The information is perceived to be of potential value at some point in the future and hence is retained in some capacity for future recall, so that it can be put into effective use for one of the other information uses (e.g., decision-making).

Improving information flow is key for the long-term improvement of productivity within an organisation. Many interviewees mentioned that a solid framework for documenting and communicating useful information has the effect of empowering employees to be more productive. Increased access to higher quality, more useful information has the flow-on effect of improving performance across the board; whether it be due to increased confidence in decisions made or otherwise.

**4.5.7 Technological Enablers for Information Use and Transfer**

A histogram of issues relating to technology enablers for information use and transfer is given in Figure 4-10.
Key Finding 16: BIM (and 3D modelling in general) is a major transforming technology for the construction sector as it changes the design and construction paradigm from a fragmented piecemeal approach, with associated errors and poor reliability (hence low quality), into a collaborative well-coordinated process, leading to higher quality outcomes. Coordination, in particular, the coordination of multidisciplinary designs between professionals working on the same project and of design and costing information were commonly mentioned areas where using technologies should lead to productivity improvements. For many interviewees, having an integrated repository to facilitate the coordination of documentation was the primary reason why they wanted to adopt BIM and other technologies.

Key Finding 17: Adoption of enabling information technologies such as BIM, geographic information system (GIS), global positioning system (GPS), bar coding and document management systems is slow and challenging in the construction sector because of the multiplicity of systems and the fragmented nature of the construction sector. Many users are unable to keep pace with the rate of change and are unable to specify what they want, because they do not know what is available or what is possible. Skill levels and the cost of training and implementation are barriers. Some of the greatest benefits identified by interviewees appear to be derived from the simpler solutions that are easy to implement. Also, some employees within the industry lack the technological know-how to be able to use the new systems. The result is that less sophisticated, low-tech communication media are frequently used across the board as a ‘lowest common denominator’ for many projects. The lack of maturity of NZ’s industry as a whole seems to be a barrier for some firms too; they do not believe that the new systems will provide a sufficient return on investment, given the market conditions prevalent in the construction sector. Hence, there is something of a vicious circle, which needs to be broken.
**Key Finding 18:** There needs to be greater levels of consistency of systems for the construction industry to be able to leverage the benefits. A simple adoption of a stand-alone technology solution is not sufficient as the more significant benefits only accrue as the whole industry collectively adopts technology, in parallel with streamlined systems. It is important for clients to specify the systems to be used and formats, and so on, as the supply chain responds to client selections. The utility of information systems obviously depends on the quality of information input. Systems such as BIM and GIS packages are effective for organising plans and asset data, but these systems often require comprehensive sets of data inputs to be truly valuable. Quite often, much of the required data inputs are not available, or are expensive to obtain. Thus, these sorts of systems carry an ongoing cost attributed to the obtaining of maintaining data.

4.5.8 **Issues Arising from and Related to the Use of Information**

A histogram of the various issues arising from and related to the use of information is given in Figure 4-11.

![Figure 4-11: Histogram for Issues Arising from and Related to the Use of Information](image)

**Key Finding 19:** Dissemination of information poses a particular challenge in that it is relatively easy to push information out; however, a push technique does not ensure information transfer. Effective dissemination requires the sender to know in advance the information preferences of the receiver. The proliferation of channels and low cost of information transfer lead to information overload, in which the bandwidth of the receiver is exceeded, hence preventing transfer of the message. A more efficient and usually effective strategy is to empower the information users to search for relevant information, using their own preferred channels and...
methods. However, there are occasions when a message must be sent out to a broad audience, in which case a dissemination strategy should be carefully selected and implemented. In the construction industry, the transfer of information is important at client briefing, design development and tender stages. There are challenges for dissemination of information between people in the industry and laypeople/stakeholders.

**Key Finding 20:** The interviewees often cited issues relating to speed and timing of information flow. As information is made for decision-making by different people concurrently (particularly in design) it is important that everybody receives the same information in a timely manner:

> So we need to get all the information to the team. The flow of information needs to be consistent, it’s not just up front; it needs to continue all the way through the job. That’s why we set these weekly meetings up. If at any time that goes off on a tangent or stops their performance takes a hit, they’re hanging round waiting for more information, they’re going off in the wrong direction so they have to come back again so their performance drops. (Participant 16)

**Key Finding 21:** Closely related to the above is the issue of information currency, in which it is necessary to ensure everybody in the team has the most up-to-date information. There is a hazard in engineering and construction around drawing and document version control. Design is iterative in nature: a solution is gradually merged from various options and contributors (design disciplines) into a coordinated solution meeting the clients’ and end users’ requirements. The iterative nature of this process means that information flow needs to be timely and coordinated to ensure currency of information for all users in a harmonised manner.

### 4.5.9 Human Agency: The Human Capacity to Process Information

We use the term human agency here as relating to the human capacity to process information; a histogram of the issues identified is given in Figure 4-12.

![Figure 4-12: Histogram for Human Agency Issues](image-url)
Key Finding 22: Information flow is of prime importance, firstly, for coordination, integration and collaboration. There is a very strong consensus among interviewees that this core principle is fundamental to how people at all levels of the construction industry act. The link between information flow and productivity appears to be via the enabling power to coordinate design and construction in a value-adding manner.

Poor planning and coordination was identified by the majority of interviewees as being prevalent in the construction sector, especially evident during the early stages of projects. More often than not, the client's expectation and requirements are poorly understood at the briefing stage. This poor understanding has the flow-on effect of poor plans and schedules being created. Poor planning seems to be the root cause of many site inefficiencies.

Key Finding 23: Interviewees identified the importance of having well-established relationships, particularly between client and supplier (either consultant or contractor), as information flows more readily in relationships of mutual trust and cooperation. Relationships also enable and facilitate the process of defining the client requirements, and finding effective solutions, as the best solutions require a deep understanding of the client's requirements and underlying business dynamics. For client-to-consultant communications, it is very important that the client trusts the consultant, in order for meaningful information transfer to occur. It was mentioned by numerous participants that building good client relations allows the clients to be more open about their requirements, thus enabling a mutual understanding to be achieved earlier on in the project. Additionally, many interviewees recognise that effective client liaison is a key aspect of information flow, and have dedicated staff (e.g., client relationship managers) to service this area.

Key Finding 24: A number of participants identified ‘knowing what you want’ as a significant issue from an efficiency perspective, as it avoids unnecessary waste in the immediate information-seeking stage and subsequent decision-making, and thereafter in actions taken by all within the construction industry supply chain. The inability for people from all levels of the industry (whether it be suppliers, consultants, clients, etc.) to communicate what they want seems to be a major and ongoing issue. Examples of this are the client's inability to produce a brief that effectively outlines their requirements and managers failing to communicate the importance of health and safety information to their subordinates. Some initiatives, such as reverse briefing of requirement to clients, intensive workshops and alliance arrangements, are being implemented to some success to improve clarity of requirements.

4.5.10 Issues Related to Context
A histogram for the engineering and construction industry contextual issues is given in Figure 4-13.
Key Finding 25: Procurement issues are a dominant factor, with a very wide variety of views being expressed on the merits and drawbacks of the various options (traditional, design and construct, early contractor involvement, collaborative, public–private partnerships, etc.). There appears to be no particular consensus on the most productive procurement route, other than the fact that procurement is important. However, from an information flow perspective there is general agreement that the procurement option selected should match the level of risk, uncertainty and degree of completeness of the information provided. While traditional and hard-dollar procurement options favour fully specified requirements, more collaborative options are more suitable for less well-defined solutions, in which information may flow more easily between the parties to facilitate greater levels of innovation. The traditional tender process has been heavily critiqued, and does not provide a sound platform of long-term health of the sector. Much time is wasted on special conditions of contract terms, which tend to serve the interest of one party (usually the client) but ultimately add little value when considering the impact upon the industry as a whole. Other interviewees blame the current standard forms of contract, for being outdated and no longer suitable for modern high-complexity projects.

Key Finding 26: Utilisation of resources, particularly staff, is identified as being important in terms of optimising productivity. This requires transparency of information that is timely and accurate, robust and in a suitable format, so that decisions on resource allocations can be made in advance, which links to the previous findings about attributes of information.
Firms within the industry generally have a difficult time retaining and developing the skills and capabilities of their employees. This issue is not confined to one particular type of employee, but is widespread, affecting site staff, professionals and managers. There are a number of issues, including causal factors such as short-term employment contracts, human resource policies and poorly conceived incentive schemes that have an impact upon staff retention and hence productivity, but are somewhat outside the scope of information flow. However, an implication arises, namely, that knowledge, know-how and intellectual property embedded in employees is constantly at risk and being wasted because of the high levels of staff turnover endemic in the engineering and construction sector. This problem applies equally to skilled labour and professionals, as the lack of apprentice schemes makes it difficult to transfer the know-how from older to younger generations in the workforce. A number of interviewees referred to the need for some kind of apprentice scheme to ensure knowledge and skill transfer.

**Key Finding 27:** There are a number of structural issues relating to the construction industry that make it inefficient and relate to utilisation of capacity, long-term strategic planning and supply chain structure. An example is overcapacity of plant and equipment, with individual contractors having to purchase resources simply to be able to compete in the tender process, but resulting in a collective industry oversupply. Such issues are deeply rooted and not easily changed. From an information flow perspective, there is a challenge in achieving performance improvement as knowledge sharing is limited, and initiatives such as national key performance indicators (KPIs) have been of limited success.

Matching supply and demand within the sector is particularly difficult, because of the fragmented nature of the industry, boom–bust cycles, increasing project sizes (increased ‘lumpiness’ of demand), and so on. There were some calls from interviewees for greater transparency of information on future pipelines of projects, including publication of long-term look-ahead programmes. The collection and publication of such data is time consuming and not simple, and while it has been attempted, it has only been partially achieved to date. Irrespective of success or otherwise to date, there was consensus that improved long-range planning in concept could achieve significant productivity gains, provided there is a good level of completeness and reliability of the data.

Many large construction projects in NZ are publicly funded, and hence politics have an influence on industry productivity. Projects are sometimes prioritised as a result of political agendas and patterns of project funding change often with different phases of the electoral cycle. The relatively short term of the political cycle is a barrier to the much longer horizons necessary for investment and decision-making in major infrastructure projects and for improvement in sector productivity.

**4.5.11 Underlying (Foundational) Issues**

Underlying (foundational) issues were identified on the basis of relevance, import and making linkages between the other nodes, and are given in Figure 4-14. In short, these core issues are the ones that go to the heart of the matter in respect to linkages between information flow and
performance. Underlying issues have at least 30 references and were discussed by at least half of the interviewees. Note, however, that this does not mean they were necessarily the most commonly referred to issues across all the nodes in the content analysis. For example, emails were referenced more frequently in interviews, but their import was not judged to be as central as these underlying (foundational) issues.

![Figure 4-14: Histogram for Underlying (Foundational) Issues](chart)

**Key Finding 28:** Effectiveness is more important than efficiency in the value creation process. Some participants found it difficult to define the terms, as illustrated in the following quote:

*Effectiveness is where tasks have greater punch, or almost a distillation of concentration. Efficiency is a lot of activity, you are doing a lot of things in a certain time, effectiveness is, maybe, when you can boil off everything that is superfluous in those tasks down.* (Participant 12)

Others were much clearer and more succinct, as in the following:

*Efficiency is about minimising the effort to achieve the outcome, whereas effectiveness is about maximising the fitness for purpose outcome.* (Participant 6)

*You can be very efficient about what you do but actually achieve nothing. To be effective you must achieve what is being asked of you or expected of you. You might be inefficient in doing that process, but at the end of the day you deliver that outcome.* (Participant 9)

*What you should be targeting is how to achieve effectiveness of the industry.* (Participant 1)

There was a consensus view that both efficiency and effectiveness are important, but there was clearly a preference for achieving the desired outcomes. What was also apparent is that effectiveness of communications is important to avoid misdirected effort, as illustrated in the following quote:

*When you are looking at waste in our organisation, it’s about effectiveness of communication of people and getting on the same page and not going down blind alleys, before you launch into the production of high volume output that’s expensive and potentially misdirected.* (Participant 1)
Key Finding 29: There is a considerable adverse impact upon efficiency in engineering and construction arising from waste at all levels of the industry due to multiplicity of constraints. The majority of such constraints upon the industry are imposed by the macro environment. Examples include regulations (Resource Management Act [RMA] and numerous other acts), the economy (access to funding, boom–bust cycles, etc.), politics (short-term decision-making arising from election cycles), and societal expectations (stakeholder consultation, etc.) Also, a particular constraint in construction is the physical conditions (weather, site topology, ground conditions, access, etc.). Such factors are largely outside the direct control of decision-makers and leaders within the construction industry. The consenting processes, and the work required to gain compliance with regulations is viewed by some as rather superfluous, as much of the compliance work does not add any real value. In this regard, a common problem identified by participants was that regional councils often have different standards and technical specifications, causing unnecessary complications leading to waste. Overall, a series of actions to address counter-productive constraints is seen as vitally important by participants in order to reduce waste and improve productivity.

Key Finding 30: Issues relating to risk perceptions, shared understanding and innovation all influence the value-creating process of turning information into valuable outcomes. An issue identified by the majority of interviewees is the absence of good planning and coordination practices industry-wide. This is especially evident during the early stages of projects, during which the role and influence of clients cannot be overly stated. From the information flow perspective, it is absolutely critical that there is clarity of the client’s brief, without which there will be waste and poor productivity. A clear brief requires shared understanding, and ideally suppliers need to have a knowledge of the clients’ business and commercial drivers in order to provide innovative solutions. Obtaining clarity of brief is not necessarily a straightforward process, as there is a range of different types of clients (from experienced, sophisticated, repeat clients such as utility companies to one-of-a-kind clients such as residential home owners). Hence, there needs to be fair risk sharing and/or allocation processes, which should be structured in ways that do not unduly affect the innovation and creativity of the industry.

Long-term partnerships are seen as a means of co-creating value. Many interviewees see that maintaining long-term relationships with clients and suppliers who can be trusted to consistently deliver good work is a way of improving productivity. Having longer term commercial relationships allows organisations to improve knowledge of each other’s needs, to cooperate and thereby co-create value for each other.

4.5.12 Content Analysis Using Industry Sector Classifications

Further detailed content analysis of each affinity group was undertaken to search for any differences or patterns in views by comparing and contrasting comments made by participants in their industry category. Industry categories are defined as client, main contractor, subcontractor, industry body (association or professional institution) and professional services provider (PSP). The means of analysis was achieved by undertaking a series of ‘matrix coding
queries' using NVivo10 software. The queries produced a series of three-dimensional graphs of the number of references made by participants in each industry category; an example is given in Figure 4-15 and the series of graphs are given in Appendix A2. The findings from this analysis are discussed in Table 4-5.

![Figure 4-15: Coding Matrix Query for Attributes of Information against Industry Sector Classification](image)

### Table 4-5: Findings from Content Analysis by Industry Sector Classification

<table>
<thead>
<tr>
<th>Affinity Group</th>
<th>Findings/Observations and Discussion Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channels</td>
<td>Frequency of issues varies for the different sectors. For example, professional service providers (PSPs) referenced video conferencing much more frequently, and contractors referenced texting. Meetings and face to face featured more strongly for main contractors and PSPs than for clients.</td>
</tr>
<tr>
<td>Types</td>
<td>Drawings dominate for PSPs, whereas as-built records dominated discussion for clients. Requests for information (RFI) featured for main contractors and consultants but not for clients.</td>
</tr>
<tr>
<td>Repositories</td>
<td>Most of the references to repositories of information were made by PSPs, reflecting their role as providers of information.</td>
</tr>
<tr>
<td>Affinity Group</td>
<td>Findings/Observations and Discussion Points</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Attributes</td>
<td>Accuracy is important for all; however, the other attributes differed significantly between industry sectors. For example, clients referenced timeliness, clarity and accessibility more frequently, whereas contractors referenced form, coordinated and indicativeness of level of risk. PSPs referenced form, clarity and currency more frequently. Such differences can be explained by considering the different primary roles of organisations; where clients need to access accurate information for their assets, contractors look for pragmatic properties that enable them to manage risk, and consultants need well-ordered current information to progress designs and solve problems.</td>
</tr>
<tr>
<td>Ways used</td>
<td>Information for decision-making dominated for clients, which can be explained by their primary role for making strategic decisions in projects. For consultants, the use of information for creating knowledge featured highly, followed by decision-making and promotion (branding). While use of information for promotion is perhaps a little surprising, it can be understood from the perspective of needing to develop and maintain professional image and reputation in the market place. Interestingly, information for empowerment featured highly with contractors, which is indicative of their business in which staff need to be empowered to take actions.</td>
</tr>
<tr>
<td>Technology</td>
<td>BIM featured more dominantly in interviews with contractors than with PSPs, which is an unexpected finding. The references by PSPs to technology featured document management systems more frequently than BIM.</td>
</tr>
<tr>
<td>Issues arising</td>
<td>The issues arising differ significantly for the contrasting sectors. For clients, information dissemination featured strongly followed by information currency. This is perhaps explained by the fact that clients need to liaise with a range of stakeholders. For contractors, information-seeking patterns featured highly, indicative of the nature of their work, where they often have the difficult job of bringing a project to successful conclusion on partially incomplete information. For PSPs, the issues are more diverse, and information-seeking patterns together with speed and timing of information were commonly referenced issues. Information overload appears to be more of an issue for PSPs than for other sectors.</td>
</tr>
<tr>
<td>Human agency</td>
<td>There is a consensus in that coordination, integration and collaboration featured strongly with all industry sectors. Other factors appear to be of secondary importance as they were discussed much less frequently.</td>
</tr>
<tr>
<td>Context</td>
<td>Procurement issues dominated in interview discussions with clients and contractors. However, for PSPs other factors featured more frequently, namely, client (and client briefs) and staff. Issues relating to tenders featured more significantly with contractors and moderately with clients. Issues relating to design featured with PSPs and clients. Standardisation was raised more frequently by clients than by the other sectors. Issues relating to planning featured more strongly with contractors than other sectors. None of these findings are unsurprising and can be understood by consideration of primary roles of the contrasting sectors.</td>
</tr>
<tr>
<td>Underlying</td>
<td>Issues relating to efficiency, effectiveness and knowledge dominated for PSPs, whereas for contractors, risk, shared understanding and value featured strongly alongside efficiency. For clients, the dominant issues were efficiency, shared understanding, knowledge and innovation.</td>
</tr>
</tbody>
</table>

**Key Finding 31:** Different sectors within the engineering and construction industry have somewhat different informational needs, expectations, preferences, issues and applications. Generally speaking, PSPs are the creators of information, needing access to data and repositories of information, and adding value via generation of new information, typically in the format of drawings and reports. Constructors are the users of information, who turn information...
into practical action and physical outputs, and hence need information to be ordered, concise and addressing pragmatics such as risk and uncertainty. Clients are the initiators and beneficiaries of information, who define the requirements (the brief), and facilitate an information flow process in order to benefit from the ultimate outputs and outcomes.

4.5.13 Content Analysis Using Interviewee Role Classifications

Affinity groups were also interrogated for any differences in views between interviewees based on their roles. Roles were previously defined in Figure 4-3 as: CEO, director, principal, senior manager and senior technical grades. The means of analysis was achieved by undertaking a series of matrix coding queries using NVivo10 software. The queries produced a series of three-dimensional graphs of the number of references made by participants against role categories; an example is given in Figure 4-16 and the series of graphs are given in Appendix A2. The findings from this analysis are discussed in Table 5-6.

Figure 4-16: Coding Matrix Query for Ways in Which Information Is Used against Interviewee Role Classification
Table 4-6: Findings from Content Analysis by Interviewee Role

<table>
<thead>
<tr>
<th>Group</th>
<th>Findings/Observations and Discussion Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channels</td>
<td>CEOs talked more about meetings and face-to-face channels than emails, but it was interesting to note that they also discussed texting to a significant degree. It is also interesting to note that senior technical grade staff talked more about meetings than emails.</td>
</tr>
<tr>
<td>Types</td>
<td>The discussions about drawings were predominantly from senior technical grade staff, which is not unsurprising given their role. Discussions about as-built records were predominantly with senior management staff, but this is more likely to be because most of the senior management grade staff were employed by client organisations.</td>
</tr>
<tr>
<td>Repositories</td>
<td>CEOs and directors talked predominantly about specifications and technical standards, whereas principals were more likely to talk about corporate and project information repositories. This may be because principals typically have some ownership of their company.</td>
</tr>
<tr>
<td>Attributes</td>
<td>The graph indicates a wide range of priorities. For CEOs, information attributes of coordination and transparency dominated. For directors and principals, attributes of accuracy and timeliness dominated. However, for senior technical grade staff, the attributes relating to form/order/format were a very dominant factor, whereas for senior management staff, accuracy and clarity attributes dominated. This indicates that different roles have different informational priorities, which are influenced by their responsibilities.</td>
</tr>
<tr>
<td>Ways used</td>
<td>The analysis indicates that the ways in which information is used varies dependent upon role, which is not surprising. For CEOs, creating knowledge, decision-making and influencing dominated. For directors, decision-making dominates, but business intelligence, empowerment and confirmation are also important. For principals, knowledge creation dominates, but business intelligence and promotion (marketing) were also important. There is a significant difference for senior technical grade staff, for whom information for empowerment and understanding the problem become more important. Finally, for senior management grade staff, information for decision-making dominated. These differences reflect the different responsibilities of the roles (similar to findings for attributes).</td>
</tr>
<tr>
<td>Technology</td>
<td>Interestingly, BIM was identified more often by CEOs than other staff. This may be because CEOs are future focused and see BIM as a future technology strategy. It should be noted that none of the interviewees were BIM dedicated users. Senior technical grade staff were more likely to talk about information technology in general and also to identify a wider range of technology options and issues.</td>
</tr>
<tr>
<td>Issues arising</td>
<td>The issues arising vary by a significant degree. Management of communications and information dominated for CEOs, whereas information dissemination and the evolving nature of information were more dominant for directors. For principals, information-seeking patterns and information overload were discussed more commonly. For senior technical staff, the information seeking and speed of information issues dominated, whereas for senior management, information dissemination and information currency issues dominated.</td>
</tr>
<tr>
<td>Human agency</td>
<td>There is a consensus in that coordination, integration and collaboration featured strongly with all industry sectors. Other factors appear to be of secondary importance as they were discussed much less frequently.</td>
</tr>
<tr>
<td>Context</td>
<td>Procurement issues dominated in interview discussions with CEOs, directors, principals and senior management staff. However, for senior technical grade staff, issues relating to staff experience, capability and skills dominated.</td>
</tr>
<tr>
<td>Underlying</td>
<td>CEOs discussed issues relating to risk, shared understanding, waste and value more than other factors such as efficiency. Other staff identified efficiency issues more often, with a spectrum of the other issues.</td>
</tr>
</tbody>
</table>

Page 94
Key Finding 32: People’s roles influence their views relating to information and productivity. Generally speaking, the executives (CEOs, directors and principals) have more far-sighted strategic views, whereas management grade staff are focused more on operational matters. This is obviously a generalisation, but the differences are more marked in the ways information is used and the issues arising, indicating that the differences in informational needs relate to role responsibilities and areas of decision-making.

4.5.14 Rationalisation and Identification of Fundamental Issues

A further period of review of the key findings and analysis was undertaken to refine the 32 key findings into Miller’s 7+/−2 issues (Miller, 1956):

1. There is a link between information flow and productivity, but the link is not direct; rather, it is via a process of information being used for decision-making leading to action, which is then dependent upon the context, ultimately leading to an impact upon performance. Thus, the linkage is somewhat loose and the degree of impact is dependent upon intermediate elements of decision-making and action-taking.

2. Improvement in productivity performance is not purely about efficiency gains, but is a function of effectiveness and efficiency. In the engineering and construction sector, the effectiveness component of performance is more important than the efficiency component (albeit being efficient is still important). This is due to the nature of the sector, in which most of the work is project-based, one-of-a-kind production (as opposed to a routine manufacturing process), in which it is more important to arrive at the right solution to the problem than it is to journey in the most efficient manner.

3. The informational needs of staff vary dependent upon their role, responsibilities and function within the sector. Therefore, there is no single best way of facilitating information flow, but rather, informational flow needs to meet the needs of the recipient. Important attributes of information, such as accuracy, degree of completeness and timeliness, will vary between individuals. Likewise, channels of information flow should be selected to suit the purpose and preference of the recipient.

4. While technology is an enabler of information flow, it is not a simple solution and is only a facilitator of improved information flow to the degree that it helps improve the qualities of information such as form, order, consistency, format, searchability and timeliness. The benefits of information technology are somewhat equivocal depending upon how well the technology is applied. BIM is seen as a potentially significant technology for the engineering and construction sector. However, other human factors such as coordination, cooperation and achieving shared understanding are deeper, more important considerations.

5. Information is the means of building knowledge. Such knowledge, stored in repositories or retained as experience in human agents, enables the generation of the next round of information. This is a constructive, virtuous circle and is fundamental to progression and
improvement. In the engineering and construction sector, repositories of information (knowledge) are not leveraged sufficiently.

6. Contextual issues such as the macroeconomic environment and the industry sector structural issues are very significant. There are many issues, including procurement systems, supply chain maturity, staff skills, recruitment and retention, boom–bust cycles, among others, which all have an impact. Isolating any particular one element is not possible because they are interrelated. This concurs with the findings of Allan et al. (2008).

4.6 Synthesis of Findings and Development to an Information Flow Productivity Causality Model

The fundamental issues identified in the previous sections are synthesised into a proposed ‘informational flow productivity causality model’ as illustrated in Figure 4-17.

This model draws together the findings of the interviews and makes the linkage between information and productivity outcomes. The model moves from left to right through five elements that we call stations. In the first informational station, issues relating to information and knowledge are linked: information is used to generate knowledge, which in turn helps to improve information in future iterations. Technology can help store, search and retrieve some informational knowledge. Components of information include the attributes, types and channels.

The second station recognises that information can only be used by intelligent agents, and is used primarily for decision-making. Information precedes decisions, and decisions are made leading into actions (excepting the ‘do-nothing’ decision option). Hence, information in itself does not link directly to productivity outcomes but is dependent upon how well the information is
understood, the degree of innovation and creativity with which it is applied to decisions, and how the information is perceived by the user from a risk perceptive.

The third station relates to how the decisions are put into action, and the quality of actions are dependent upon the quality of preceding decision-making. Factors that affect the quality of action also include the degree to which actions create value and minimise waste through the production action-taking processes employed. Human factors such as levels of coordination and collaboration also affect the quality of actions, as the human actors employed in taking actions can negatively influence good decisions, or enhance poor decisions. There is also a range of related issues on how information is used, such as empowerment.

The fourth station recognises that there is a wide range of external factors at play in the remote environment that influence outcomes to a greater or lesser degree, irrespective of the quality of actions. Such context issues are hard to control directly because they relate to factors typically outside of the control of the decision-maker. For example, the macroeconomic factors of the economy can affect decisions made by clients on project investment decisions. At a different level, procurement strategy may affect outcomes for an individual supplier on a project, but the supplier may be powerless to influence the procurement strategy adopted by the client. There is a wide range of such factors, which all have some greater or lesser implication, and hence there is a potential amplification of such factors. The ways in which such factors affect productivity outcomes is unclear, and the degree to which they can amplify or diminish the quality of outcomes is not well understood. Further classification of such factors along the lines of a range of layers of action is needed (presented in further sections of this thesis). The concentric circles in the diagram are indicative of how the impact of such contextual issues can be amplified or diminished when overlapping, analogous with ripples of water in a pond.

The fifth and final station recognises that outcomes are a function of both effectiveness and efficiency. While productivity metrics relate more towards concepts of efficiency, it is important to recognise that, ultimately, overall performance relates to being simultaneously effective and efficient. For example, we could improve the efficiency of the roading subsector of construction by building many roads in flat green field locations, but they would not solve the congestion problem of our major cities. Hence, ultimately, we need information flows that facilitate the most effective solutions while being efficient about implementation of resources, and within the context of robust decision-making, quality of actions and a healthy thriving industry sector.

4.7 Limitations for This Research Stage (Semi-Structured Interviews)

The main limitation of this stage of the research is that it draws upon only one research methodology, namely, qualitative data collection via semi-structured interviews. We argue, however, that the qualitative research methodology adopted was appropriate for gaining depth of understanding for this initial phase of our investigations. We recognise that our results are based upon the subjective opinions of participants and have not been subjected to comparative quantitative analyses. Nevertheless, the findings and conclusions from such data are insightful.
and have validity as they draw upon the knowledge and experience of an appropriate cross-section of participants from the sector.

4.8 Conclusions for This Research Stage

Productivity is linked to information flow, but not directly. Rather, the linkage is indirect via the quality of knowledge, decision-making and actions taken. There is also a range of other contextual factors that may have a greater or lesser influence upon the outcomes. The proposed informational flow productivity causality model illustrates the linkages.

It is arguable that in the engineering and construction sector the quality of decision-making and actions should be oriented more towards maximisation of effective solutions than optimisation of efficient processes. This is because of the nature of the products produced by the sector, in which each project is unique. Hence, it is a one-of-a-kind production system, in which the opportunities to create valuable outcomes by being effective are greater than the opportunities to reduce and minimise waste through efficient processes. However, efficiency is still important, and should be optimised as far as possible, but not to the detriment of effectiveness.
5 Explorations into Information Flow Productivity Performance and Context Factors in Engineering and Construction

5.1 Introduction

In this chapter we expand on the findings of the previous chapter by presenting additional data and further analysis on the industry factors affecting productivity outcomes. We present the results of an anonymous questionnaire survey and use the results to segment the industry contextual issues. The results are combined with the findings from Chapter 3 to develop and refine the informational flow productivity causality model presented in Chapter 4.

5.2 Objectives and Goals of This Research Stage

As outlined in Chapter 1, the overall objective of this research was defined as:

*To gain an understanding of the linkages between information flow and productivity in the engineering and construction sector; and thereby to identify future directions for improving productivity.*

The specific objectives of this stage of the research were to advance the findings from the semi-structured interviews and gain a greater depth of understanding in two specific areas:

- to gain some quantitative evidence for the linkage between information flow as an input and productivity as an outcome;
- to gain a more structured breakdown of the contextual influences on productivity.

They link with our research goals as outlined in Table 5-1.

Table 5-1: Goals for This Research Stage (Industry Surveys)

<table>
<thead>
<tr>
<th>#</th>
<th>Overall Research Goals</th>
<th>More Specific Goals for This Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To investigate the linkages between information flow and productivity within the sector and determine the extent to which productivity outcomes are dependent upon information flow inputs.</td>
<td>To explore how strong the linkage is between information flow and organisational performance, with some quantitative evidence, either in support or refuting the linkage.</td>
</tr>
<tr>
<td>2</td>
<td>To understand the mechanisms by which information flow affects productivity and thereby build a framework or causality model linking information flow with productivity.</td>
<td>To enhance the information flow productivity causal model developed in Chapter 4.</td>
</tr>
<tr>
<td>3</td>
<td>To identify the impact of information flow upon the quality of problem-solving and decision-making within the engineering and construction context.</td>
<td>To enhance the information flow productivity causal model developed in Chapter 4.</td>
</tr>
<tr>
<td>4</td>
<td>To investigate the relative effectiveness of different information search strategies for decision-makers.</td>
<td>To enhance the information flow productivity causal model developed in Chapter 4.</td>
</tr>
</tbody>
</table>
Overall Research Goals | More Specific Goals for This Phase
---|---
5 | To identify the relative effectiveness of a range of information dissemination and transfer systems, including new and emerging information technology and management solutions. | Not addressed in this chapter.
6 | To provide some directions for productivity improvement for the engineering and construction sector in NZ. | While the context issues are relevant to productivity performance, a clearer understanding of such contextual matters will be beneficial for finding solutions to improving productivity and to inform future areas of research.

In the discussions and conclusion to the previous chapter we proposed a model (Figure 4-17) based on the findings of in-depth interviews. Our two objectives stated above are illustrated by means of an annotated version of the model in Figure 5-1.

![Figure 5-1: Twin Objectives of This Stage of the Research](image)

Hence, we are building upon the findings of the previous stage of research towards a better understanding of our overall objective and goals.

### 5.3 Research Design
A comprehensive literature review of the productivity issues relating to engineering and construction is given in Chapter 2; however, some pertinent elements for this research stage are discussed here as they informed our research design.
Huang et al. (2009) contend that the nature of the construction process points to a need for consideration of construction productivity at three levels: task, project and industry. Table 5-2 summarises some of the issues at these three levels.

**Table 5-2: Task–Project–Industry Productivity Summary**

<table>
<thead>
<tr>
<th>Level</th>
<th>Key Points from Huang et al. (2009)</th>
</tr>
</thead>
</table>
| Industry | At the industry level, the value of output produced per unit of input provides a productivity measure that is indicative of industrial efficiency.  
Industry-level productivity data is generally available (e.g., published by SNZ in New Zealand).  
Construction sector productivity trends in developed nations are generally declining. |
| Project | Since a project is a collection of tasks, project-level metrics are complicated.  
Publicly available project-level productivity estimates are rare. Compilation of a data set requires considerable data collection and is ultimately limited by contributing organisations’ projects and not of the industry as a whole. Changes in productivity might reflect changes in the composition of projects.  
Project productivity trends are unknown. |
| Task | Most task-level metrics are single-factor measures and focus on labour productivity. Typical task-level metrics estimate how much a given output is produced in a normal eight-hour day.  
Available from published data such as RSMeans (USA), Spons (UK) and Rawlinsons (NZ).  
Some international research indicates task-level productivity has improved over the period of the past two to three decades. |

While this segmentation of productivity considerations into task, project and industry is useful, in our view, it misses important considerations of productivity of the team and productivity issues relating to organisations. Much of engineering and construction sector work is undertaken by self-directed teams, with site crews being responsible for progressing elements of projects. Also, in design offices, consulting engineers tend to work in discipline teams, sharing work between team members on multiple projects. Hence, there is justification for introducing team productivity into the hierarchy. At the level of organisations most firms have a portfolio of projects, which when combined form the majority of organisations’ endeavours (Payne & Turner, 1999; Turner, Ledwith, & Kelly, 2010; Winch, 2006). Hence, we introduced two additional levels of consideration into the productivity hierarchy, namely, team and organisation levels, as given in Table 5-3.
**Table 5-3: Our Proposed Task–Team–Project–Organisation–Industry Productivity Hierarchy**

<table>
<thead>
<tr>
<th>Level</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>The aggregate performance of the industry sector, based upon the performance of the constituent organisations</td>
</tr>
<tr>
<td>Organisation</td>
<td>The next level of consideration, and can be conceptualised as a coordinated programme of projects to achieve outcomes and goals (i.e., as being the way in which businesses are organised)</td>
</tr>
<tr>
<td>Project</td>
<td>The principal way in which efforts in engineering and construction are coordinated to achieve outputs with sets of deliverables</td>
</tr>
<tr>
<td>Team</td>
<td>The core level of work, in which small groups of people work together to coordinate tasks in ways that individuals working alone cannot achieve by themselves</td>
</tr>
<tr>
<td>Task (individual)</td>
<td>The lowest level of consideration for productivity of a single task undertaken by an individual</td>
</tr>
</tbody>
</table>

Most of the literature referring to information flow refers to either theoretical concepts of information or mathematical models for technical applications in the ICT sector. We needed some means of referring to information in tangible ways so that we could solicit views from participants for this stage of the research. One set of pragmatic classifications of information products and services is offered in the literature by Orna (2004), which identified 15 different questions for auditing a company’s information management systems. As no previous studies had been undertaken comparing information flow with organisational performance, we categorised the 15 questions from Orna (2004) into three main groups and aligned them with our informational flow productivity causal model, as summarised in Table 5-4.

**Table 5-4: Informational Product Affinity Groupings**

<table>
<thead>
<tr>
<th>Informational Category</th>
<th>Link to Our Information Flow Productivity Model</th>
<th>Informational Products Questions Based on Orna (2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating-focused information</td>
<td>Information for decision-making and action-taking</td>
<td>Informational products relating to day-to-day operations of a company such as finance and production. Mainly internally focused.</td>
</tr>
<tr>
<td>Market-focused information</td>
<td>Information relating to context</td>
<td>Informational products relating to markets of a company such as customers and competitors. Mainly externally focused.</td>
</tr>
<tr>
<td>Institutional-knowledge-based information</td>
<td>Knowledge</td>
<td>Information relating to know-how and organisational capability, such as knowledge sharing. A mix of internal and external focus.</td>
</tr>
</tbody>
</table>

Five questions taken from Orna (2004) were allocated to each affinity group category as given in Table 5-5.
### Table 5-5: Categorisation of Information Products Questions

<table>
<thead>
<tr>
<th>Informational Category</th>
<th>Informational Products Questions Based on Orna (2004)</th>
</tr>
</thead>
</table>
| Operating-focused information                | Financial performance reporting  
Operating/project plans and budgets  
Feedback reporting from monitoring of production processes / project progress  
Information from suppliers that are inputs for the organisation’s products and services  
The information products of the organisation for the internal audience of employees |
| Market-focused information                   | Industry sector information (e.g., market trends, legislation)  
Competitor information  
Customer records  
The information products of the organisation that are outputs to the outside world  
Supplier records |
| Institutional-knowledge-based information    | Knowledge sharing within the organisation (i.e., between staff)  
Research and development information  
Information relating to the broad environment (e.g., the economy, social trends, demographics)  
Lessons learned from previous projects  
Knowledge sharing between organisations (e.g., sharing of know-how, tools, techniques, methods) |

As one of our objectives was to gain a quantitative understanding of the relationship between productivity performance and information, we developed a simple input–process–output model. Because productivity is a somewhat complex concept that could potentially be misunderstood by participants, we selected design questions about performance in a more general sense to avoid the risk of misinterpretation. We wanted to gain different perspectives on performance than simple profitability and therefore we selected questions to align with the four dimensions of quadruple bottom line performance (Bratt, 2012; Elkington, 1998; Sawaf & Gabrielle, 2014). Our model is illustrated figuratively in Figure 5-2.

![Figure 5-2: Assumed Model Developed for Industry Performance Survey](image-url)
5.4 Data Collection Methods for This Research Stage: Industry Questionnaire

In order to obtain a representative sample of views from industry practitioners, an industry questionnaire survey was selected as the most appropriate means of data collection. The survey was distributed via invitations to practitioners in NZ by professional bodies and associations, namely, BRANZ, Institution of Professional Engineers New Zealand (IPENZ), Project Management Institute New Zealand (PMINZ) and New Zealand Centre for Infrastructure Development (NZCID).

The questionnaire design comprised development of a mix of quantitative and qualitative questions. For quantitative questions we used 1–5 Likert scales in which participants were asked to rate importance and performance of factors using their subjective judgements. Qualitative views from participants relating to the factors that influence performance at the different levels of productivity for task, team, project, organisation and industry levels of consideration were solicited via a series of open-ended questions inviting participants to identify relevant factors.

Research ethics considerations identified issues relating to confidentiality and obtaining informed consent from participants. The Survey Monkey instrument was used to conduct the survey, in which participation was anonymous. Details of the research ethics documentation and a copy of the questionnaire are provided in Appendix A3.

The questionnaire was attempted by 72 participants and completed successfully by 63 participants. The response rate was low due to the passive nature of advertising the research in newsletters of the industry bodies. With an estimated population of 17,000, a sample size of 63 gives a margin of error of 12.3% at confidence level of 95%. Hence the findings of quantitative analysis should be considered as indicative, but still provide useful insight towards answering the research questions.

From the 63 responses, 37 participants responded to the open-ended qualitative questions relating to task, team, project, organisation and industry productivity factors. A review of the data revealed that one of the participants did not undertake the survey properly, selecting all maximum options in all questions, and the participant’s response was therefore removed from the results on the basis that it was unlikely to be serious.

5.5 Quantitative Findings and Analysis

This section presents the key findings, with a range of results presented in graphical form, followed by results of statistical analysis. Statistical analyses were completed using SPSS. Analyses of qualitative answers to open-ended questions were undertaken by means of content analysis aided by the use of NVivo10 software.

5.5.1 Participant Demographics

Demographics were collected on a range of factors, including role, employment sector, age and employer organisation size. Demographics on sex were not collected as differences in preferences between male and female are not the subject of this research.
A representative sample of participants from industry by different roles was obtained in technical and managerial grades at middle and senior levels, but representation was somewhat poorer in junior grades, as indicated in Figure 5-3. Given that performance factors are best understood by people in more experienced roles, the distribution is considered appropriate for this research.

**Figure 5-3: Participant Demographic by Role**

The distribution by sector of the industry is skewed heavily towards the project management profession, as indicated in Figure 5-4. A limitation of this section of the research therefore is that the views of project managers may not be representative of the engineering and construction sector as a whole.

**Figure 5-4: Participant Demographic by Industry Sector**

Demographics of the participants by age is given in Figure 5-5, showing that there is a reasonable representation across the different age bands.
The final demographic data collected was the size of employer, which is given in Figure 5-6.

**Figure 5-6: Participant Demographic Size of Employer (Number of Employees)**

### 5.5.2 Quantitative Findings

In separate questions we asked participants to rate both the importance and the actual performance of four key areas of organisational performance factors, namely, economic, social, environmental and cultural performance. Both the importance rankings and the actual performance rankings were measured in 1–5 Likert scales. The findings are given in Figure 5-7 and Figure 5-8 to show the relative importance and performance rankings.
Comparing the importance and performance rankings, we see a gap, with participants generally rating the performance of their organisations lower than the importance rankings. We also see a pattern with the relative rankings between economic, social, environmental and cultural showing a similar pattern in relative rankings of both importance and performance criteria, with economic being seen as the most important and cultural the least.

The strengths of the relationships between the importance and performance were measured using Spearman’s rank-order correlation, the results of which are given in Table 5-6.
Table 5-6: Correlation Results for Relationships between Importance and Performance

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_s = .289, n = 62, p = .023 )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Importance: Social</td>
<td>-</td>
<td>( r_s = .602, n = 62, p &lt; .001 )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Importance: Environmental</td>
<td>-</td>
<td>-</td>
<td>( r_s = .714, n = 62, p &lt; .001 )</td>
<td>-</td>
</tr>
<tr>
<td>Importance: Cultural</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>( r_s = .687, n = 62, p &lt; .001 )</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

We see the least well correlated of performance against importance is in the economic category, indicating a greater degree of variance in organisations’ economic performance against importance than the other bottom line metrics.

We also asked participants to rate the importance and performance of a range of information products using a similar approach to that of performance factors outlined above. The results are given in Figure 5-9 and Figure 5-10.

![Figure 5-9: Ratings of Importance of Organisational Informational Products](image-url)
The graph in Figure 5-9 is presented in order of highest to lowest ratings for ‘Very important’ and ‘Important’ ratings. Likewise, the graph in Figure 5-10 is presented in order of highest to lowest ratings for ‘Excellent’ and ‘Good’ ratings.

Comparing the importance and performance rankings, we see a gap, with participants generally rating the performance of their organisation’s management of information lower than the importance rankings. However, the relative rankings of the types of information products differ in order of priority, with ‘Lessons learned from previous projects’, ‘Feedback reporting’ and ‘Information from suppliers’ all showing significant change in their position in the rank order as illustrated in Table 5-7.

![Figure 5-10: Ratings of Performance of Organisational Informational Products](image_url)
Table 5-7: Rank order of Importance and Performance of Information Products

<table>
<thead>
<tr>
<th>Information Product</th>
<th>Rank Order of Importance</th>
<th>Rank Order of Performance</th>
<th>Change in Position of Rank Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating / project plans and budgets</td>
<td>1</td>
<td>2</td>
<td>−1</td>
</tr>
<tr>
<td>Financial performance reporting</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Knowledge sharing within the organisation (i.e., between staff)</td>
<td>3</td>
<td>6</td>
<td>−3</td>
</tr>
<tr>
<td>The information products of the organisation that are outputs to the outside world</td>
<td>4</td>
<td>5</td>
<td>−1</td>
</tr>
<tr>
<td>Industry sector information (e.g., market trends, legislation)</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Customer records</td>
<td>6</td>
<td>7</td>
<td>−1</td>
</tr>
<tr>
<td>Lessons learned from previous projects</td>
<td>7</td>
<td>11</td>
<td>−4</td>
</tr>
<tr>
<td>Feedback reporting from monitoring of production processes / project progress</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>The information products of the organisation for the internal audience of employees</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Information from suppliers that are inputs for the organisation’s products and services</td>
<td>10</td>
<td>14</td>
<td>−4</td>
</tr>
<tr>
<td>Information relating to the broad environment (e.g., the economy, social trends, demographics)</td>
<td>11</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Competitor information</td>
<td>12</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Knowledge sharing between organisations (e.g., sharing of know-how, tools, techniques, methods)</td>
<td>13</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Research and development information</td>
<td>14</td>
<td>15</td>
<td>−1</td>
</tr>
<tr>
<td>Supplier records</td>
<td>15</td>
<td>13</td>
<td>2</td>
</tr>
</tbody>
</table>

In response to a series of positivistic statements about the fundamental dependence of outcomes upon information flow, there was a strong degree of agreement, as indicated in the response results given in Figure 5-11.
Figure 5-11: Degree of Agreement to Positivistic Statements about Information Flow

There is a high degree of agreement, indicating that, in general, participants see a link between information flow and performance. It is interesting to note that the greatest agreement relates to customer satisfaction, which relates to outcomes, rather than to aspects of project time, cost and quality outputs. However, the lack of variability in responses between statements indicates that the questions are effectively asking the same underlying question.

5.5.3 Statistical Testing of Hypotheses

Two hypotheses were developed relating to the reported performance ratings. An alpha level of 0.05 was identified as appropriate for the exploratory nature of this research. A total performance scale was constructed as the sum of the 1–5 Likert scores for the four performance factors. The new scale was called the Quadruple Bottom Line Organisational Performance. A Cronbach's alpha for the constructed scale was 0.76, indicating that the variables have an acceptable degree of internal consistency. Assumptions of normality, linearity and homoscedasticity were tested by examining histograms, normal probability plots of residuals and scatter diagrams of residuals versus predicted residuals.

Null Hypothesis $H_{01}$: There is no difference in reported performance using the quadruple bottom line metric between different industry sectors.

Alternative Hypothesis $H_{01}$: There is a difference in reported performance using the quadruple bottom line metric between different industry sectors.

In Hypothesis $H_{01}$ we made a conjecture that there would be no difference in reported performance using the quadruple bottom line metric between industry sectors, on the rationale that organisations in all sectors have a similar range of performance outcomes.
A one-way analysis of variance (ANOVA) was conducted to explore the impacts of industry sectors (Gp1, constructor, \(n = 11\); Gp2, professional service provider, \(n = 36\); Gp3, client, \(n = 2\); Gp4, academia, \(n = 2\)) on performance. There was no statistically significant effect for industry sector at the \(p < .05\) level: \(F (3, 47) = .223, p = .88\).

Hence, there was a failure to reject the Null Hypothesis \(H_{01}\).

**Null Hypothesis \(H_{02}\):** There is no difference in reported performance using the organisational quadruple bottom line metric between organisations of different sizes.

**Alternative Hypothesis \(H_{a2}\):** There is a difference in reported performance using the organisational quadruple bottom line metric between organisations of different sizes.

In Hypothesis \(H_2\) we made a conjecture that there would be no difference in reported performance using the organisational quadruple bottom line metric between different organisations of different sizes, on the rationale that organisations of all sizes have a similar range of performance outcomes.

A one-way ANOVA was conducted to explore the impacts of organisational size (Gp1, 1–5 employees, \(n = 7\); Gp2, 6–25 employees, \(n = 5\); Gp3, 26–250 employees, \(n = 11\); Gp4, > 250 employees, \(n = 33\)) on performance. There was a statistically significant effect for employer size at the \(p < .05\) level: \(F (3, 52) = 3.23, p = .03\). The size effect, calculated using partial eta squared, was .16, which is a large effect on the Cohen classification. Post-hoc comparisons indicated that the mean score for organisations > 250 employees was the greatest (Gp1, 1–5 employees, \(M = 13.0\); Gp2, 6–25 employees, \(M = 13.0\); Gp3, 26–250 employees, \(M = 14.6\); Gp4, > 250 employees, \(M = 15.5\)), with Tukey’s honestly significant difference (HSD) test indicating significance between Gp1 and Gp4, and Gp2 and Gp4, but with differences between other groups not differing significantly. Possible reasons for this finding is that large organisations are seen to perform better than smaller ones simply because of size or alternatively because they have in fact performed better in the market place, resulting in growth. Causation is not proven by the statistical test. However, this result indicates that there is a relationship between perceived performance using the Quadruple Bottom Line Organisational Performance scale and organisational size.

Hence, the Null Hypothesis \(H_{02}\) was rejected.

In summary, our findings show that organisational size is of statistical significance but sector is not with regard to performance.

### 5.5.4 Relationships between Informational Inputs and Organisational Performance Using Multiple Regression Analysis

Multiple regression techniques were used to investigate the relationships between the three informational categories and organisation performance. Factors shown in Figure 5-2 were reviewed to design a simplified model suitable for regression analysis as given in Figure 5-12:
Figure 5-12: Model for Exploring Relationships between Informational Inputs and Organisational Performance Using Multiple Regression Analysis

A summary of information inputs used as independent factors in the regression modelling is given in Table 5-8: Cronbach's alpha based on standardised items for all three constructed independent variables > 0.7, indicating that these variables have an acceptable degree of internal consistency. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. Variables were also tested for normality using the Kolmogorov-Smirnov statistic.

Table 5-8: Summary of Independent Variables Used in Regression Analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Cronbach's Alpha</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating information</td>
<td>.794</td>
<td>17.9</td>
<td>9</td>
<td>25</td>
<td>62</td>
</tr>
<tr>
<td>Market information</td>
<td>.757</td>
<td>17.1</td>
<td>9</td>
<td>25</td>
<td>62</td>
</tr>
<tr>
<td>Knowledge information</td>
<td>.829</td>
<td>16.4</td>
<td>7</td>
<td>25</td>
<td>62</td>
</tr>
</tbody>
</table>

Regression analysis revealed that the model explains 46% of the variation in quadruple bottom line performance, $F (3, 57) = 18.14$ $p < .001$, indicated by the results given in Table 5-9.

Table 5-9: Summary of Multiple Regression Results for Organisational Performance

<table>
<thead>
<tr>
<th></th>
<th>$F$</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F (3, 57) = 18.14$</td>
<td>.49</td>
<td>.46</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

In the model, only 'market information' and 'institutional knowledge information' categories were statistically significant, with 'institutional knowledge information' recording the highest $\beta$ value, as given in Table 5-10.
### Table 5-10: Final Model Results from Multiple Regression Organisational Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>Std. Error</th>
<th>Standardised $\beta$</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating-focused information</td>
<td>.079</td>
<td>.159</td>
<td>.083</td>
<td>.49</td>
<td>.624</td>
</tr>
<tr>
<td>Market-focused information</td>
<td>.315</td>
<td>.133</td>
<td>.331</td>
<td>2.38</td>
<td>.021</td>
</tr>
<tr>
<td>Institutional-knowledge-based information</td>
<td>.292</td>
<td>.137</td>
<td>.354</td>
<td>2.14</td>
<td>.037</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

It would appear, therefore, that the most significant opportunity for performance improvement (by reducing variability) lies in improving the institutional-knowledge-based information products, followed by the market-focused information products, rather than in the operating-focused information products.

The strength or the $R^2$ and the statistical significance of the findings indicate that there is a relationship between information and performance of organisations. However, this is a simple regression model based on a relatively small sample size, using newly constructed scales, and therefore should be interpreted as a preliminary finding. There is potential to explore this relationship in greater detail via further research. Development of suitable reliable scales for types of information would be helpful, together with identification and measurement on a continuous scale of a more objective performance metric for future quantitative modelling.

### 5.6 Qualitative Findings and Analysis

In this section we focus on the responses to five qualitative questions through which we solicited views from participants on the factors that affect productivity at the different levels of task, team, project, organisation and industry. Each question is presented together with some examples of the responses, followed by the results of coding analysis. The coding was made against the Project Management Body of Knowledge (PMBoK) (2013) knowledge areas in order to provide structure against a widely recognised classification of knowledge areas.

The PMBoK (2013) knowledge areas are organisational influences, scope, time, cost, quality, human resource, communications, risk, procurement, stakeholder and integration management. Most of these are self-explanatory; however, for the sake of clarity, integration management is defined as “the processes and activities needed to identify, define, combine, unify and coordinate the various processes and project management activities” (PMBoK, 2013, p 554).

This is akin to overall coordination. When coding participant responses, we found that a number of comments related to matters not covered in the PMBoK knowledge areas, and were invariably related to wider socio-economic and societal issues, and therefore we introduced a new category for the coding, which we labelled ‘macro factors’. Where participants’ comments related to multiple issues, we mapped them against all relevant PMBoK knowledge areas (i.e., multiple responses), as we wished to gain insight into the trends of all the influences. A limitation of our research is that we have not attempted to measure the quantum of impact...
(severity) of the factors and have only identified the frequency at which contributing factors are identified.

5.6.1 Task-Level Factors

Qualitative Q1) Please describe some factors that have an impact on your daily task-level productivity performance as an individual worker (i.e., task-level issues). N = 37 responses. Examples of responses are as follows:

- Slow decision-making by decision-makers higher in the hierarchy (Task #1)
- Poor IT services – although we have many online tools they are not user friendly and there is such a multitude of tools, which are all different it makes for inefficient working (Task #2)
- Lack of good administration processes (e.g., filling out multiple information forms for expense claims) (Task #3)
- Too many diverse tasks (Task #4)

It is notable that the comments relate to typical day-to-day frustrations at a task level, some of which are outside the areas of direct control of the worker (e.g., Task #1). The results of the coding (N = 65) against PMBoK (2013) knowledge areas is given in Figure 5-13.

![Figure 5-13: Findings of Coding Analysis of Task-Level Productivity Factors](image)

5.6.2 Team-Level Factors

Qualitative Q2) Please describe some factors that have an impact on the productivity performance of your immediate team (i.e., team-level issues). N = 35 responses. Examples of responses are as follows:

- Ineffective meetings, which don’t lead to any actions (Team #1)
- Lack of coordination of efforts in the team – individualistic selfish pursuits (Team #2)
- Incentive systems are designed around individual achievements rather than team
achievements, resulting in complete lack of incentives to collaborate in team projects (Team #3)

Lack of information-sharing system for the team (reliance on emails) (Team #4)

Irregular meetings (Team #5)

The productivity performance is dependent on individual attitudes, and intrinsic motivational levels. The use of systems and technology will not have a major impact on productivity (Team #6)

The results of the coding ($N = 59$) against PMBoK (2013) knowledge areas is given in Figure 5-14.

![Figure 5-14: Findings of Coding Analysis of Team-Level Productivity Factors](image)

Many of the comments relate to communications and coordination, which is to be expected as teamwork relies on coordination of people to achieve objectives that individuals cannot on their own. Issues relating to inefficient and ineffective meetings appeared as a common factor (e.g., Teams #1 and #5). Also, human resource management feature commonly (e.g., Team #3). Again, the wider macro factors do not appear to have much direct bearing on productivity at a team level. Management of time features more commonly than management of cost and other factors, including risk and procurement issues.

### 5.6.3 Project-Level Factors

Qualitative Q3) Please describe some factors that have an impact on the productivity performance of projects you are involved with (i.e., project-level issues). $N = 38$ responses.

Examples of responses are as follows:

- Having the right resources at the right time (i.e., ordering and coordination of resources to suit project delivery process) (Project #1)
- Client changing their mind, poor project definition, lack of stakeholder identification and involvement (Project #2)
- People are generally not managed or encouraged to go the extra mile to get the job done. Expectation that individuals will do most things – as in no specialisation possible (as so much to do). People tired out and generally de-motivated. (Project #3)
- Unclear understanding of work required – i.e., poor communications (Project #4)
- The project’s management office and internal approvals (Project #5).
The results of the coding \((N = 72)\) against PMBoK (2013) knowledge areas is given in Figure 5-15.

![Figure 5-15: Findings of Coding Analysis of Project-Level Productivity Factors](image)

At a project level, matters relating to project integration management dominate (e.g., Project #1). Our qualitative findings indicate that coordination is the most commonly recognised determinant of project efficiency, which concurs with expectations and our findings in Chapter 4. At a project level, the features that are also commonly identified are human resources (e.g., Project #3), communications (e.g., Project #4) and scope management (e.g., Project #2), which all refer in turn to matters of coordination of effort towards some common purpose.

### 5.6.4 Organisational-Level Factors

Qualitative Q4) Please describe some factors that have an impact on the productivity performance of the organisation you work for (i.e., organisational level issues). \(N = 33\) responses. Examples of responses are as follows:

- **Political changes in the external environment** (Organisation #1)
- **Lack of transparency on funding flows** (Organisation #2)
- **Often lip service is paid to performance improvement** (Organisation #3)
- **Turnover of staff, who take their knowledge with them (i.e., lack of institutionalising knowledge)** (Organisation #4)
- **Approval process** (Organisation #5)
- **Clear processes and difficulty with managing all the different systems all our related organisations use** (Organisation #6)

The results of the coding \((N = 53)\) against PMBoK (2013) knowledge areas is given in Figure 5-16.
At an organisational level, the most commonly featured issues naturally relate to organisation management (e.g., Organisation #6), but also human resource and communication again feature commonly (e.g., Organisations #4 and #5). Macro factors also start to feature as commonly identified issues (e.g., Organisation #1). While macro factors do not appear to be issues that commonly impact directly upon task-, team- and project-level productivity performance, they start to influence organisations’ productivity.

### 5.6.5 Industry-Level Factors

Qualitative Q5) Please describe some factors that have an impact on the productivity performance of the industry sector you work in (i.e., industry-level issues). N = 34 responses. Examples of responses are as follows:

- **Continuity of funding of capital development projects (Industry #1)**
- **Society’s environmental and social expectations (Industry #2)**
- **Fairness and equity of employment within the industry (Industry #3)**
- **Inadequate level of national resources (Industry #4)**
- **Lack of opportunities for collaboration, joint ventures and off-shore performance (Industry #5)**
- **Lack of economic growth (Industry #6)**

The results of the coding (N = 46) against PMBoK (2013) knowledge areas is given in Figure 5-17.
At the level of industry, productivity macro factors dominate (e.g., Industries #1, 2, 3, 4 and 6). There is also common recognition of organisational management factors (e.g., Industry #5), but traditional scope, time and cost issues do not feature at all.

5.6.6 Summary Analysis and Synthesis of Findings

These findings illustrate the breadth of matters that relate to productivity in engineering and construction. They also show that the issues are not homogeneous. When we talk about productivity in general, there is a tendency by many to think about the broad socio-economic macro factors such as boom–bust cycles in the construction industry, but in reality there are a different range of factors at different levels of consideration. A summary of our results as given in Figure 5-18 illustrates the diversity of factors as a stratified set of factors.
Our findings show that the matters that influence task-level productivity the most are organisational matters and communications, followed by scope management issues. At the level of team coordination, communications and human resources are particularly important, which is to be expected. At a project level, matters relating to project integration management dominate. Therefore, it makes sense that the coordination of effort and resources is the main determinant of project efficiency. At the level of the construction industry, our findings show that the influences on productivity are predominantly the macro socio-economic and societal factors, such as economic cycles and regulation. When we combine all the matters \((N = 295)\) and rank in order, as given in Figure 5-19, we find that integration management followed by organisational and communication management issues are identified most frequently.

![Figure 5-19: Summary Findings for Aggregated Productivity Factors Coded to PMBoK Knowledge Areas in Rank Order](image)

Integration management and communications appear to offer the greatest opportunity to improve productivity, in the coordination of multiple tasks at the different levels of activity. Organisational factors and human resource management factors are also commonly identified, reflecting that engineering and construction requires the input of very significant levels of human effort. Our results indicate that these factors are more commonly identified than the wider macro socio-economic factors such as regulation. Therefore, the tendency to attribute the productivity problem to such wider macro factors could be somewhat overplayed, as decision-makers within the construction sector have ample opportunity to address matters of integration, communication and human resource management.

We would argue that there is little benefit to be gained from improving task-level productivity unless there are simultaneous improvements in the overall coordination and integration of such tasks. Increased task-level specialisations, enabled, for example, by advances in technology, therefore need to be implemented in parallel with improvements at the project coordination level, which also need to be supported, for example, by more efficient organisations and so on. The stratification of productivity issues by task, team, project, organisation and industry helps us to better understand matters that affect productivity and to break down the issue, rather than
trying to deal with poor productivity as a homogeneous whole. Figure 5-20 provides an illustrative model of the relationships between the performances at the different levels.

![Illustrative Model of Productivity Performance](image)

**Figure 5-20: Relationship between Productivity Performance at Task, Team, Project, Organisation and Industry Levels**

The challenge is the simultaneous improvement of all layers in the model, which requires considerable effort and coordination. Investment in one area could prove of limited benefit if other layers in the stratified model are not improved simultaneously. Here the wider socio-economic factors introduce some thorny challenges for the industry that make it hard to invest in improving across all factors simultaneously. It is a system-wide issue, and following the breakdown of the problem to gain better understanding of the issues, a solution to the productivity challenge needs to address the whole system in a systems thinking approach.

### 5.7 Overall Discussion Combining Quantitative and Qualitative Findings

In this research we aimed to gain a better understanding of factors that influence performance and to find evidence that information flow is an important contributing factor. Our findings advance knowledge towards these objectives in two main aspects:

- Key Finding 1: There is a link between information flow and performance outcomes.
- Key Finding 2: The factors that influence productivity performance from task through to team, project and organisation to wider industry productivity performance are not homogeneous, but rather are somewhat stratified at these five levels of consideration.

Key Finding 1 is supported by the quantitative analyses, which show that our proposed information flow model explains 46% of the variation in quadruple bottom line performance of
organisations. From the three variables considered in the model, the most significant opportunity for performance improvement, by reducing variability, lies in improving the institutional-knowledge-based information products, followed by the market-focused information products, rather than in the operating-focused information products. While not providing a complete model for performance variability at an organisation level, it does give evidence that information flow is linked to performance of the organisation. We recognise that our model is somewhat simplistic, and is based upon subjective opinions of participants; however, it does provide a new step forward in our understanding of how information flow affects performance outcomes. This finding is supported by the qualitative results and analyses, which indicate that communications management is one of the most commonly identified issues relating to productivity performance at an organisational level. Furthermore, in an overall summary of productivity issues across the five levels of task–team–project–organisation–industry, communications management is the second most commonly identified issue, with integration management (i.e., coordination) being narrowly more commonly cited. Information flow is self-evidently the foundation for communications, as communications cannot happen without flows of information between intelligent agents. We consider that information flow is also a significant foundational component towards integration management, as coordination of effort in an integrated manner is likewise dependent upon a flow of information with suitable feedback loops, to bring about integrated outputs in a system.

In our second key finding, we progress knowledge in the field of productivity of the engineering and construction sector in NZ by breaking down the issue into a more stratified model. This is a departure from many of the previous productivity studies, which tend to address the issue from the perspective of the industry as a whole and from a macroeconomic perspective (Davis, 2007), or from a narrow focus on one aspect of productivity at the task level (Thomas, Horman, Minchin Jr, & Chen, 2003; Thomas & Yiakoumis, 1987). While other authors recognise that productivity drivers differ at levels of task, project and industry (Huang et al., 2009), they do not recognise the influences on the overall system of team and organisation productivity, which are missing from previous studies and models. Our model therefore advances understanding of the factors by providing five distinct stratified levels of consideration, and proposes linkages between the five levels to help drive productivity performance improvement as a system using systems thinking.

There is a need to improve integration management and communications management in the construction sector in order to address the productivity improvement imperative. An interesting consideration is identifying the people of greatest influence able to effect the improvements in light of our findings regarding information flow. We suggest that project managers are the people with the main responsibility for coordination and integration of tasks and for being the facilitators of information flows. Others all have responsibilities, from decision-makers at the highest to lowest levels, to site and design, to policy makers; however, project managers have a central role in the overall system. Often the project management role is undertaken by engineers, and we would differentiate the project manager by role rather than necessarily
qualification or formal title, and therefore, the project manager might be a professional engineer, project manager or somebody from one of the other professional backgrounds. Whatever the background, the role is one of coordination and communication. Therefore, the project manager has a key role in addressing the productivity problem in the sector. Task-level efficiency improvements can be translated into team and project efficiency improvements if (and only if) the project manager is mindful of the relationship between task activity and productivity improvements.

The people with the greatest opportunity to address the productivity challenge at the top two layers in Figure 5-20 are the leaders and senior decision-makers in industry. Project-level productivity improvements can only translate into wider organisational and industry improvements if (and only if) leaders and decision-makers are also mindful of the complex relationships. It is here that leaders and decision-makers have the opportunity to improve information products, especially the organisational-knowledge-based information products, which should bring improvements to organisational productivity, to the benefit of the organisations, employees, shareholders and wider stakeholders.

A separate finding was the relationship between perceived performance using the Quadruple Bottom Line Organisational Performance scale and organisational size. Organisations of large size (> 250) are seen as performing better than smaller organisations (small to medium-sized enterprises [SMEs] in 1–5 employees and 6–25 employees categories), the size of the difference being large and statistically significant. Possible reasons for this finding is that larger organisations are seen to perform better than smaller ones simply because of their size or alternatively because they have in fact performed better in the market place, thereby resulting in growth. Causation is not proven by the statistical test. However, if we follow a line of reasoning that accepts that larger organisations have grown to be large because of superior performance, a likely reason is their superior performance in underlying information flow, particularly knowledge-based and market information. This line of reasoning would concur with the core competencies theories (Hamel & Prahalad, 1994; Prahalad & Hamel, 1990) and also the literature on intellectual capital (Teece, 2000). This line of reasoning gives us some direction for improving productivity in the sector by means of ensuring companies invest in ICT in order to improve systems and hence also enhance productivity performance.

5.8 Limitations for This Research Stage (Industry Questionnaire)

As noted previously, this research is limited to subjective judgements of participants responding to an anonymous questionnaire. The ratings of organisation performance and information products have not been verified by observations against objective data of actual performance levels. Also, the model used for the regression analysis is based upon newly constructed scales, which while useful should be researched further to test the reliability of the scales for the independent and dependent variables. Also, other independent variables could be identified and tested in the model to improve the predictability of the dependent variable.
The qualitative findings are based on fairly short written responses to open-ended questions in an online survey. While the quality and quantity ($n_{\text{min}} = 33, n_{\text{max}} = 38$) of the responses are generally acceptable, the depth of insight is not as deep as qualitative research undertaken via semi-structured interviews.

5.9 Conclusions for This Research Stage
The relationship between productivity performances and information flows in the engineering and construction sector is not well understood in the existing literature. The findings from the industry survey provide evidence that the root causes for poor productivity performance, as measured by variability of organisation performance, are partly due to performance in a range of information-based products and services. In particular, knowledge-based information products and market-based information are of statistical significance in explaining performance variability at an organisational level. Performance is also related to organisation size, with larger organisations being perceived to perform better than SMEs. Although causation is not proven by our research, a possible reason for the difference is that larger organisations invest more, and perform better, in managing their information flows within their organisation and externally in the market place.

We also conclude that productivity performance in the construction sector can be considered at five broad levels of operation, namely, task, team, project, organisation and broad industry levels. These should be considered in a stratified manner with the issues relating to productivity performance varying between each level. Hence, productivity performance improvement needs a systems thinking approach, with a good understanding of each part of the system, rather than a simplistic thinking approach that views the problem as a homogeneous phenomenon. Our study indicates that project integration management, communications and human resource management are particularly important factors in productivity. This is a marked difference to the traditional productivity research in NZ, which tends to focus on macroeconomic factors.

5.10 Further Conclusions Combining Chapters 4 and 5
In the conclusions to Chapter 4 we proposed an informal flow causal model for productivity showing the linkage between information stations to productivity outcomes via intermediate stations of decision-making, action-taking and contextual issues. In the proposed model the details of the context issues were not well developed, but based on the findings of Chapter 5, the model can now be developed. Having decomposed the contextual issues relating to productivity in task, teams, project, organisation and industry, we propose a more detailed model, based on the initial model, but enhanced to provide more useful guidance for productivity improvement in practice and for further research. The more detailed model is given in Figure 5-21, which is applicable to the engineering and construction sector. We show the detailed model alongside the original more generic model in Figure 5-22 for ease of comparison. We suggest that the original generic model might be applicable to other sectors of
industry, whereas the more detailed model is specific to the engineering and construction sector.

Figure 5-21: Detailed Model for Information Flow and Productivity in Engineering and Construction

Figure 5-22: Generic Information Flow and Productivity Causality Model
In the detailed model we include the stratified levels of productivity consideration, with some examples of pertinent issues in the NZ context for each level of consideration. This serves to illustrate that information flow, decision-making and action-taking need to match the constraints and contextual issues at each level. The examples should be interpreted as indicative of the types of issues and not necessarily a comprehensive list of all the contextual factors. The inclusion of the stratified contextual layers in the model serves firstly to make the model more contextually specific for the sector, but also to emphasise the importance of tailoring the information flow, decision-making and action-taking to suit the constraints and issues pertinent at the different levels of consideration. For example, the information flows and decision-making for task-level activities need to be rather different than, say, information flows for project reporting to head office to facilitate decisions by senior management in utilisation of company resources.

In the conclusions to Chapter 4 we argued that the fifth and final station recognises that performance outcomes are a function of both effectiveness and efficiency. While productivity metrics relate more to concepts of efficiency, it is important to recognise that, ultimately, overall performance relates to being simultaneously effective and efficient. This is illustrated in the 3E triangle of efficiency, effectiveness and economy (Ramanathan, 1985). In the detailed model we illustrate number of consecutive 3E triangles, and deliberately so, on the basis that performance at each level of consideration depends upon the cumulative effects of the lower levels. It is possible, for example, to improve the productivity of specific tasks at a task level of consideration by optimising the outputs or inputs. Examples could include allocation of new tools to the particular task or adoption of a mass-production approach to the said task. However, such a focus at the task level could easily lead to wasteful efforts at other levels of consideration. For example, individualistic pursuit of task outputs can lead to negative impacts upon the team, as identified in one of the responses to the questionnaire:

*Lack of coordination of efforts in the team – individualistic selfish pursuits.*

Similar examples can be seen elsewhere. For example, at a project level, focus on the productivity of a single project could be to the detriment of outcomes for a pipeline of projects over time, or other projects in different geographic locations or projects being undertaken by different organisations. An example identified by a participant in the semi-structured interviews in Chapter 4 spoke to an issue of oversupply of bitumen plants in the Auckland region, as each company competing in the roading sector needs capability, but the sum of the total capacities of the various plants far outweighs demand in the region, hence leading to waste in the industry as a whole.

Selfish pursuit of efficiency at one level typically incurs costs elsewhere in the system, which ultimately need to be borne by somebody else in the wider system. Hence, a systems-wide thinking approach is necessary. It is here that our model provides a potentially powerful new way of understanding productivity performance giving insight into performance improvement in industry, and also direction for possible future research. The multiple 3E triangles in the detailed
model serve to illustrate that the key to improving productivity is not to focus on efficiency at each level of consideration, which all too often leads to waste elsewhere in the wider system. Rather, taking a bottom-up approach, the focus should be on maximising effectiveness, without unduly affecting the efficiency of outputs.

This requires a somewhat unselfish approach, in which people understand the greater rewards that can be achieved from the wider system. For example, many people working in teams put in extra effort for the sake of the benefits that accrue to their team. This tends to occur best when expectations of reciprocity are met, or incentive systems are devised to incentivise the individual to contribute to the good of the wider team. Similar arguments apply to other levels of consideration in our model.

Our model may explain why Goodrium and Haas (2002) found a steady increase in task-level productivity metrics over a period of time in the USA construction industry, while simultaneously observing a steady decrease in industry-level productivity performance. While task-level productivity was found to be driven by improvements in technology, they failed to be translated into broader productivity improvements in the industry as a whole because of waste elsewhere in the system, perhaps at the project coordination level.

In final conclusion, our model serves to illustrate the linkages between information flow and productivity. Our research indicates both qualitatively and quantitatively that there is a link between information flow and productivity performance in the engineering and construction sector. Furthermore, our model provides new insight into the productivity problem by decomposing the issues and applying systems thinking in bringing the various components together. This gives insight that a suitable approach to improving productivity is to focus not on efficiency per se, but rather on optimising effectiveness without causing undue negative impact upon efficiency.
6 Information Search Patterns in Engineering and Construction

6.1 Introduction
In this chapter we present the findings of an anonymous questionnaire designed to gain an understanding of the information search patterns deployed by decision-makers in engineering and construction. The findings of the questionnaire are used to enhance our understanding of information flow and the impact upon productivity.

6.2 Objectives and Goals of This Research Stage
In the conclusions to Chapter 4 we introduced an information flow and productivity causality model, and in Chapter 5 we explored the linkage between information flow and performance, and also extended the model in relation to contextual consideration for the engineering and construction sector. After we had done so, our next objective was to explore in greater depth the information and decision-making stations of the model to gain a better understanding of the information search patterns of engineers and decision-makers working in the sector. This chapter therefore has one main objective:

• to gain detailed understanding of information search patterns and issues relating to decision-making in the engineering and construction sector.

Our objective for this chapter links with the overall objective, which was defined as:

To gain an understanding of the linkages between information flow and productivity in the engineering and construction sector; and thereby to identify future directions for improving productivity.

This is illustrated with reference to our model in Figure 6-1.
Aspects identified as potentially pertinent for obtaining depth of insight on information-seeking patterns displayed by decision-makers in the engineering and construction sector identified from previous findings in Chapters 4 and 5 are as follows:

- types of decisions being made;
- preferred sources of information, both human agents (people) and documentary;
- channels of communication and channels deployed in collecting information for the decision;
- most useful sources of information, both for the understanding process and the solving process;
- the number of iterations needed for the decision and reasons why;
- the attributes of information that are most important.

An important part of the objective is to understand the relationship between prior knowledge and information, and the role that technology plays in helping structure and access knowledge. In order to gain insight into the role of technology, we identified an opportunity to make comparison of the information-seeking patterns deployed currently by professionals in industry with patterns deployed before the advent of modern digital technology communications, such as the internet. The study by Patterson and Farrant (1982) on information search and dissemination strategies in the engineering and construction sector of NZ gives a means of

Figure 6-1: Objective of Information Search Patterns Chapter with Reference to Information Flow and Productivity Causality Model
making a meaningful comparison at a detailed level. They undertook in-depth analyses of 444 decisions taken by 118 decision-makers and found that decision-makers relied heavily on people in their search for information and also that the manufacturers and suppliers through their representatives and product data were a major source of information in the early 1980s.

In the early 1980s digital technology was in its infancy; there were a number of fledgling connected networks developed by academia, government agencies in the USA and Europe, and the first CD player was sold in Japan, but it was not until the late 1980s that the first internet service providers were formed. Typewriters were the predominant means of producing written documents and technical drawings were still produced by hand; computer aided drafting (CAD) was an emerging technology. Fax machines were common and the first commercial cellular phone network in North America became available in 1983. Patterson and Farrant (1982) commented with respect to computer systems that “widespread use of computer terminals in most offices still appears to be some time away in New Zealand”.

Therefore, a study comparing and contrasting the findings of Patterson and Farrant (1982) in the same industry context in NZ, using similar data collection methods and questions, offers an opportunity to explore not only contemporary information search patterns, but also insight into the impact that modern ICT may have made. Such comparative studies are useful for identifying changes over intervening time periods, and are a powerful means of extending knowledge by extending the findings of previous studies.

In this chapter we progress towards our goals as described in Table 6-1.

**Table 6-1: Research Goals for This Chapter (Decision Survey)**

<table>
<thead>
<tr>
<th>#</th>
<th>Overall Research Goals</th>
<th>More Specific Goals for This Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To investigate the linkages between information flow and productivity within the sector and determine the extent to which productivity outcomes are dependent upon information flow inputs.</td>
<td>To enhance our information flow and productivity causality model developed in Chapter 4.</td>
</tr>
<tr>
<td>2</td>
<td>To understand the mechanisms by which information flow affects productivity and thereby build a framework or causality model linking information flow with productivity.</td>
<td>To enhance our information flow and productivity causality model developed in Chapter 4 by deeper understanding of linkages between information and decision-making.</td>
</tr>
<tr>
<td>3</td>
<td>To identify the impact of information flow upon the quality of problem-solving and decision-making within the engineering and construction context.</td>
<td>To enhance our information flow and productivity causality model developed in Chapter 4 by deeper understanding of linkages between information and decision-making.</td>
</tr>
<tr>
<td>4</td>
<td>To investigate the relative effectiveness of different information search strategies for decision-makers.</td>
<td>Undertake a detailed comparison of the information search strategies undertaken in the 1980s by means of comparative study with that of Patterson and Farrant (1982).</td>
</tr>
</tbody>
</table>
# Overall Research Goals

## More Specific Goals for This Phase

<table>
<thead>
<tr>
<th>#</th>
<th>Overall Research Goals</th>
<th>More Specific Goals for This Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>To identify the relative effectiveness of a range of information dissemination and transfer systems, including new and emerging information technology and management solutions.</td>
<td>To undertake a detailed comparison of the information search strategies undertaken in the 1980s by means of comparative study with that of Patterson and Farrant (1982).</td>
</tr>
<tr>
<td>6</td>
<td>To provide some directions for productivity improvement for the engineering and construction sector in NZ.</td>
<td>To identify some recommendations with respect to modern ICT options.</td>
</tr>
</tbody>
</table>

### 6.3 Data Collection Methods for This Research Stage: Decision Questionnaire

A survey was designed to capture data replicating aspects of the survey used by Patterson and Farrant (1982), supplemented by additional questions. The data was captured via a detailed questionnaire, with invitations to participate extended to the engineering design and construction community via professional institutions and direct approaches to consulting engineering firms. A total of 115 responses was received, of which 98 were properly completed. This equates to a completion rate of 85% of those who started the questionnaire, a relatively low rate, which is likely to be because of the extensive nature of the various questions. Participants did not have to answer every question in the survey; nevertheless, some participants exited after the first two to three questions.

Research ethics considerations identified issues relating to confidentiality and obtaining informed consent from participants. The Survey Monkey instrument was used to conduct the survey, in which participation was anonymous. Some demographics of participants were solicited, including role, industry sector, age and size of employing organisation. Details of the research ethics documentation are provided in Appendix A4.

### 6.4 Results and General Analysis

This section presents the key findings, with a range of results presented in graphical form, followed by results of statistical analyses. Statistical analyses were completed using SPSS software by IBM.

#### 6.4.1 Participant Demographics

Demographics were collected on a range of factors, including role, employment sector, age and employer organisation size. Demographics on sex were not collected as differences in preferences between male and female are not the subject of this research.

A representative sample of participants by different roles was obtained in technical and managerial grades, but representation was somewhat poorer in administrative, junior and academic roles, as indicated in Figure 6-2. Given that design and managerial decisions in the industry are typically made by staff in technical and management grade roles, the distribution is considered appropriate for this research.
Figure 6-2: Participant Demographic by Role

The distribution by sector of the industry, however, is skewed heavily towards PSPs, as indicated in Figure 6-3. A limitation of this section of the research, therefore, is that the views of contractors and clients are not captured adequately in the sample, and the findings need to be interpreted as presenting the views primarily of consultants.

Figure 6-3: Participant Demographic by Industry Sector

Demographics of the participants by age is given in Figure 6-4, and the representation across the different age bands is reasonable.
The final demographic data collected was the size of employer, which is given in Figure 6-5.

Figure 6-5: Participant Demographic Size of Employer (Number of Employees)

A larger proportion of participants from large organisations (> 250 employees) was obtained than expected. However, this can be accounted for by the fact that most of the participants were from PSPs, where a smaller number of large engineering consultants employ a significant proportion of professional staff in the engineering and construction sector.

In relation to the study of Patterson and Farrant (1982), the demographics of the participant samples are broadly similar, as illustrated in Figure 6-6.
Figure 6-6: Comparison of Participant Demographics between Patterson and Farrant (1982) and This Research

The sample size is similar \( (n = 98 \text{ participants in this research vs. } n = 139 \text{ in Patterson and Farrant, 1982}) \) and both have a majority of participants in the professional service provider sector.

6.4.2 Decision Descriptions as a Means of Framing the Questionnaire

The first question in the questionnaire asked participants to identify a decision they had made recently, qualifying that it should be from the workplace, that involved a degree of complexity and some information gathering, ideally on some aspect of engineering, construction management, design or project execution. We deliberately designed this to give participants freedom of choice within these parameters in order to gain insight on subsequent information gathering and dissemination patterns for a range of decision types and we did not want to precondition the type of decision. We asked participants to briefly describe their decision qualitatively. An analysis of the answers indicates that the majority of the decisions relate to the participants’ design decisions, as indicated in Figure 6-7, but also include a wide range of types of decisions. All subsequent questions about information sources and dissemination related to the specific decision point. Some examples of participants’ answers are given in Table 6-2, which illustrate the wide variety of decisions being made by participants.

Table 6-2: Examples of the Types of Decisions Made by Participants

<table>
<thead>
<tr>
<th>Selected Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whether or not to use pile foundation for a commercial warehouse development</td>
</tr>
<tr>
<td>Labour allocation</td>
</tr>
<tr>
<td>Reduction in the amount of equipment required</td>
</tr>
<tr>
<td>Whether to undertake additional geotechnical scope</td>
</tr>
<tr>
<td>Which contractor to award contract for construction</td>
</tr>
<tr>
<td>Deciding between methods of analysis of structural frame</td>
</tr>
<tr>
<td>Hollow core deck girder for railway bridge, to use either concrete or steel</td>
</tr>
<tr>
<td>Investing in a new building for staff in our Christchurch office</td>
</tr>
</tbody>
</table>
In a separate question we asked participants to rank on a five-point Likert scale the significance of a number of predetermined generic decision constraints, ranging from factors such as regulations to commercial considerations. These constraints and responses are given in Figure 6-8.

While the primary decision constraints are financial and technical, it is pertinent that codes and regulations are identified as the third most significant constraint for the decision-making process. Functional constraints and time are also identified as significant constraints. The time constraint is interesting as it probably applies more to the decision-maker than the decision itself, although we did not differentiate this in the questionnaire.
We asked participants to identify an estimate of the monetary value of the decision within predefined bands, and with options to state 'confidential' or 'don’t know'. The results are given in Figure 6-9, and indicate a wide range of magnitude of decisions being taken. Of surprise was the large percentage (circa 24%) of respondents who stated that they did not know the financial value of the decision for which they were taking responsibility.

We also asked the question ‘If the decision related to a project what is the total cost of the project?’ The results are shown in Figure 6-10, and it is surprising the number of participants who did not know the overall project cost, indicating that decisions are often made without consideration of financial implications or knowledge of the commercial context. This has implications for productivity in the sector when a significant portion of decision-makers have no appreciation of financial implications.

![Figure 6-9: Values of the Decisions](image1)

![Figure 6-10: Values of the Projects](image2)

### 6.4.3 Contribution to Decision from Self and Others

On the basis of this decision point we asked participants to reflect upon the contribution made to the decision from personal knowledge and experience. The findings are illustrated in Figure
6-11. We then asked participants to rate the contribution of others to the decision, the results of which are summarised in Figure 6-12.

![Figure 6-11: Participant Rating of the Contribution they made to the Decision from their Personal Knowledge and Experience](image)

This was an interesting finding and provides evidence that work experience is considered more valuable when making decisions than formal training or education. These results serve to highlight the importance of learning from professional experience.

![Figure 6-12: Participant Rating of the Contribution Made by Others to the Decision](image)

Approximately 90% of participants identified some input from others, indicating that decisions are only occasionally made by a single person without some input from other humans. Again, general knowledge is most highly valued, but participants also identified the expertise of others who they consulted as being of importance. Being able to tap into others' networks was not seen as being particularly important, which may indicate that people prefer to find the help they need immediately rather than being referred on to somebody else.
6.4.4 Preferred Information Sources and Channels

As noted in the introduction, we were particularly interested in who decision-makers communicate with for their decision-making. Our findings are summarised in Figure 6-13 (Human Agent Information Sources) and Figure 6-14 (Documentary Information Sources). These charts present the data in raw counts (rather than percentages), with a breakdown of the channel of communication used.

Figure 6-13: Human Agent Information Sources and Communication Channel
The following points from these results are immediately striking:

- A wide range of information sources is used, coupled with a broad mix of communication and access channels, indicating that participants are adept at finding the information they need for decision-making.
- Face-to-face interactions are significant, and reliance upon colleagues is the most commonly used source of information.
- Unsurprisingly, email also features heavily, and is more commonly used than telephone. This may in part be because telephone conversations are often backed up by a confirmation email, especially for important decisions, as the email forms a record of the conversation.
- Many participants reported that they still use hard copies to a significant degree. In particular, technical drawings are still referred to predominantly in hard copy format.
- It is apparent that informal face-to-face communications are used with colleagues and superiors, whereas more formal means of communication such as meetings and email become more predominant when dealing with external agencies, regulators, and so on. Video conferencing is not used to any significant degree, which warrants further investigation.

As mentioned previously, the questionnaire replicated some of the questions asked by Patterson and Farrant (1982), and hence a comparison of findings can be made, giving an
indication of possible changes in information-seeking patterns that have occurred over the past three decades. Normalised comparisons are given in Figure 6-15 and Figure 6-16 and presented in percentage of total sources of information used, which is necessary because of the different sample sizes. Note that Patterson and Farrant (1982) did not collect data on channels of communication, and therefore it is only possible to compare the total counts.

Figure 6-15: Comparison of Human Agent Information Sources Used

It should be noted that Patterson and Farrant (1982) did not include the role of the project manager in their list of parties, which is perhaps indicative that in the early 1980s the role did not exist particularly as a separate professional role, and would often be undertaken by the lead consultant. The project manager is now identified as somebody who is commonly consulted in making decisions. There is a striking difference in the degree to which manufacturers or suppliers are consulted in making decisions. Also notable are subcontractor, superior and subordinate. These give insights into the ways in which information-seeking patterns have changed over the intervening period of time. Manufacturers and suppliers of products and services are now treated at greater arm’s length in the decision-making. We can only speculate on the reasons why, as the data does not give causality. Possible factors may include changes in procurement practices and reduction in the role of the manufacturers’ representatives (a role that used to be common practice in which manufacturers employed representatives who established relationships with designers). Patterson and Farrant (1982) commented with respect to the role of the representatives that “the better representatives through their contacts and visits provide an informal communication system between staff of different firms and generally keep people up with progress”. They also identified that even in the early 1980s firms were cutting back on their employment of representatives as a means of promoting their
products and forecast that such a trend in the industry would lose an important set of information sources.

![Diagram of documentary information sources used](image)

**Figure 6-16: Comparison of Documentary Information Sources Used**

A comparison of the documentary sources of information also shows a striking difference in the degree to which product data is consulted in decision-making, which concurs with the previous finding on the dramatic fall in information sources from manufacturers’ representatives. However, previous work and standards are much more readily referenced now, which indicates that database and information retrieval systems better enable decision-makers to reference previous examples. It should be noted that the category of technical drawings was not included in the Patterson and Farrant (1982) survey.

A comparison of all sources together is informative in showing the changes that have occurred, and this is given in Figure 6-17.
We see that the most commonly referenced sources of information nowadays are colleagues, superiors, codes and regulations, and previous work. This is a very different pattern from that of the early 1980s, where the product representatives and product data sheets featured strongly. This indicates that the industry has become more codified and regulated and that there is more ready access to previous work. It also gives strong evidence that, despite the advances of ICT, the immediate work environment of ready access to peers for information remains vitally important in the modern digital era. A chart showing the percentage change of usage, presented in decreasing rank order, is given in Figure 4-16. It should be noted that technical drawings and project manager were not identified as categories in the Patterson and Farrant (1982) survey.
If we accept that that these results are indicative of a shift in the industry away from reliance on information embedded in manufacturers’ representatives and product data sheets towards greater use of standards, codes, regulations and previous work, then we are seeing an increase generally in the amount of codification of information. This should be interpreted with reference to works by Boisot et al. (2007) and their conceptual framework, in which the speed and extent to which information diffuses within a population of agents is a function of how far that information has been structured. The structuring of information facilitates both information processing and information transformation. This shift in the structuring of information in the engineering and construction industry could therefore be argued as demonstrating progress according to Boisot et al.’s (2007) theories. However, it would only be progress in reality if the efficacy of the more preferred modern information sources is better than in previous decades. One has to question whether information contained in a code, or previous work, would be better, about the same or possibly worse than information obtained from a human agent. Of
course, manufacturers’ representatives would seek to promote their own products and services, and codes would eliminate inherent bias.

The overall picture is one in which decisions are made in greater isolation within the supply chain, and are less integrated with those who will be responsible for delivery of the physical works. We have become more regulated, contractual and standardised, but less consultative with those in the delivery chain. This result is unsurprising given the trends over the past 30 years in the following areas:

- increasing regulations and red tape;
- proliferation of standards and codes of practice;
- emphasis in procurement practices on avoiding nominating subcontractors and specific suppliers and using generic options instead.

It is unclear whether these changes in information search strategies would have a positive or adverse impact upon outcomes within the industry. Increased use of standards should in theory help improve the quality of deliverables; however, the reduction in the degree of integration down the supply chain must be a matter for concern, and is likely to result in worsening considerations of constructability and integration of specialist know-how into design.

However, on a more positive note, it is encouraging to see increased use of previous work. This indicates increased availability and accessibility of previous work, examples, case studies, and so on. Modern database systems may have helped facilitate the capture and retention of institutional knowledge in the form of previous work and internal reports. This is likely to be a good thing; however, on its own it is insufficient to ensure improved outcomes, as the decision-maker still needs to discern the merits or otherwise of previous work. There is a risk of mindless copying of previous design work, playing it safe, rather than finding a better solution.

Overall, the picture also indicates a shift from human agents (who offer an interactive information source) to passive documentary sources. This shift is understandable given the increased availability of data at our fingertips enabled by modern technology. Our findings indicate that decision-makers, while still consulting readily with immediate colleagues in the workplace, are relying more on documentary sources than making the extra effort required to source information from elsewhere.

It is also interesting to note that in the research of Patterson and Farrant (1982), just five information sources account for half (54%) of the total information sources consulted, whereas in our current research we find that the first 50 percentile of sources is comprised of a more diverse cross-section of sources, as illustrated in Table 6-3.
Table 6-3: Comparison of the Most Commonly Consulted Information Sources

<table>
<thead>
<tr>
<th>Information Source</th>
<th>Cumulative % of All Sources</th>
<th>Information Source</th>
<th>Cumulative % of All Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer or supplier</td>
<td>16%</td>
<td>Colleague</td>
<td>10%</td>
</tr>
<tr>
<td>Colleague</td>
<td>29%</td>
<td>Superior</td>
<td>17%</td>
</tr>
<tr>
<td>Product data</td>
<td>42%</td>
<td>Codes and regulations</td>
<td>23%</td>
</tr>
<tr>
<td>Client</td>
<td>49%</td>
<td>Previous work</td>
<td>29%</td>
</tr>
<tr>
<td>Superior</td>
<td>54%</td>
<td>Technical drawings</td>
<td>34%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standards (NZ)</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technical publication</td>
<td>43%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product data</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Client</td>
<td>52%</td>
</tr>
</tbody>
</table>

Having a more diverse range of information sources that are commonly consulted is very likely to have a positive benefit on the quality of the decision-making process, as there is less likelihood for bias of opinion and errors and omissions of facts in data when using a wider range of information sources. The identification of the most commonly used information sources also gives us insight into areas of communication and information dissemination to improve in the construction industry with the aim of improving productivity.

Overall, these results indicate that systems, processes and workplace design should seek to improve the following:

- Day-to-day interactions between colleagues, superiors and clients, possibly in shared office space where staff can interact readily. Single project offices with open plan spaces, such as those implemented by Project Alliances, provide a work environment for day-to-day information flow between human agents.
- Robust, simple and effective access to key documentary information sources, ideally from shared database systems. The advent of database systems for documents such as Standards NZ (which already exist) undoubtedly helps, but there is scope for further development of databases for previous work, for example, technical drawings and product data.

6.4.5 Most Useful Sources of Information

When we asked participants to identify the best information sources, there was a clear consensus that most participants found human agents, particularly colleagues and superiors, to be of greatest assistance when making decisions, as illustrated in Figure 6-19.
Despite the significant proliferation of data and information sources, with increasingly easy access facilitated by ICT, the results indicate that intelligent human sources are still far superior. In a supplementary question, we asked participants to give qualitative reasons why the best source was particularly useful, many of which refer to the experience and knowledge of the person consulted:

*Excellent reliability, availability, relevance, timeliness, factual correctness and trustworthiness.*

*Previous experience and able to interpret implications in light of New Zealand standards and codes. Also able to help with implementing some of the work.*

*Able to use his experience to quickly identify a way of solving the problem. Was able to explain the implications and teach me how to solve similar problems in the future.*

Of the 98 participants who completed the questionnaire, 73 provided a qualitative answer to this question, and 45% of these respondents identified the experience or expertise of the other person as the reason. Hence, information is being sought that is coloured by experience, making it particularly valuable. However, with this in mind and referring back to previous findings showing a lack of consultation with the supply chain, it is disappointing that such
experience-rich information from contractors, suppliers and manufacturers is not available (or being sought) by the decision-makers.

We asked participants to rate the significance of the best and second-best sources for:

- helping with the understanding process (i.e., problem identification);
- helping with the solving process (i.e., solution identification).

Ratings were given on a five-point Likert scale and the results are given in Figure 6-20.

![Figure 6-20: Ranking of Best Sources of Information with Respect to Significance for Helping with Understanding Process and Solving Process](image)

We found that decision-makers value information that helps with the understanding process slightly more than information that helps with the solving process.

**6.4.6 Length of Time for Decision-Making**

We were interested in the overall length of time taken from start to finish of the decision, and also the amount of time taken by the decision-maker in sourcing information using different channels of communication. In separate questions, we asked in the first instance for an estimate of the overall time span of the decision-making process, and our findings are given in Figure 6-21.
It is interesting to note that approximately 40% of decisions are made in less than one day, and 70% are made in a matter of days (not weeks). The split of time using different communication channels is presented in Figure 6-22, with raw count and percentage bar graphs side by side.

Here we find that informal face-to-face communications, email and telephone are most commonly used, and also appear to be the most efficient, in the sense that the percentage of time spent is greater for these channels of communication than for other channels. However, this data does not indicate which form of communication is necessarily the most effective in helping achieve better decisions.
6.4.7 Decision Iterations

We asked participants to indicate the number of iterations made before finalising their decisions, within predetermined bands, and the results are given in Figure 6-23. We found that 80% of decisions are iterative.

![Figure 6-23: Number of Iterations before Finalising the Decision](image)

A supplementary question asked participants to describe qualitatively the reasons for the iterative nature of finalising the decisions. Of all the participants, 60 provided qualitative answers, with reasons given including coordination of decisions with others, client amendments, natural process and changing information. Of the 69 responses, 29 (i.e., approx. 50%) referred to changing information received from others:

- Discussion, new information and ongoing change until all involved parties were happy with the decision.
- Natural design process of refining the solution – taking on board feedback from reviews and comments from those consulted.
- As more people got involved then more discussions and alterations.
- Exchange of information between others.

It is clear, therefore, that the information flow process is not linear, and that there is a natural process of discovery in decision-making in which ongoing increments of increasing information (and hence knowledge) lead to reiteration on the matter in question before reaching a final decision. Only 20% of decisions are made in a linear fashion without the need for some iteration.

6.4.8 Qualitative Attributes of Information Sources

In the final part of our survey we asked participants to rank a number of predetermined attributes of information. The predetermined attributes were informed by previous work, primarily that of Gitt (2006) and our findings from the qualitative research reported in Chapter 4. Gitt (2006) identified six parameters, namely, semantic quality, relevance, timeliness,
accessibility, existence and comprehensibility. However, of these parameters, semantic quality and existence were not identified by participants in our qualitative research, but rather other factors such as accuracy and reliability were identified as important. Hence, a finalised set of information parameters were listed, as summarised in Table 6-4.

Table 6-4: Parameters of Information Included in Questionnaire

<table>
<thead>
<tr>
<th>For people sources of information, please rate the importance of the following attributes:</th>
<th>For documentary sources of information, please rate the importance of the following:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timely availability</td>
<td>Timely availability</td>
</tr>
<tr>
<td>Reliable</td>
<td>Comprehensibility</td>
</tr>
<tr>
<td>Accessible</td>
<td>Accessible</td>
</tr>
<tr>
<td>Trustworthiness</td>
<td>Reliable</td>
</tr>
<tr>
<td>Understandable/comprehensible</td>
<td>True / factually correct</td>
</tr>
<tr>
<td>Relevant/constructive towards purpose</td>
<td>Relevant / fit for use</td>
</tr>
</tbody>
</table>

We asked participants to rate the importance of these parameters on a five-point Likert scale ranging from unimportant to very important, the results of which are given in Figure 6-24 and Figure 6-25:

![Figure 6-24: Importance Ratings of Parameters for People Sources of Information](image)

Figure 6-24: Importance Ratings of Parameters for People Sources of Information
We see from these results that parameters that relate to the integrity of the information using the descriptions of reliability and trustworthiness (people courses) and true / factually correct and reliability (documentary sources) are particularly important and valuable. We also see that all parameters are in general important.

6.5 Statistical Analysis

6.5.1 Approach

A number of hypotheses were developed and tested for statistical significance and relationship using SPSS software. In this section we present our hypotheses together with the results of the statistical analyses. An alpha level of 0.05 was used for all statistical analyses, which is appropriate for the exploratory nature of this research. As a number of tests were undertaken on the same data set, a Bonferroni adjustment to the alpha level was applied to protect against Type 1 errors (Pallant, 2013). As 33 tests were undertaken, a more stringent alpha was set using Bonferroni adjustment calculated at $0.05/33 = .0015$. Significance levels are reported with exact levels of $p$ values, except where results returned $p < 0.001$. Statistically significant results are highlighted in bold text.

Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. Most of the variable scales were found to have a lack of normality, and hence the non-parametric tests were deployed to investigate relationships.

The types of decision were categorised into two main categories, namely, management ($n = 38$) and design/technical ($n = 60$) categories in order to reduce the number of types of decision variables. The reason for selecting these two categories was that they are clearly different types of decisions relevant to the context of engineering and construction. It would have been preferable to analyse the results for all 14 categories of decisions; however, a much greater sample size of data set would have been needed. Consolidation of the categories was
undertaken by consolidating the categories in Question 3, as given in Table 6-5. Reference was also made to the qualitative description of the decision given by participants as a cross-check when categorising into management and design/technical.

Table 6-5: Affinity Grouping of Decision Categories into Management and Design/Technical Primary Categories

<table>
<thead>
<tr>
<th>Question 3 Categories</th>
<th>Management</th>
<th>Design/Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td></td>
<td>Applicable</td>
</tr>
<tr>
<td>Layout / space issue</td>
<td></td>
<td>Applicable</td>
</tr>
<tr>
<td>Physical works / construction</td>
<td></td>
<td>Applicable</td>
</tr>
<tr>
<td>Project management related</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Choice of materials or system</td>
<td></td>
<td>Applicable</td>
</tr>
<tr>
<td>Use of human resources (labour)</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Implementation methodology</td>
<td></td>
<td>Applicable</td>
</tr>
<tr>
<td>Investment decision</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Procurement decision</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Coordination</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Risk mitigation / risk management decision</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Use of capital resources (plant and equipment)</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>Contractual related</td>
<td>Applicable</td>
<td></td>
</tr>
<tr>
<td>General management</td>
<td>Applicable</td>
<td></td>
</tr>
</tbody>
</table>

Scales for ‘total of self contributions to the decision’ and for ‘total of others’ contribution to the decision’ were generated from the questionnaire results. ‘total of self contributions to the decision’ was constructed as a sum of 1–5 rating scales for the five categories reported in Section 6.4.3, and ‘total of others’ contribution to the decision’ was constructed as a sum of 1–5 rating scales for the five categories reported in Section 6.4.3. Internal consistency of the scales was checked using Cronbach alpha tests, with coefficients of 0.70 and 0.74 respectively, indicating acceptable levels of internal consistency.

A scale for ‘total of constraints’ was also constructed. Internal consistency of the scale was checked using a Cronbach alpha test, with coefficients of 0.69, indicating a very slightly below acceptable level of internal consistency (Cronbach alpha > 0.7 desirable) however the scale was used given the very close coefficient.

6.5.2 Statistical Hypothesis Testing

A series of hypotheses were generated and are presented in the following sections. Each hypothesis is presented with a null and an alternative, followed by a rationale and the findings of the relevant statistical test. A summary of the various tests is given in Figure 6-26.
<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Type of Hypothesis</th>
<th>Test for Difference</th>
<th>Significance</th>
<th>Bold text in results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis 01</td>
<td>Differences in</td>
<td>Mann-Whitney U test</td>
<td>U = 714, z = -.73, p = .472</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 02</td>
<td>Differences in</td>
<td>Mann-Whitney U test</td>
<td>U = 581, z = -3.21, p &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 03</td>
<td>Differences in</td>
<td>Mann-Whitney U test</td>
<td>U = 701, z = -3.22, p &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 04</td>
<td>Differences in</td>
<td>Mann-Whitney U test</td>
<td>U = 701, z = -3.22, p &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 05</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 69) = 21.21, p &lt; .001</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 06</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 07</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 84) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 08</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 09</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 10</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 11</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 12</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 13</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 14</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 15</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 84) = 9.74, p = .045</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 16</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 98) = 9.74, p = .045</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 17</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 98) = 9.74, p = .045</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 18</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 98) = 9.74, p = .045</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 19</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 98) = 9.74, p = .045</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 20</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 21</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (3, n = 98) = 10.74, p = .013</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 22</td>
<td>Differences in</td>
<td>Chi-Sq Test</td>
<td>Chi-Sq (4, n = 98) = 9.74, p = .045</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 23</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 24</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 25</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 26</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 27</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 28</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 29</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 30</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 31</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 32</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 33</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 34</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 35</td>
<td>Differences in</td>
<td>Spearman rho</td>
<td>rs = .25, n = 44, p = .05</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-26: Matrix of Statistical Hypotheses and Tests
**Null Hypothesis H01:** There is no difference between the amount of people information sources used in management-related decisions and that used in design/technical decisions.

**Alternative Hypothesis H01:** People information sources are used to a greater extent in management-related decisions than design/technical-related decisions.

In Hypothesis H01 we made a conjecture that management-related decisions would require greater degrees of consultation with people than design/technical-related decisions, on the basis that management issues are more people oriented in factors such as obtaining agreements, building consensus and motivation of people.

A Mann-Whitney U test was conducted to compare the number of people information sources for the two types of decision. For people information sources, there was a statistically significant difference in scores for management-related decisions ($Md = 7.5$, $n = 38$) and design/technical decisions ($Md = 4.0$, $n = 60$); $U = 701$, $z = -3.22$, $p = .001$, $r = .32$. The magnitude of the difference is medium using Cohen’s (1988) criteria.

Hence, the Null Hypothesis H01 was rejected.

**Null Hypothesis H02:** There is no difference between the amount that documentary information sources are used in design/technical decisions and that used in management-related decisions.

**Alternative Hypothesis H02:** Documentary sources are used to a greater extent in design/technical decisions than in management-related decisions.

In Hypothesis H02 we made a conjecture that design/technical decisions would be more likely to require reference to documentary sources of information (e.g., technical documents, codes and specifications) than management-related decisions.

A Mann-Whitney U test was conducted to compare the number of documentary information sources for the two types of decisions. For documentary information sources there was no statistical significant difference at the $p < .0015$ level, with scores for management-related decisions ($Md = 5.0$, $n = 38$) and design/technical decisions ($Md = 4.0$, $n = 60$); $U = 978$, $z = -1.19$, $p = .24$, $r = .12$. The magnitude of the difference is small using Cohen’s (1988) criteria.

Hence, there was failure to reject the Null Hypothesis H02.

**Null Hypothesis H03:** There is no difference between the amount of time needed to make management-related decisions and that needed to make design/technical decisions.

**Alternative Hypothesis H03:** Management-related decisions take longer to make than design/technical decisions.

In Hypothesis H03 we made a conjecture that management-related decisions would take longer than design/technical-related decisions, on the basis that management issues typically require more consultation time with people.

A Mann-Whitney U test was conducted to compare the ‘Overall time span of the decision-making process’ for the two types of decisions. There was no statistical significant difference at the $p < .0015$ level, with scores for management-related decisions ($Md = 3.0$, $n = 28$) and
design/technical decisions \( (Md = 3.0, n = 56); U = 970, z = -.14, p = .88, r = .01 \). The magnitude of the difference is small using Cohen’s (1988) criteria.

Hence, there was failure to reject the Null Hypothesis \( H_{03} \).

**Null Hypothesis \( H_{04} \):** There is no difference between the number of iterations taken in management-related decisions and that taken in design/technical decisions.

**Alternative Hypothesis \( H_{a4} \):** Management-related decisions require a greater number of iterations than design/technical decisions.

In Hypothesis \( H_{04} \) we made a conjecture that a greater number of iterations would be required before finalising management-related decisions than design/technical decisions, as they are more likely to be iterative based on subjective information, whereas technical decision-making is by contrast more objective.

A Mann-Whitney U test was conducted to compare the number of iterations before finalising the decision. There was no statistical significant difference at the \( p < .0015 \) level, with scores for management-related decisions \( (Md = 2.0, n = 28) \) and design/technical decisions \( (Md = 2.0, n = 56); U = 714, z = -.73, p = .47, r = .08 \). The magnitude of the difference is small using Cohen’s (1988) criteria.

Hence, there was failure to reject the Null Hypothesis \( H_{04} \).

**Null Hypothesis \( H_{05} \):** There is no association between ‘role’ and likelihood of making management-related decisions rather than design/technical decisions.

**Alternative Hypothesis \( H_{a5} \):** There is an association between ‘role’ and likelihood of making management-related decisions rather than design/technical decisions.

In Hypothesis \( H_{05} \) we made a conjecture that management-related decisions would be more likely to be taken by senior grades of staff on the rationale that higher levels of experience and responsibility are needed for making management-related decisions. Roles were categorised as executive, senior, middle, junior and support/admin/trainee.

A \( 2 \times 5 \) chi-square test for independence indicated no statistical significant association at the \( p < .0015 \) level between type of decision and seniority of role, \( \chi^2 (4, n = 98) = 7.48, p = .112, V = 0.28 \). A possible reason for this is that the type of decision is not a function of seniority.

The data was structured in such a way that enabled an alternative classification of roles as management, design/technical and support/admin/trainee. Executives were classed as management.

A \( 2 \times 3 \) chi-square test for independence indicated statistical significant association between type of decision and role in the alternative classification, \( \chi^2 (2, n = 98) = 32.6, p < .001, V = 0.58 \). The strength of the association is large.

Hence, the Null Hypothesis \( H_{05} \) was rejected.
Null Hypothesis H06: There is no difference between management- and design/technical-related decisions in the amounts of time spent using the different channels of communication with people.

Alternative Hypothesis H06a: There is a difference between management- and design/technical-related decisions in the amounts of time spent using the different channels of communication with people.

In Hypothesis H06 we made a conjecture that there would be no difference in the amounts of time spent using different communication channels between management-related decisions and design/technical-related decisions. The basis of the hypothesis was that all decision-makers are likely to deploy multiple communication strategies equally.

A series of Mann-Whitney U tests were conducted to compare the time spent in informal face-to-face, formal meetings, workshops, email, telephone, video conferencing and web-based communication. The was no statistical significant difference at the \( p < .0015 \) in any categories of people information sources.

Hence, there was a failure to reject the Null Hypothesis H06.

Null Hypothesis H07: There is no difference between management-related and design/technical-related decisions in the amounts of time spent accessing different documentary sources of information.

Alternative Hypothesis H07a: There is a difference between management- and design/technical-related decisions in the amounts of time spent accessing different documentary sources of information.

Hypothesis 07 is similar to Hypothesis 06.

A series of Mann-Whitney U tests were conducted to compare the time spent accessing information. There was no statistically significant difference at the \( p < .0015 \) in all categories of documentary sources of information.

Hence, there was a failure to reject the Null Hypothesis H07.

Null Hypothesis H08: There is no difference between management- and design/technical-related decisions in the importance of information attributes for people information sources.

Alternative Hypothesis H08a: There is a difference between management- and design/technical-related decisions in the importance of information attributes for people information sources.

In Hypothesis H08 we made a conjecture that there would be no difference in the importance of information attributes for people information sources between management- and design/technical-related decisions, on the basis that the attributes of information are inherently of equal importance irrespective of the type of decision being made.

A Mann-Whitney U test was conducted on the total importance scale of information from people sources. There was no statistical significant difference at the \( p < .0015 \) level, with scores for management-related decisions (\( Md = 25.0, n = 15 \)) and design/technical decisions (\( Md = 25.5, n = 28 \)); \( U = 197, z = -.33, p = .74, r = .05 \). The magnitude of the difference is small using Cohen’s (1988) criteria.
Hence, there was a failure to reject the Null Hypothesis H0₉₀.

Null Hypothesis H0₉₀: There is no difference between management- and design/technical-related decisions in the importance of information attributes for people information sources.

Alternative Hypothesis H0₉₀: There is a difference between management- and design/technical-related decisions in the importance of information attributes for people information sources.

In Hypothesis H0₉₀ we made a conjecture that there would be no difference in the importance of information attributes for documentary information sources between management- and design/technical-related decisions, on the basis that the attributes of information are inherently of equal importance irrespective of the type of decision being made.

A Mann-Whitney U test was conducted on the total importance scale of information from documentary sources. There was no statistical significant difference at the \( p < .0015 \) level, with scores for management-related decisions (\( Md = 32.0, n = 15 \)) and design/technical decisions (\( Md = 30.5, n = 28 \)); \( U = 180, z = -.75, p = .41, r = .11 \). The magnitude of the difference is small using Cohen’s (1988) criteria.

Hence, there was a failure to reject the Null Hypothesis H0₉₀.

Null Hypothesis H1₀₀: In making a decision there is no correlation between the ‘total number of people information sources used’ and the ‘total of constraints’.

Alternative Hypothesis H1₀₀: In making a decision there is a positive correlation between the ‘total number of people information sources used’ and the ‘total of constraints’.

In Hypothesis H1₀₀ we made a conjecture that there would be a positive correlation between the ‘total number of people information sources used’ and the ‘total of constraints’, on the rationale that the greater the constraints relating to the decision then the more people that would need to be consulted to find solutions to the constraints.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and strong positive correlation between the two variables, \( r_s = .63, n = 98, p < .001 \), with high total of constraints being associated with high total of people information sources.

Hence, the Null Hypothesis H1₀₀ was rejected.

Null Hypothesis H1₁₀₀: In making a decision there is no correlation between the ‘total number of documentary information sources used’ and the ‘total of constraints’.

Alternative Hypothesis H1₁₀₀: In making a decision there is a positive correlation between the ‘total number of documentary information sources used’ and the ‘total of constraints’.

Hypothesis H1₁₀₀ is similar to Hypothesis H1₀₀ with a similar rationale.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and medium positive correlation between the two variables, \( r_s = .47, n = 98, p < .001 \), with high total of constraints being associated with high total of documentary information sources.

Hence, the Null Hypothesis H1₁₀₀ was rejected.
Null Hypothesis H12\(0\): In making a decision there is no correlation between the ‘overall time span of the decision-making process’ and the ‘total of constraints’.

Alternative Hypothesis H12\(a\): In making a decision there is a positive correlation between the ‘overall time span of the decision-making process’ and the ‘total of constraints’.

In Hypothesis H12 we made a conjecture that there would be a positive correlation between the overall time span in making a decision and the ‘total of constraints’, on the rationale that the greater the constraints relating to the decision then the longer needed to obtain necessary information for decision-making.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and medium positive correlation between the two variables, \(r_s = .35, n = 84, p < .001\), with high total of constraints being associated with longer time spans.

Hence, the Null Hypothesis H12\(0\) was rejected.

Null Hypothesis H13\(0\): In making a decision there is no correlation between the ‘number of iterations’ and the ‘total of constraints’.

Alternative Hypothesis H13\(a\): In making a decision there is a positive correlation between the ‘number of iterations’ and the ‘total of constraints’.

In Hypothesis H13 we made a conjecture that there would be a positive correlation between the number of iterations taken in making a decision and the ‘total of constraints’, on the rationale that the greater the constraints relating to the decision then the more iterations will be necessary to satisfy the constraints.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a medium positive correlation between the two variables but it failed to reach statistical significance at the \(p < .0015\) level, \(r_s = .25, n = 84, p = .02\).

Hence, there was a failure to reject the Null Hypothesis H13\(0\).

Null Hypothesis H14\(0\): There is no correlation between ‘total of self contribution’ and ‘total of others’ contribution’ to a decision.

Alternative Hypothesis H14\(a\): There is a correlation between ‘total of self contribution’ and ‘total of others’ contribution’ to a decision.

In Hypothesis H14 we made a conjecture that there would be a correlation between the ‘total of self contribution’ and ‘total of others’ contribution’ to the decision. The rationale of the hypothesis was that decision-makers who rate their own contribution to a decision highly are less likely to seek information from others before making their decision than those who rate their own contribution to a lower degree. In other words, people use a compensatory strategy and seek the help of others when they are less sure of their own knowledge, skills and experience, and so on.

The relationship between ‘total of self contributions to the decision’ with ‘total of others’ contribution to the decision’ was investigated using Spearman’s rank-order correlation coefficient. There was a medium positive correlation between the two variables, \(r_s = .43, n = 95\),
p < .001, with high levels of self contribution to decision associated with high levels of contribution by others.

While correlation was found, the correlation was in the opposite direction to expectations. A possible explanation for this finding is that the importance of the decision and the strength of the constraints may demand simultaneous contributions to decisions by self and others. A strategic decision, for example, is likely to involve significant contributions by self and others. Another possible reason is that experienced decision-makers develop skills in bringing both their own and others' contributions to decisions simultaneously, whereas less experienced decision-makers may deploy less rigorous approaches to their decision-making. Further investigation was undertaken to analyse the strength of the correlation for different staff grades, and the results are given in Table 6-6.

Table 6-6: Spearman’s Rank-Order Correlation Results for ‘Total of Self Contribution’ and ‘Total of Others’ Contribution’ to the Decision at Different Staff Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>rs</th>
<th>n</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive</td>
<td>.795</td>
<td>9</td>
<td>.010</td>
</tr>
<tr>
<td>Senior grade</td>
<td>.519</td>
<td>35</td>
<td>.001</td>
</tr>
<tr>
<td>Middle grade</td>
<td>.384</td>
<td>29</td>
<td>.040</td>
</tr>
<tr>
<td>Junior grade</td>
<td>.381</td>
<td>15</td>
<td>.162</td>
</tr>
<tr>
<td>Support/admin/trainee grade</td>
<td>.118</td>
<td>7</td>
<td>.801</td>
</tr>
</tbody>
</table>

While there is a clear pattern in the strength of the relationship, it is not possible to test the statistical significance of the differences because of lack of normality in the distribution of ‘total of others’ contribution’ to the decision and limited sample size of some of the staff grades. These results can only be interpreted as indicative and further research is needed to test further hypotheses in this area. Overall, however, there is a correlation at statistical significance.

Hence, the Null Hypothesis H14\textsubscript{0}: There is no relationship between ‘total of self contribution’ to a decision and seniority of ‘role’.

Alternative Hypothesis H15\textsubscript{a}: There is a positive relationship between ‘total of self contribution’ and seniority of ‘role’.

In Hypothesis H15 we made a conjecture that there would be a positive relationship between ‘total of self contributions to the decision’ and the seniority of ‘role’, on the rationale that the more senior the person the more experience, skills and self-confidence they would bring to bear in the decision-making process.

A Kruskal-Wallis test revealed no statistically significant difference at the p < .0015 level in ‘total of self contributions to the decision’ across the five levels of ‘role’ seniority (Gp1, n = 9: executives, Gp2, n = 38: senior, Gp3, n = 29: middle, Gp4, n = 15: junior, Gp5, n = 7: support/admin/trainee), \( \chi^2 \) (4, n = 98) = 9.74, p = .045. The median scores for the groups followed level of seniority (Md = 20, 16, 15, 12, 13 respectively).
Hence, there was a failure to reject the Null Hypothesis $H_{15_0}$.

*Null Hypothesis $H_{16_0}$: There is no relationship between ‘total of self contribution’ to a decision and the ‘number of employees’ in the organisation in which the decision-maker works.*

*Alternative Hypothesis $H_{16_a}$: There is a relationship between ‘total of self contribution’ and ‘number of employees’.*

In Hypothesis H16 we made a conjecture that there would be no relationship between ‘total of self contributions’ to the decision and the size of the employing organisation (measured by ‘number of employees’), on the rationale that decision-makers’ contributions are made irrespective of the size of the employer.

A Kruskal-Wallis test revealed no statistically significant difference at the $p < .0015$ level in ‘total of self contributions’ to the decision across the four bands of number of employees ($G_{p1}$, $n = 7$: 1–5 employees, $G_{p2}$, $n = 6$: 6–15 employees, $G_{p3}$, $n = 34$: 26–250 employees, $G_{p4}$, $n = 50$: > 250 employees), $\chi^2(3, n = 98) = 10.74, p = .013$.

Hence, there was a failure to reject the Null Hypothesis $H_{16_0}$.

*Null Hypothesis $H_{17_0}$: There is no correlation between the ‘total of others’ contribution’ to a decision and ‘total number of people information sources’ used.*

*Alternative Hypothesis $H_{17_a}$: There is a positive correlation between ‘total of others’ contribution’ to a decision and ‘total number of people information sources’ used.*

In Hypothesis H17 we made a conjecture that there would be a positive correlation between the ‘total of others’ contribution’ to the decision and the ‘total number of people information sources’ consulted, on the rationale that the greater the number of people consulted the more likely it is that their contribution to the decision will be more substantial.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and medium positive correlation between the two variables, $r_s = .41, n = 95, p < 0.001$, with high total of others’ contribution being associated with more people being consulted.

Hence, the Null Hypothesis $H_{17_0}$ was rejected.

*Null Hypothesis $H_{18_0}$: There is no relationship between ‘total of others’ contribution’ to a decision and seniority of ‘role’.*

*Alternative Hypothesis $H_{18_a}$: There is an inverse relationship between ‘total of others’ contribution’ and seniority of ‘role’.*

In Hypothesis H18 we made a conjecture that there would be an inverse relationship between ‘total of others’ contributions’ to the decision and the seniority of ‘role’, on the rationale that the less senior the person the more the person would confer with superiors and others to help with decision-making.

A Kruskal-Wallis test revealed no statistically significant difference at the $p < .0015$ level in ‘total of others’ contributions’ to the decision across the five levels of ‘role’ seniority ($G_{p1}$, $n = 9$:...

Hence, there was a failure to reject the Null Hypothesis $H_{18}$.

**Null Hypothesis $H_{18}$:** There is no relationship between ‘total of others’ contribution’ to a decision and the ‘number of employees’ in the organisation in which the decision-maker works.

**Alternative Hypothesis $H_{18}$:** There is an inverse relationship between ‘total of others’ contribution’ to a decision and the ‘number of employees’.

In Hypothesis $H_{18}$ we made a conjecture that there would be no relationship between ‘total of others’ contribution’ to the decision and the size of the employing organisation (measured by ‘number of employees’), on the rationale that contributions from others are made irrespective of the size of the organisation.

A Kruskal-Wallis test revealed no statistically significant difference at the $p < .0015$ level in ‘total of others’ contribution’ to the decision across the four bands of number of employees (Gp1, $n = 7$: 1–5 employees, Gp2, $n = 6$: 6–15 employees, Gp3, $n = 34$: 26–250 employees, Gp4, $n = 50$: > 250 employees), $\chi^2(3, n = 98) = 4.41, p = .221$.

Hence, there was a failure to reject the Null Hypothesis $H_{18}$.

**Null Hypothesis $H_{19}$:** There is no correlation between ‘total of others’ contribution’ to a decision and ‘total time spent using communication channels’.

**Alternative Hypothesis $H_{19}$:** There is a positive correlation between ‘total of others’ contribution’ to a decision and ‘total time spent using communication channels’.

In Hypothesis $H_{19}$ we made a conjecture that there would be a positive correlation between the ‘total of others’ contribution’ to the decision and the ‘total time spent using communication channels’, on the rationale that the greater the amount of time spent communicating the greater the contribution of others to a decision.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a medium positive correlation between the two variables, but it failed to reach statistical significance at the $p < .0015$ level, $r_s = .37, n = 44, p = .013$.

Hence, there was a failure to reject the Null Hypothesis $H_{19}$.

**Null Hypothesis $H_{20}$:** There is no correlation between the ‘total number of people information sources’ and the ‘total number of documentary information sources’ used in making a decision.

**Alternative Hypothesis $H_{20}$:** There is a positive correlation between the ‘total number of people information sources’ and the ‘total number of documentary information sources’ used in making a decision.

In Hypothesis $H_{20}$ we made a conjecture that there would be a positive correlation between the ‘total number of information sources’ and the ‘total number of documentary sources’ used in making a decision. The rationale was that information seekers deploy multiple information search strategies, and that seekers who are attempting to extract a lot of information from
available sources will search from people and documentary sources simultaneously. This hypothesis was informed in advance by the findings of H14.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and large positive correlation between the two variables, \( r_s = .58, n = 98, p < .001 \).

Hence, the Null Hypothesis H21 was rejected.

Null Hypothesis H22: There is no correlation between the ‘overall time span of the decision-making process’ and the ‘number of iterations’.

Alternative Hypothesis H22: There is a positive correlation between the ‘overall time span of the decision-making process’ and the ‘number of iterations’.

In Hypothesis H22 we made a conjecture that there would be a positive correlation between the ‘overall time span of the decision-making process’ and the ‘number of iterations’. The rationale of the hypothesis was that the greater the number of iterations necessary before finalising a decision the greater the overall time span is likely to be.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and strong positive correlation between the two variables, \( r_s = .53, n = 84, p < .001 \), with high numbers of iterations being associated with longer overall time spans.

Hence, the Null Hypothesis H22 was rejected.

Null Hypothesis H23: There is no correlation between the monetary ‘value of the decision in $s’ and the ‘overall time span of the decision-making process’.

Alternative Hypothesis H23: There is a positive correlation between monetary ‘value of the decision in $s’ and the ‘overall time span of the decision-making process’.

In Hypothesis H23 we made a conjecture that there would be a positive correlation between the ‘value of the decision in $s’ and the ‘overall time span of the decision-making process’. The rationale of the hypothesis was that the greater the monetary value of the decision the longer the overall time span is likely to be because of the relative financial importance.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a medium positive correlation between the two variables, but it failed to reach statistical significance at the \( p < .0015 \) level, \( r_s = .32, n = 61, p = .012 \).

Hence, there was a failure to reject the Null Hypothesis H23.

Null Hypothesis H24: There is no relationship between the ‘overall time span of the decision-making process’ and seniority of ‘role’.

Alternative Hypothesis H24: There is an inverse relationship between the ‘overall time span of the decision-making process’ and seniority of ‘role’.

In Hypothesis H24 we made a conjecture that there would be no relationship between ‘overall time span of the decision-making process’ and the seniority of ‘role’, on the rationale that decision-makers do not necessarily have control of the overall time span.
A Kruskal-Wallis test revealed no statistically significant difference at the $p < .0015$ level in ‘overall time span of the decision-making process’ across the five levels of role seniority (Gp1, $n = 6$: executives, Gp2, $n = 31$: senior, Gp3, $n = 26$: middle, Gp4, $n = 14$: junior, Gp5, $n = 7$: support/admin/trainee), $\chi^2 (4, n = 84) = 9.66, p = .047$. The median scores for the groups followed level of seniority ($Md = 4, 3, 2.5, 3, 1$ respectively).

Hence, there was a failure to reject the Null Hypothesis H24$_0$.

<table>
<thead>
<tr>
<th>Null Hypothesis H25$_0$: There is no correlation between ‘overall time span of the decision-making process’ and ‘total time spent using communication channels’.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Hypothesis H25$_a$: There is a positive correlation between ‘overall time span of the decision-making process’ and ‘total time spent using communication channels’.</td>
</tr>
</tbody>
</table>

In Hypothesis H25 we made a conjecture that there would be a positive correlation between the ‘overall time span of the decision-making process’ and ‘total time spent using communication channels’, on the rationale that the greater the amount of time spent communicating the longer the overall period needed to finalise the decision.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and strong positive correlation between the two variables, $r_s = .64, n = 44, p < .001$, with high time spent using communication channels associated with a longer overall time span for the decision-making process.

Hence, the Null Hypothesis H25$_0$ was rejected.

<table>
<thead>
<tr>
<th>Null Hypothesis H26$_0$: There is no correlation between ‘overall time span of the decision-making process’ and ‘total time spent finding documentary sources’ of information.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Hypothesis H26$_a$: There is a positive correlation between ‘overall time span of the decision-making process’ and ‘total time spent finding documentary sources’ of information.</td>
</tr>
</tbody>
</table>

In Hypothesis H26 we made a conjecture that there would be a positive correlation between ‘overall time span of the decision-making process’ and ‘total time spent finding documentary sources’ of information, on the rationale that the greater the amount of time spent finding information the longer the overall period needed to finalise the decision.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and strong positive correlation between the two variables, $r_s = .53, n = 44, p < .001$, with high time spent finding documentary sources of information being associated with a longer overall time span for the decision-making process.

Hence, the Null Hypothesis H26$_0$ was rejected.
Null Hypothesis H27.\( _0 \): There is no relationship between the ‘stage of the project at the time of the decision’ and the ‘number of iterations’ needed to finalise the decision.

Alternative Hypothesis H27.\( _a \): There is a relationship between the ‘stage of the project at the time of the decision’ and the ‘number of iterations’ needed to finalise the decision.

In Hypothesis H27 we made a conjecture that there would be no relationship between ‘stage of the project at the time of the decision’ and the ‘number of iterations’, on the rationale that the stage of a project has no bearing on the decision-making process for an individual decision.

A Kruskal-Wallis test revealed no statistically significant difference at the \( p < .0015 \) level in ‘number of iterations’ across the four bands of ‘stage of the project at the time of the decision’ (Gp1, \( n = 12 \): pre-design feasibility, Gp2, \( n = 40 \): design, Gp3, \( n = 15 \): tender and construction, Gp4, \( n = 2 \): post construction), \( \chi^2 (3, n = 69) = 2.83, p = .419 \).

Hence, there was a failure to reject the Null Hypothesis H27.\( _0 \).

Null Hypothesis H28.\( _0 \): There is no correlation between the monetary ‘value of the decision in $s’ and the ‘number of iterations’.

Alternative Hypothesis H28.\( _a \): There is a positive correlation between monetary ‘value of the decision in $s’ and the ‘number of iterations’.

In Hypothesis H28 we made a conjecture that there would be a positive correlation between the ‘value of the decision in $s’ with the ‘number of iterations’. The rationale of the hypothesis was that the greater the monetary value of the decision the larger the number of iterations is likely to be because of the relative importance.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a small positive correlation but it failed to reach statistical significance at the \( p < .0015 \) level, \( r_s = .30, n = 61, p = .021 \).

Hence, there was a failure to reject the Null Hypothesis H28.\( _0 \).

Null Hypothesis H29.\( _0 \): There is no correlation between the monetary ‘value of the project in $s’ and ‘number of iterations’.

Alternative Hypothesis H29.\( _a \): There is a positive correlation between monetary ‘value of the project in $s’ and ‘number of iterations’.

In Hypothesis H29 we made a conjecture that there would be no relationship between the ‘value of the project in $s’ with the ‘number of iterations’, on the rationale that the value of the project has no direct bearing upon the value of the individual decision or the decision-making process.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was no statistically significant correlation between the two variables, \( r_s = .25, n = 53, p = .071 \).

Hence, there was a failure to reject the Null Hypothesis H29.\( _0 \).
Null Hypothesis H30: There is no relationship between the ‘number of iterations’ taken in making a decision and seniority of ‘role’.

Alternative Hypothesis H30: There is a relationship between the ‘number of iterations’ taken in making a decision and seniority of ‘role’.

In Hypothesis H30 we made a conjecture that there would be no relationship between ‘number of iterations’ and the seniority of ‘role’, on the rationale that causal factors for iterations are unlikely to be linked to the seniority of the decision-maker.

A Kruskal-Wallis test revealed no statistically significant difference at the p < .0015 level in ‘number of iterations’ across the five levels of ‘role’ seniority (Gp1, n = 6: executives, Gp2, n = 31: senior, Gp3, n = 26: middle, Gp4, n = 14: junior, Gp5, n = 7: support/admin/trainee), \( \chi^2 (4, n = 84) = 9.85, p = .043 \). The median scores for the groups followed level of seniority (Md = 3, 2, 2, 2, 2 respectively).

Hence, there was a failure to reject the Null Hypothesis H30.

Null Hypothesis H31: There is no correlation between ‘age’ and seniority of ‘role’.

Alternative Hypothesis H31: There is a positive correlation between ‘age’ and seniority of ‘role’.

In Hypothesis H31 we made a conjecture that there would be a positive correlation between ‘age’ and seniority of the ‘role’, on the rationale that greater seniority demands greater levels of experience and hence age.

The relationship between the variables was investigated using Spearman’s rank-order correlation coefficient. There was a statistically significant and large positive correlation, \( r_s = .74, n = 85, p < .001 \), with higher levels of seniority being associated with older ages.

Although this finding was somewhat trivial, the strong correlation means it is unnecessary to undertake tests between age and other variables. Role is of more interest than age per se, and hence other tests focus on seniority of ‘role’, rather than ‘age’.

Hence, the Null Hypothesis H31 was rejected.

Null Hypothesis H32: There is no relationship between the ‘total time spent using communication channels’ and seniority of ‘role’.

Alternative Hypothesis H32: There is a relationship between the ‘total time spent using communication channels’ and seniority of ‘role’.

In Hypothesis H32 we made a conjecture that there would be no relationship between the ‘total time spent using communication channels’ and seniority of ‘role’, on the rationale that decision-makers of all levels of seniority will deploy search patterns to suit the needs of the decision irrespective of their seniority.

A Kruskal-Wallis test revealed no statistically significant difference at the p < .0015 level in ‘time spent using different communication channels’ across the five levels of role seniority (Gp1, n = 5: executives, Gp2, n = 10: senior, Gp3, n = 16: middle, Gp4, n = 7: junior, Gp5, n = 6: support/admin/trainee), \( \chi^2 (4, n = 44) = 16.14, p = .003 \). The median scores for the groups
followed level of seniority (Md = 24, 21, 14, 9, 6 respectively). While the results are not statistically significant at the \( p < .0015 \) level, they would have been significant at the \( p < .05 \) level and the low alpha level set has increased the risk of making a Type 2 error (Pallant, 2013). Therefore, this result needs to be interpreted with care. There is a trend in the relationship of the median scores for the groups, with a higher median score being associated with higher levels of seniority. A possible explanation could be that senior people are more likely to be involved in the harder decisions than the easier routine decisions; however, this is not proven and requires further research.

Hence, there was a failure to reject the Null Hypothesis \( H_{320} \) (but is worthy of further study given that \( p = .003 \)).

**Null Hypothesis \( H_{330} \): There is no relationship between the ‘total time spent finding documentary sources’ and seniority of ‘role’.

**Alternative Hypothesis \( H_{33a} \): There is a relationship between the ‘total time spent finding documentary sources’ and seniority of ‘role’.

In Hypothesis \( H_{33} \) we made a conjecture that there would be no relationship between the ‘total time spent finding documentary sources’ and seniority of ‘role’, on the same rationale as \( H_{32} \).

A Kruskal-Wallis test revealed no statistically significant difference at the \( p < .0015 \) level in ‘time spent finding different documentary sources’ across the five levels of role seniority (Gp1, \( n = 5 \): executives, Gp2, \( n = 10 \): senior, Gp3, \( n = 16 \): middle, Gp4, \( n = 7 \): junior, Gp5, \( n = 6 \): support/admin/trainee), \( \chi^2 \) (4, \( n = 44 \)) = 11.37, \( p = .023 \). The median scores for the groups followed level of seniority (Md = 33, 17, 16, 12, 5 respectively). These results are similar to those for Hypothesis \( H_{32} \) and similar interpretation needs to be taken.

Hence, there was a failure to reject the Null Hypothesis \( H_{330} \). (but is worthy of further study given that \( p = .023 \)).

**6.5.3 Summary of Findings from Statistical Testing**

A review of the findings of the various hypotheses indicates the following:

Hypotheses \( H_{01} \) to \( H_{09} \) tested for differences between management- and design/technical-related decisions with respect to uses of information. The findings show there is little difference between the types of decisions, except the finding that decision-makers are more likely to consult with people information sources for management-related decisions than they are for design/technical-related decisions. There is also a statistically significant association between roles and types of decision, but such association is somewhat trivial and not of prime interest in our research. What is of more relevance is the finding that there is little difference in information search patterns between the different types of decisions.

Hypotheses \( H_{10} \) to \( H_{13} \) tested the relationships between strength of constraints with the information search patterns deployed by decision-makers. Findings of statistical significance show that the stronger the constraints the more intensive the information search efforts become.
Hypotheses H14 to H20 explored the relationships between own and others’ contributions to decisions with factors of roles and employer size. Hypothesis 14 returned the most interesting result, at a statistical significance level, with high levels of self contribution to decisions associated with high levels of contribution by others. This finding indicates that the information search strategies employed by decision-makers are not compensatory between own and others’ contributions. Other factors must therefore determine the extent to which decision-makers rely on contributions from others. There was a correlation between others’ contribution and people information sources, which could indicate that people who are more networked with others value the contributions from others to a higher extent. Another possible explanation is that experienced decision-makers develop skills in bringing both their own and others’ contributions to decisions simultaneously. Other tests failed to reach statistical significance.

Hypothesis H21 found that there is a positive correlation between the ‘total number of people information sources’ and the ‘total number of documentary information sources’ used in making a decision. A possible explanation is that information seekers deploy multiple information search strategies, and that the seekers who are attempting to extract a lot of information from available sources would search in people and documentary sources simultaneously. This hypothesis probably concurs with the result for Hypothesis H14.

Hypotheses H22 to H26 explored the relationships of the ‘overall time span of decision-making process’ with factors such as ‘number of iterations’ and ‘values of the decision in $s’ and ‘total time spent using communication channels’. Duration of decision-making is implicitly connected with efficiency and hence of special interest for our research into information flow and productivity. Of particular interest is the strong correlation between the overall timespan and the number of iterations (Hypothesis H22), which indicates that the greater the iterative nature of iterations to a decision the longer the duration. Cause and effect are not proven with statistical tests and while the number of iterations may at face value be the cause, leading to longer durations, there could also be an effect in which longer durations allow for a decision to lead to more iterative fine-tuning of the decision (i.e., the number of iterations fill the time allowed). More research is needed to understand the cause and effect, and this could be an interesting direction for further investigation.

Hypotheses H27 to H30 explored the relationships of numbers of iterations for decisions with different factors. The findings indicated that factors associated with the number of iterations for a decision are outside of the project factors for stage of the project and value of project in monetary value. H13 is also of interest in this respect as it failed to find statistical significance in the relationship between the number of iterations and the number of constraints to the decision. The number of iterations is also not related to the monetary value of the decision at a statistically significant level. Other factors that have not been included in this study are therefore likely to be influencing the number of iterations.

Hypotheses H31 to H33 explored the relationships between role, age and times taken in information searches. The relationship between role and information search patterns revealed
patterns in which the higher the seniority of role the greater the time taken in a search for information (both people and documentary sources). However, the tests failed to reach statistical significance at the $p < .0015$ level. Collection of a separate data set asking the same questions could help resolve the statistical significance.

While the results for a number of the tests were not statistically significant at the $p < .0015$ level, they would have been significant at the $p < .05$ level, and the low alpha level set in order to limit the risk of a Type 1 error has increased the risk of making a Type 2 error (Pallant, 2013). Therefore, careful interpretation of statistical significance needs to be made for results where $p > .0015$ and $p < .05$. Collection of additional more-targeted data to test these hypotheses is therefore recommended in order to clarify the statistical significance.

6.6 Discussion

From the rich data set presented in the previous sections, some useful information can be extracted. Developing themes are offered in this discussion section, presented in no particular order of priority.

Firstly, it is evident that there have been a number fundamental changes in the way decision-makers in engineering and construction access information in the period between when Patterson and Farrant (1982) undertook their research and when we undertook ours. Examples include the dramatic reduction in frequencies with which participants acknowledge inputs from product data sheets and manufacturers’ representatives. Other examples include the increased use of standards, codes and regulations, and previous reports. These findings are not particularly surprising given the significant changes in technology available to the vast majority of the modern workforce, not least of which are personal computers, access to information online via internet and databases, and modern communication channels such as emails. While the impact of ICT cannot be denied, probably the most important finding is the similarity with which information is drawn from people sources, particularly colleagues and superiors. Also in this regard, the finding for preference in consulting with these people via face-to-face communication channels rather than via technology is very interesting and points to workplace design needing to be cognisant of the need to maximise opportunities for face-to-face communications. This concurs with one of the findings from the literature review on lean thinking for workplace design (Womack & Jones, 1996).

Our findings with respect to the best information for helping with the understanding process and for helping with the solving process shed useful information with respect to the preference for face-to-face communications with people. Here we found that the very best information is given by people (colleagues and superiors) as opposed to documentary sources, and that such information is valued more for helping with the understanding process than with the solving process. A possible explanation is that humans are able to use their intelligence to help explore the nature of a problem in an interactive way, whereas other passive forms of information are not able to explore the problem space in such a meaningful manner. Furthermore, the insight generated from investigation of a problem in a deeper manner via sharing of information
between humans is valued to a greater degree generally than arriving at a solution. The deeper understanding of the problem may help at arriving at a better solution, rather than satisficing at an acceptable but perhaps suboptimal solution.

Our findings with respect to the significance participants attach to contributions made by self and others to decisions based on attributes for experience, knowledge and education revealed some useful insights. Here we found that participants generally valued their own work experience and knowledge more highly than formal training and education, and likewise, for contributions made by others, they valued the others’ general knowledge and expertise above their experience and networks. This poses an interesting challenge for educators of professionals in engineering and construction and implies that a high degree of consideration should be given to generating opportunities for relevant experiential learning.

We hypothesised that participants who rated their contribution by self relatively lowly would be more likely to seek help from others, and hence that contribution by others would be inversely correlated to contribution by self. However, our findings (H14) indicated a relationship in the opposite direction (i.e., positive correlation); there was a medium positive correlation between the two variables, with high levels of self contribution to decision associated with high levels of contribution by others. Other parameters, such as decision constraints, type of decision and the value of the decision, appear to influence the decision-makers’ strategies to involve others, and when the relative importance of such other factors is high it merits higher levels of contribution of both self and others simultaneously. This is supported by the findings to Hypotheses H01, H10, H13 and H22.

It is clear that not all decisions are equal and that the information search patterns deployed by human agents are adjusted depending upon the nature of the parameters such as type of decision, constraints and monetary value of the decision. We found statistical significance between management- and design/technical-related decisions for parameters of numbers of people sources (H01), and time spent accessing people and documentary information sources (H06 and H07). Unfortunately, our data set sample size was not sufficient to explore statistical differences and relationships for more fine-grained differentiation between types of decisions, but nevertheless it does suffice to demonstrate that there are meaningful differences between types of decisions.

Our results and analyses show that the constraints to the decision influence the information-seeking patterns to a high degree, with higher degrees of constraint being associated with longer time spans, use of more information sources and longer time spent using information channels. Although correlation does not prove cause and effect, it is a reasonable assumption that the level of constraint is the cause in this case, although we acknowledge other possible hidden factors may also be at play. If we accept that constraints are the causal factor influencing information-seeking patterns, then gaining an understanding of the root cause of such constraints may be a good strategy for improving the efficiency of the information-seeking
and decision-making processes. This observation is similar to the one made previously about the best sources of information being most valued for helping with the understanding process.

We also found that the nature of the decision-making process is highly iterative, with 80% of decisions taking two or more iterations, and approximately 13% of decisions taking six or more iterations. Content analysis of the qualitative reasons given by participants identified that 50% of the reasons for iteration were related to emergent information issues. It is apparent, therefore, that often all the information needed for a decision cannot be gathered within one linear decision-making process. Rather, new information comes to the fore, which redefines either the objective or the preferred solution, that is of sufficient import to justify a need to iterate back on the initial (or previous) decision. We found a statistically significant association between the number of iterations and the overall time span of the decision process (H22). It could be that the iterative nature of decision-making results in longer time spans, but this result could also be interpreted as longer time spans result in more iterations. The time spans could be set by other parameters such as organisational or industry-wide systems and processes. Causality in this regard is unproven, although the qualitative answers given by participants to the reasons for iterations do give insight into the predominant root cause, being information. Further results of interest are the correlation between number of iterations and the monetary value of the decision but lack of evidence for a relationship between the number of iterations and the monetary value of the project (H28 and H29). This indicates that it is the value of the decision itself rather than the overall value of the end product or project that is of significance to the decision-maker. A further finding is that seniority of role (akin to experience) does not reduce the number of iterations; rather, our results indicate an inverse relationship. This latter finding may, however, be due to causal factors outside the correlation test. Overall, these results regarding the iterative nature of decision-making indicate that a possible direction for improving productivity in engineering and construction is to focus on generating as complete and full information as possible early to enable robust decision-making without the need to reiterate, which may help shorten time spans and hence improve productivity. While such a strategy would improve the efficiency of decision-making, it needs to be tempered by consideration of the quality of decision-making, and iterations may serve to generate more robust finalised decisions, which we were not able to determine from this research.

A final area to comment upon in this discussion section is the findings relating to the importance of scoring of aspects of information for both people and documentary sources. These questions were set to understand which aspects of information are most desirable, be it reliability, timeliness, relevance or something else. The interesting finding here is how highly all aspects are ranked, with little differentiation between the different parameters. It would appear that good-quality information needs to contain all the attributes simultaneously, as indicated by the examination of the means and medians shown in Table 6-7.
Table 6-7: Rankings of Attributes of Information (1–5 Likert Scale, \( n = 43 \))

<table>
<thead>
<tr>
<th>Attribute of Information</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>People Information Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timely availability</td>
<td>4.38</td>
<td>5.0</td>
</tr>
<tr>
<td>Reliable</td>
<td>4.63</td>
<td>5.0</td>
</tr>
<tr>
<td>Accessible</td>
<td>4.26</td>
<td>4.0</td>
</tr>
<tr>
<td>Trustworthiness</td>
<td>4.56</td>
<td>5.0</td>
</tr>
<tr>
<td>Understandable/comprehensible</td>
<td>3.55</td>
<td>4.0</td>
</tr>
<tr>
<td>Relevant/constructive towards purpose</td>
<td>4.24</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Documentary Information Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timely availability</td>
<td>4.42</td>
<td>4.0</td>
</tr>
<tr>
<td>Comprehensibility</td>
<td>4.32</td>
<td>4.0</td>
</tr>
<tr>
<td>Accessible</td>
<td>4.30</td>
<td>4.0</td>
</tr>
<tr>
<td>Reliable</td>
<td>4.56</td>
<td>5.0</td>
</tr>
<tr>
<td>True / factually correct</td>
<td>4.60</td>
<td>5.0</td>
</tr>
<tr>
<td>Relevant / fit for use</td>
<td>3.89</td>
<td>4.0</td>
</tr>
<tr>
<td>Standardised format</td>
<td>3.26</td>
<td>3.0</td>
</tr>
<tr>
<td>Presentation</td>
<td>3.03</td>
<td>3.0</td>
</tr>
</tbody>
</table>

While we anticipated seeing greater differentiation between parameters, we found these results helpful in understanding the nature of information, to help define a semantic model of information, which is developed in Chapter 8.

6.7 Limitations for This Research Stage (Decision Questionnaire)

We acknowledge that the data set is heavily oriented towards design decisions, rather than construction or other phases in a typical life cycle of physical assets. The demographic of the participants is also dominated by the PSPs. However, these limitations are acceptable given the focus of this research into engineering and construction, with design process arguably being the central sphere of information processing.

We also acknowledge that the findings are based on subjective estimates of participants about a recent decision, and there is no way of verifying the accuracy of the participants’ subjective estimates.

The survey was designed to mirror the research undertaken by Patterson and Farrant (1982). While the data set is useful for comparing results using simple frequency tables and graphs, it was not possible to make statistical comparisons with the previous authors’ results as their raw data was not available, and only graphical presentation of data is made in their 1982 report.

The data set returned a number of useful scales, but with the exception of ‘total of self contribution’, all scales failed tests for normality. Hence, the statistical analyses were limited to non-parametric tests and it was not possible to undertake some of the potentially more powerful parametric tests such as regression. Despite such limitation, a series of non-parametric tests did find useful statistical results to test a number of hypotheses.
6.8 Conclusions for This Research Stage

Our analyses and interpretation have generated a number of very useful insights into the nature of the relationship between information and decision-making, which was the objective of this chapter. These findings give insight into possible ways of improving productivity. In particular, we found that the nature of the decision, the constraints and other factors such as number of iterations, role and monetary values of the decision are all of relevance. The nature of information flows from people sources and documentary sources is also important, and we can conclude from our findings that technology has changed information sourcing patterns in some important aspects over the past three decades, based on a comparison with similar research by Patterson and Farrant (1982). However, at the same time, the preference for information sources from people, particularly colleagues and superiors, remains dominant and has not significantly changed over the intervening period, and our findings give a high degree of confidence that people prefer to source information from these two sources via face-to-face communications. Hence, a useful further direction of research would be to collect further primary data of information flows between people in face-to-face communications, and a suggested way forward in this regard is to undertake direct observations of information communications in a series of meetings in a longitudinal study of a project or projects in the engineering and construction sector. This direction is developed further in Chapter 7.

Our findings also provide useful insight into the nature of decision-making in the sector, and here we found that it is a highly iterative process in general. As any engineering project is likely to involve multiple decisions to bring it from conception to final completion (thousands, possibly millions of decision), it indicates that the process of gradually moving forward through design stages and into production (construction) must involve many information searches leading to a highly complex scenario. We found that the quantum of constraints on the decision was a statistically significant factor in a number of the relationships, such as the number of people consulted, overall time spans and time spent in communications. Reducing the constraints could therefore be a good strategy for improving time spans and productivity.

6.9 Recommendations for Further Research

Recommendations for further research are as follows:

- Undertake additional data collection on information flows between human agents in face-to-face settings, ideally over a period of time in an engineering design and construction setting, in a series of regular design coordination meetings. This is developed further in Chapter 7.

- Undertake additional data collection using the survey tools at future points in time to monitor ongoing changes in information search patterns to understand the ongoing nature of the impact of ICT.

- Expand the survey tool to include additional questions to seek to measure efficiency and effectiveness of the decision-making by participants. Seek to expand the data set to allow statistical analyses of different types of decisions and constraints. Seek to refine
some of the measures to obtain normal distribution scales to allow for more powerful parametric tests.

6.10 Further Conclusions Combining Chapters 4, 5 and 6

In the conclusions to Chapter 4 we proposed an informal flow causal model for productivity showing the linkage between information stations to productivity outcomes via intermediate stations of decision-making, action-taking and contextual issues. In Chapter 5 we decomposed the contextual issues relating to productivity into task, teams, project, organisation and industry and proposed a more detailed model, based on the initial model, but enhanced to provide more contextual matters in engineering and construction. In this chapter we have explored the information search patterns deployed typically by decision-makers at various levels in the sector, and compared them with similar research undertaken in the early 1980s to make comparisons of patterns before and after the digital ICT revolution.

![Annotated Generic Information Flow and Productivity Causality Model with Objectives of This Chapter](image_url)

With reference to the information station, we found a number of fundamental changes in the way decision-makers in engineering and construction access information in the period between when Patterson and Farrant (1982) undertook their research and when we undertook ours. Examples include the dramatic reduction in frequencies with which participants acknowledge inputs from product data sheets and manufacturers’ representatives. Other examples include the increased use of standards, codes and regulations, and previous reports. In the discussion
we expressed a view that these findings are not particularly surprising given the significant changes in technology available to the vast majority of the modern workforce. While the impact of ICT cannot be denied, probably the most important finding is the similarity with which information is drawn from people sources, particularly colleagues and superiors. In this regard, there appears to have been very little change in information search preferences in the intervening period of time. Hence, we summarise with two key findings:

- **Key Finding 1:** Technology has significantly changed the ways in which prior knowledge shapes and informs information, with a significantly wider range of knowledge sources being available and used. This suggests that technology can be used to leverage access to knowledge.

- **Key Finding 2:** Information search preferences have not changed significantly, with preference remaining for face-to-face communications with best sources, being information from colleagues and superiors. While there is greater diversity of information channels such as emails and video conferencing, preferences for types of information (i.e., people) and attributes of information have not particularly changed.

These key findings are illustrated in the annotated copy of the model given in Figure 6-28.

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**Figure 6-28:** Annotated Generic Information Flow and Productivity Causality Model with Key Findings Relating to Information Stations

We also concluded in this chapter that constraints to the decision influence the information-seeking patterns to a high degree, with higher degrees of constraint being associated with longer time spans, use of more information sources and longer time spent using information
channels. Our conclusions also identified the highly iterative nature of the decision-making process, with 80% of decisions taking two or more iterations, and approximately 13% of decisions taking six or more iterations. Content analysis of the qualitative reasons given by participants identified that 50% of the reasons for iteration were related to emergent information issues. It is apparent, therefore, that often all the information needed for a decision cannot be gathered within one linear decision-making process and is dependent upon context. Hence, there is a feedback loop that has an important impact upon decision-making and productivity, and it is indicated by the modification of our model given in Figure 6-29 and Figure 6-30.

![Diagram of updated generic information flow and productivity causality model recognizing iterative nature of the process.](image)

**Figure 6-29:** Updated Generic Information Flow and Productivity Causality Model Recognising Iterative Nature of the Process
Figure 6-30: Updated Detailed Information Flow and Productivity Causality Model
Recognising Iterative Nature of the Process

Hence, our findings in this chapter have helped to validate our model (at least in the relevant parts), and also show that the model is useful and constructive for decomposing the issues relating to information flow and productivity.
7 Information Flow via Meetings and the Impacts upon Performance Outcomes in Engineering and Construction

7.1 Introduction
In this chapter we expand on the findings of the previous chapters by obtaining more data and undertaking more analysis on information flow and productivity in a series of design and construction coordination meetings in a case study project. We present the results of a series of industry observations of meetings and use the findings to test the nature of the relationships between information flow and productivity. We also explore the nature of information flow as a phenomenon and develop some metrics for measuring productivity of information flow in meetings. We make conclusions on the importance of focusing on the quality of information to maximise the effectiveness of meetings, not just on the efficiency of concluding the meetings themselves. Finally, we include some recommendations on possible ways to optimise the efficiency and effectiveness of meetings in the engineering and construction context.

7.2 Objectives and Goals of This Research Stage
The purpose of this stage of the research was to investigate the linkages between information flow and productivity more specifically during meetings, taking up one of the key findings presented in previous chapters that face-to-face forms of communication and meetings are preferred. The focus of this chapter therefore has one main objective:

- Objective 1: Gain detailed understanding of issues of information flow and productivity in project team coordination meetings.

This is illustrated with reference to our model in Figure 7-1, and as illustrated gives a means of progressing research into the model across all the stations, from information source through to decision-making and actions, giving insight into contextual factors and the impacts upon performance outcomes.
Direct observation of meetings was also identified as a suitable methodology in Chapter 3 for collecting a combination of qualitative and quantitative data concurrently in order to better understand the linkages between the qualitative nature of information and the more quantitative nature of productivity. A series of observations of meetings on a single extended case study project involving engineering design and construction was considered a more appropriate approach than observations of multiple unrelated meetings in order to track issues and to limit the scope and potential variability of factors between projects.

7.3 Data Collection Methods for This Research Stage: Industry Observations of a Case Study

Case studies are acknowledged as a suitable research methodology for gaining significant qualitative and quantitative data and for gaining depth of insight into contextual issues that potentially affect the research area (Liu & Fellows, 2015). The Waterview Connection project was identified as a suitable case study project, being a major engineering and construction project of significant complexity. The project was considered suitable to study information flows as it provided examples of significant co-ordination challenges with multiple information flows between different engineering design and construction professionals. The alliance nature of the project also provided a project context of a no-blame culture in which individuals focus on collaborative communications without risk of possible litigious actions of parties against each
other. The selection of one major project enabled a longitudinal study of information flows in single case study, rather than attempting to compare information flows between different types of projects procured under a range of project delivery mechanisms. The purpose of the case study was not to compare information flows between different types of projects, but rather to focus upon the detailed information flows via meetings within a single project, and hence a large alliance project provided the ideal setting to obtain data pertinent to the research questions.

The board of the Well-Connected Alliance were approached and approval was obtained from the chairman of the board for participation in this research project. Research ethics considerations identified issues relating to confidentiality and obtaining informed consent from all meeting participants. As the research methodology involved the researcher sitting in the series of meetings to identify ways in which information flows between participants, the granting of informed consent from all meeting participants was necessary. The consent conditions allowed for any meeting participant to withhold consent without giving any reason. Furthermore, they allowed participants to withhold consent for a part of any meeting and request that the researcher retire from the meeting for that part, and recommence for the consented parts of the meeting only. The chair of the meeting had the right to remove the researcher from the meeting at any stage. In the group context, discussions cannot be kept confidential and anonymous from other meeting participants. In order to address sensitiveness relating to lack of anonymity, no data was collected that identified individuals by name. Participants also had the right to review any data collected during the meetings. Details of the research ethics documentation are provided in Appendix A5.

7.3.1 Case Study Project: Waterview Connection

The Waterview Connection project in Auckland is NZ’s largest and most ambitious roading project procured to date. It comprises twin 2.4 km long tunnels, each carrying three lanes of traffic, connecting State Highways 16 and 20. It also includes four ramps totalling 1.7 km of elevated highways. It is the final link in the motorway network to complete the Western Ring Route, and a road of national significance. The project is of national significance not just because of its size and complexity, but because of the contribution it will make to Auckland’s future growth and prosperity, improving travel times for business and pleasure journeys, increasing connectivity, and improving the resilience of the transport network by lowering the dependence upon State Highway 1 and the Auckland Harbour Bridge.

The project itself employs between 800 and 1,000 people at any one time. The task involves construction spread over three different locations, a disused quarry where excavated spoil is dumped, a pre-cast concrete factory for manufacturing of the tunnel segments, urban design improvements, 2.5 km of walking and cycling shared paths and the tunnel itself. The tunnels are constructed using a tunnel boring machine, the 10th largest in the world (New Zealand Transport Agency, 2016).

The project cost is approximately NZ$1.4 billion (2017) and procured using a project alliance model. The alliance is named the Well-Connected Alliance and the partners comprise the
owner, constructors and designers. The partner organisations are NZ Transport Agency, Fletcher Construction, McConnell Dowell Constructors, Beca Infrastructure, Tonkin & Taylor, Parsons Brinckerhoff and Obayashi Corporation. Sub-alliance partners are Spanish tunnel controls specialists SICE NZ Ltd (Sociedad Ibérica de Construcciones Eléctricas) and NZ precast concrete suppliers Wilson Tunnelling.

The nature of the alliance model means that all alliance partners have a commercial stake in the project via an alliance gain-gain sharing mechanism. The partners effectively collaborate as a single entity in a new organisation created for the purposes of the project. Staff from home organisations are seconded into the project and work full-time in the alliance. The alliance has its one shared office, management structure, systems and processes. There is significant leadership input from the senior executives of the organisations, and leadership effort is dedicated to the project. There is a conscious effort to create a positive alliance culture, with a best-for-project approach.

Project enabling works commenced in January 2012, with major construction effort commencing in June of the same year. The period of data collection for this research was the period between April and November 2012, which was a key stage of maximum effort in detailed design and coordination for commencement of construction. The project completion date is early 2017 (pending at time of writing this thesis).

7.3.2 Industry Observations and Data Collection

The data collection was undertaken via observations of the Waterview Alliance weekly coordination meetings. The researcher sat in the series of meetings to make observations of the flow of information. The researcher did not participate in the meetings, but rather made passive observations only, so as not to interfere with the natural flow of the meeting. In total, 49 meetings were observed over a period of 30 weeks.

Data was collected using a standard data record sheet. Initially, a paper version of the data collection sheet was used and completed manually by hand by the researcher during the meeting. The records were then entered into a spreadsheet manually from the meeting notes. A database system was seen as providing opportunity to optimise the data recording and subsequent information retrieval and search for reporting of the results. This was a logical consideration given the findings of our research from interviews into information flow and productivity, particularly the findings relating to harnessing the potential of technology and database systems for improving efficiency (i.e., we implemented one of our own recommendations). The criteria for the database system were identified as:

- providing the functionality of a relational database system;
- enabling quick data entry during meetings, preferably via an Apple iPad;
- customisable to suit data entry fields needed for the meeting observations;
- cross-platform application with options to export data directly into MS Excel format for subsequent analysis.
FileMaker Pro was identified as meeting these criteria. It is a relational database application from FileMaker Inc., a subsidiary of Apple Inc. The application integrates a database engine with a graphical user interface, allowing the researcher to customise the database, including its screen layouts, forms and database tables. It integrates with FileMaker Go for the Apple iPad.

Direct data entry into a relational database proved to be an effective and efficient strategy. The time taken to build the customised database was worth the initial investment, as it saved considerable time and effort that otherwise would have been incurred recording all data points by hand with separate data entry. The 49 meetings observed resulted in observations of 539 agenda items, each of which had approximately 120 data fields, giving a total of circa 65,000 data points in the database. Descriptive notes were also taken by hand during meetings for the majority of the agenda items in order to capture subjective observations of qualitative factors, which were then subsequently logged into the database after the meetings.

7.4 Meeting Input–Processing–Output Model

In order to structure the data, a meeting input–processing–output model was developed. The model is illustrated diagrammatically in Figure 7-2.

![Figure 7-2: Meeting Input–Processing–Output Model](image)

Categories for the various inputs, meeting factors and outputs were identified as far as possible to enable the researcher to quickly categorise the issues while observing the meeting.
discussions for each agenda item. Two of the fields (apparent complexity and apparent age factor) were given ordinal scales (Likert 1–5 scale), which the researcher measured based on subjective judgement of the discussion.

7.5 Results and General Analysis

This section presents the key findings, with a range of results presented in graphical form, followed by statistical analysis.

Some of the chairpersons were responsible for chairing multiple meetings, which brings into question whether the meetings were independent for the purposes of undertaking meaningful statistical analyses (i.e., there was a potential risk of contravening the requirement for independence of observations). Also, the nature of the group setting for the data collection, where participants were involved in some interaction, introduced a potential for participants to be influenced by each other, and therefore for the data to become skewed. However, no two meetings comprised the same combination of participants, or the same combination of chairpersons and agenda items. Furthermore, each agenda item had unique combinations of people contributing to the discussion. As the primary data collection level was at the agenda item level, rather than the meeting level, each observation was for a unique event, which avoided the risk of contravening independence of observations to a significant extent. Also, it should be noted that the data collected was not a repeated measure via questionnaire of participants' views or judgements, but rather observational data such as time durations, number of contributors and number of agreed actions. Hence, we were not collecting repeated measures of participants' subjective judgements against a metric, which also helped us to avoid the risk of contravening independence of observations to a significant extent. Nevertheless, the nature of the group setting, and repeated chairing by the same chairpersons for some of the meetings, is acknowledged.

7.5.1 Meeting Descriptions

In total, 49 meetings were observed over a period of 30 weeks from April to November 2012. Descriptive statistics for the lengths of time of the meetings and number of people attending are given in Table 7-1.

| Table 7-1: Descriptive Statistics for Lengths of Time and Number of People Attending |
|-----------------------------------------------|----------------|-------------|-------------|-------------|------|
|                                              | Mean | Min  | Max  | SD  | N   |
| Total time of the meeting (minutes)          | 68.7 | 26.7 | 125.2| 22.8| 49  |
| Number of people attending the meeting (count)| 15  | 6    | 25   | 4.9 | 49  |
The types and styles of meetings varied, and four main types of meetings were identified:

- **Meeting type 1**: Traditional meetings with a chair, prior agenda, and note-taker.
- **Meeting type 2**: Free-style meetings called ‘hot topics’ meetings with a chair, but with no prior agenda and more informal than a traditional meeting. Notes taken usually by the chair with just key actions. The focus of these meetings was to identify and resolve contemporary issues, and usually started with brainstorming of current hot topics that needed to be discussed and progressed.
- **Meeting type 3**: Facilitated meetings, with a facilitator rather than a chair. The role of the facilitator was to enable participants to work through processes, such as risk analysis and treatment. The facilitator was independent from the discussion and from the meeting participants. Examples included risk and safety in design workshop meetings.
- **Meeting type 4**: Last Planner meetings. Last Planner is a bespoke workshop style of meeting to progress scheduling of planned work in a collaborative approach between participants. Last Planner was developed by Glen Ballard (2000a) and is derived from lean thinking philosophy.

The split of types of meetings were as shown in Figure 7-3,

![Figure 7-3: Types of Meetings and Frequencies of Meetings Observed](image)

A number of different chairs and facilitators were involved in chairing and facilitating the meetings. Names of chairs are anonymised and a breakdown of the numbers and types of meeting they chaired are given in Table 7-2.
<table>
<thead>
<tr>
<th>Chair</th>
<th>Traditional</th>
<th>Free Agenda</th>
<th>Facilitated</th>
<th>Last Planner</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting Chair 01</td>
<td>9</td>
<td>2</td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Meeting Chair 02</td>
<td>2</td>
<td>6</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Meeting Chair 03</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Meeting Chair 04</td>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Meeting Chair 05</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Meeting Chair 06</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Meeting Chair 07</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 08</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 09</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 10</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 11</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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<tr>
<td>Meeting Chair 12</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 13</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 14</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 15</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Meeting Chair 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>19</td>
<td>5</td>
<td>2</td>
<td>49</td>
</tr>
</tbody>
</table>

The chairperson was nominated in advance of the meeting, and was accepted by everybody else as being the chairperson. All meetings started promptly on time, with participants having been previously invited to the meeting via diary meeting invitations with details of the purpose of the meeting, time, location and details of other participants.

Participants to the meetings already knew each other, as they all worked in the same shared office and were already involved in working on the Waterview Alliance project before the start of the meeting observations research. Hence, there was no need for introductions at the start of meetings, and participants were already aware of others’ roles and responsibilities. Occasionally, a new person might join the project, but that person would have already been introduced to others in the project before the meetings.

All meeting participants were working to common shared goals and objectives, being the successful delivery of the project. It was very apparent in the meetings that without exception everybody was highly committed to the project. There was a very high degree of cooperation between people, with positive proactive engagement, and low levels of conflict were apparent. There were no especially dominant participants in any of the meetings, although naturally some people were more vocal and articulate than others. Everybody had opportunity for airtime to speak and generally there was good active listening, with only one person speaking at any time.

All the meetings were multidisciplinary, with professionals from a range of engineering and construction specialisations, including designers, constructors and managers. Specialisations included tunnel specialists, geotechnical, environmental, structural, civil, tunnel systems, electrical, mechanical, fire safety, traffic management systems and temporary works designers,
among others. Other specialists included stakeholder communication managers, consenting planners, procurement specialists, programme schedulers, accountants and managers. A considerable number of agenda items related to the interface issues between design disciplines, between designers and constructors, and between technical and management issues. These meetings were very multifaceted with an extremely complex set of different interfaces.

Most meetings were held in the same room, which was set up in boardroom style with a large oval table able to accommodate 25 people. A few meetings were held in other rooms, details of which are given in Table 7-3.

<table>
<thead>
<tr>
<th>Table 7-3: Frequency Table for Rooms Used and Meeting Room Layout Style</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Meeting Room</strong></td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Boardroom style</td>
</tr>
<tr>
<td>Informal</td>
</tr>
<tr>
<td>U shape</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

The meeting room facilities were generally good, with rooms set up specifically for needs of meetings with whiteboards, audio-visual technology options including a digital projector and teleconferencing equipment. Meeting rooms were well lit with natural daylight, ventilated and spacious.

Although video conferencing facilities were available in the meeting rooms, they were never used in any of the meetings observed. All meetings were held face to face with participants physically present in the room. It was not clear, however, whether this was a conscious policy, a preferred choice or just coincidence. It is possible that the need for using technology for video conferencing style meetings was avoided because the Waterview Alliance was set up with shared office space, with all people working on the project dedicated full-time to the project.

Meetings were held during normal working hours, both mornings (44.9%) and afternoons (55.1%), mid-week on either Tuesdays (16.3%) or Thursdays (83.7%).

7.5.2 Meeting Inputs
The meeting inputs identified from the observations were the agenda item, issues, information inputs, information channels used and the issue constraints. The findings are presented in a series of graphs in the following sections.

The agenda item issues were categorised as given in Figure 7-4.
Some agenda items referred to more than one issue and hence categorised against multiple issues (min 1, max 7). Design issues dominated the discussions, which is perhaps indicative of the stage of the project and the fact that many of the meetings had the stated objective of being design coordination meetings. The second most significant issue of focus in the meetings was construction related, which probably reflects the collaborative design and construction nature of the alliance. Project management issues related to schedule, cost and quality of the project. It is notable that stakeholder and consent issues accounted for a large number of the agenda item discussions.

The information inputs used for agenda items are given in Figure 7-5.

![Figure 7-4: Meeting Agenda Item Issue Categories](image)

![Figure 7-5: Informational Inputs Used for Agenda Items](image)
Some agenda items used more than one informational input (min 1, max 5). Apart from the briefings from individuals, which dominate, other significant informational inputs were the minutes of previous meetings and the agendas (meeting inputs) and the schedule and drawings (project inputs). It would appear, therefore, that the individual briefings, together with the documents prepared for the meetings (i.e., agenda and minutes) had ascendency and this finding indicates the importance of people’s verbal briefings on agenda matters, together with preparation of the agenda and having reliable minutes.

The information channels used are given in Figure 7-6.

![Figure 7-6: Informational Channels Used for Agenda Items](image)

N (Information Channel) 653, N (Agenda Items) 539

Some agenda items used more than one informational input (min 1, max 4). Obviously, each agenda item had some verbal discussion, and hence verbal media dominated. The amount of other media used was somewhat small and lacking in diversity.

The agenda item constraints are given in Figure 7-7.

![Figure 7-7: Issue Constraints Apparent from Agenda Item Discussions](image)

N (Constraints) 704, N (Agenda Items) 539

Some agenda items had more than one constraint apparent from the discussions (min 1, max 7). Often the constraints were not apparent from the discussion, and were recorded as ‘not apparent’. It should be noted that categorisation as such does not necessarily mean that the agenda item and decisions were unconstrained, but rather that it was not possible to infer any
constraints on the issue from the meeting observations. The dominant constraint was technical factors, indicative of the design and construction focus of the meetings; thereafter, a lack of information and stakeholders was a common constraint for the decision-making.

7.5.3 Meeting Outputs

Invariably, each agenda item led to some discussion, and a decision with some agreed actions and outputs. The meeting outputs observed by the researcher were actions, responsibilities and information/data outputs.

The rate of decisions leading to actions is given in Figure 7-8.

![Figure 7-8: Type of Decision (Action) Observed in the Meeting for Each Agenda Item](image)

N (Decisions) 539, N (Agenda Items) 539

While the majority of agenda items led to some positive decision for action of one kind or another, 29% of agenda items ended without any explicit action. Of these, the reasons for no action was generally apparent because of reasons given in Figure 7-9.

![Figure 7-9: Subcategories for Agenda Items Ending without an Action](image)

N (No Explicit Action) 155, N (Agenda Items) 539

It would appear, therefore, that the vast majority of agenda items were useful and purposeful, and even the 29% that did not lead to any specific actions performed a useful function by keeping people informed with updates, and securing buy-in for decisions that had already been made. Only a very small number of agenda items were deferred or dumped as being not relevant.
Some responsibilities assigned had more than one category, for example, assigning a responsible person and a checker concurrently (min 1, max 6). While a responsible person was generally identified (as being the person to carry forward the agreed action), other responsibilities such as an accountable person (owner) were often not considered or indicated.

The information and data outputs identified from agenda discussions are given in Figure 7-11.
A diverse range of information and data outputs were nominated during the meetings. Some actions were assigned multiple information outputs; for example, drawings, reports and risk register concurrently (min 1, max 9). It is notable that the most common information output was to hold another meeting, typically with other people who were not present at the current meeting. Minutes of meetings were identified as a category and noted by the researcher where people in the meeting explicitly referred to a need for the action point to be minuted, which should be differentiated from general minutes taken for all agenda items. The next most commonly identified information output was to hold an offline discussion with just pertinent people (typically two to three people), which was an action selected when the issue was not relevant to the wider group, or when greater in-depth discussions were needed and offline discussion was deemed to be a more efficient and effective use of time. It is also interesting to note how key documents such as drawings, registers and reports were referred to as being the means of recording decisions, whereas other documents such as legal agreements, letters and variation orders were not commonly used. The selection of the most appropriate means of documenting the decisions and disseminating information was not typically debated, and it would appear that participants chose the means based on relevance and known (or assumed) use of the information channel. It is also interesting to note the diverse range of informational and data options available to participants. It was not possible to follow up on the effectiveness of such channels or whether actions were generally implemented because of the limitations of the research being focused on the meetings.

7.5.4 Meeting Factors and Meeting Agenda Factors

The meeting factors recorded included the chairperson, number of people participating, location, day of the week and start time, all of which referred to the overall context of the whole meeting. The results of the factors were reported in Section 7.5.1. The meeting agenda factors were recorded for each individual agenda discussion item and included the following: time taken, number of people contributing to the agenda item, information-seeking approach, method of deciding on the issue, method of determining actions, apparent complexity of the issue, apparent age factor of the issue, and a description of the issue. Descriptive statistics for the number of agenda items and length of discussion are given in Table 7-4.

| Table 7-4: Descriptive Statistics for Lengths of Time and Number of People Attending |
|---------------------------------|---------|-------|------|-----|------|
|                                 | Mean    | Min   | Max  | SD  | N    |
| Number of agenda items / meeting (count) | 6.7     | 1     | 21   | 4.2 | 539  |
| Length of time of discussion for an agenda item (minutes) | 5.8     | 1     | 72   | 6.4 | 539  |

The information-seeking approach adopted during each agenda item varied depending upon the nature of the issue and the decision-making. The researcher categorised them based on subjective judgement of the type, tone, nature and body language of the participants into categories as given in Figure 7-12.
Figure 7-12: Information-Seeking Approach Adopted by Participants

N (Seeking Approach) 836, N (Agenda Items) 539

Some agenda items used more than one information-seeking approach before deciding on actions (min 1, max 8). The vast majority of agenda items had some ‘constructive dialogue’, sometimes supplemented by other search strategies such as ‘brainstorming’. ‘Constructive dialogue’ was characterised by proactive positive contributions to the issue from participants. By contrast, ‘open questioning’ consisted of more open-ended questions to explore the issue or problem, often characterised by multiple questions in search of better understanding of the issue at a deeper level. ‘Interrogation’ was a more assertive form of ‘open questioning’, in which there was some evidence of forceful and/or defensive behaviour by the people asking and answering questions. ‘Direct confrontation’ was rare but occasionally some aggressive behaviour led to elements of argumentative exchanges. Sometimes the discussion would move quickly from one style of information seeking to another in quick succession.

The methods of deciding an action are summarised in Figure 7-13.

Figure 7-13: Method of Deciding on Issue and Action Points Arising from Agenda Items

N (Method) 418, N (Agenda Items) 539

Some agenda items did not decide explicitly on any particular action, while some other agenda items had more than one (min 1, max 3). For example, a decision or action point might be identified by the person with responsibility for the issue, confirmed by the chairperson and clarified by the minute taker. The majority of decisions were offered after some discussion and
were generally made by either the chairperson or the person with responsibility for the issue being discussed. Other possible options such as voting, polling or formal proposals (with proposer, seconder and acceptance or otherwise) were not used in any of the meetings. Generally, the decision-making followed a pattern in which a discussion would be held until either the chair or the responsible person would indicate the way forward, which would then either be quickly agreed to by general consensus or negotiated further until an agreeable way forward was identified. These findings indicate the importance of the role of the chairperson in propelling the meeting forward with decisions.

The apparent complexity and age factor for each agenda item was recorded by the researcher using subjective judgements based on the scales given in Table 7-5.

Table 7-5: Scales for Apparent Complexity and Apparent Age Factor

<table>
<thead>
<tr>
<th>Scale</th>
<th>Apparent Complexity</th>
<th>Apparent Age Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simple</td>
<td>New (first discovery)</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>Emerging/Evolving</td>
</tr>
<tr>
<td>3</td>
<td>Complex</td>
<td>Pre-existing and Changing</td>
</tr>
<tr>
<td>4</td>
<td>Very Complex</td>
<td>Mature</td>
</tr>
<tr>
<td>5</td>
<td>Extremely Complex</td>
<td>Old and Protracted</td>
</tr>
</tbody>
</table>

Table 7-6: Descriptive Statistics for Apparent Complexity and Apparent Age Factor

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
<th>Median</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Complexity (1–5 Likert Scale)</td>
<td>2.2</td>
<td>1</td>
<td>5</td>
<td>1.2</td>
<td>2</td>
<td>539</td>
</tr>
<tr>
<td>Apparent Age Factor (1–5 Likert Scale)</td>
<td>2.9</td>
<td>1</td>
<td>5</td>
<td>1.1</td>
<td>3</td>
<td>539</td>
</tr>
</tbody>
</table>

7.6 Qualitative Findings and Analysis

7.6.1 General Observations of Information Flow in Meetings

There was a general pattern in which all meetings followed a series of agenda items. Sometimes agenda items would be formally identified in advance and listed in a formal agenda or from the minutes of the previous meeting. Often agenda items would be more emergent in nature, generated from the discussion; even so, it was generally easy to observe them as discrete agenda items. Hence, generally meetings would follow a series of discrete and observable agenda items irrespective of whether they were formally planned in advance or more emergent during the meeting from discussions.

Within each agenda item there was typically a three-stage pattern: in the first stage the agenda item would be introduced, in the second stage some time was spent on exploring the issues arising, and the third stage comprised some resolution or agreement on the way forward or means of addressing the issues arising. The first stage would typically comprise an introduction briefing or update provided by one person. This was invariably given verbally, sometimes of short duration (less than one minute), other times of longer duration, but generally delivered as
information dissemination from one person to the rest of the participants at the meeting. In the second stage there was typically some exchange of information between people in the form of questions and answers, and/or a series of constructive comments from various people advancing additional information to the meeting. This second stage typically comprised elements of both information searching and information dissemination, undertaken concurrently and perhaps subconsciously by participants. The goal of the second stage appeared to be to gain a better understanding of the issue and implications arising before making any decisions. The third stage typically comprised making agreements between participants and resolution of appropriate ways forward. Often this involved at least one decision and action point with responsibilities; rarely was a matter discussed that did not lead to some kind of decision and agreement on an action, even if that decision was to refer the matter elsewhere or offline. Sometimes the final stage would involve some negotiating between participants before they reached agreement on roles and responsibilities for actions. Hence, in this third stage the focus moved from information searching and dissemination within the meeting, to capturing the value generated from the discussion via decisions about future actions. This could be described as transforming information into actionable value. These stages are illustrated in Figure 7-14.

![Diagram of typical stages of meeting agenda item discussions](image)

**Figure 7-14: Illustration of Typical Stages of Meeting Agenda Item Discussions**

Generally, only a subgroup of the meeting attendees would contribute to the discussion on any one particular agenda item (rarely more than five or six people). This is not to say that some meeting attendees did not participate in the meeting at all, as the participation subgroup would vary from one agenda item to the next. Invariably all meeting attendees contributed to the meetings at some point, to some agenda items, but not to all agenda items. Only the chairperson would typically contribute to all the agenda item discussions, and even then that
might be just to briefly steer discussions to the final stages of decision-making and action points.

Each style of meeting comprised some subtle but important differences in patterns and participation. The traditional meetings comprising a prior agenda were typically more highly structured than the other styles, with only small or moderate discussions on issues outside the set agenda. In contrast, the free-style meeting would typically start with brainstorming on hot topics, which would be written up on a whiteboard by the chairperson and used to define the agenda for the rest of the meeting. Hence, these meetings were typically less structured, and more open to a diverse range of issues than traditional style meetings. Also, the free-style meetings were somewhat subject to the quality of the participation in the initial brainstorming, as this set not only the agenda but also the general tone and energy of the meeting. The facilitated meetings generally were more focused on particular matters, and the chairperson’s role was to facilitate involvement by all participants as actively as possible. Likewise, the Last Planner meetings were similar to workshops in that all attendees participated in generating a collective schedule for future work. Both the facilitated meeting and Last Planner meeting styles tended to have elements of doing in conjunction with discussion, for example, producing pieces of work during the meeting such as a risk register, safety in design schedule or programme schedule. Also, both of these involved breaking the meeting into smaller subgroups for parts of the meeting.

The different styles of meetings were more suited for different purposes. Traditional style meetings were suited for keeping abreast of ongoing issues and monitoring and controlling progress on a regular basis. They appeared to be effective and efficient for predefined agendas. In contrast, free-style meetings were suited for dissemination of issues, keeping abreast of new and important issues and collective problem-solving of contemporary hot topic issues. Facilitated and Last Planner meetings were suitable for gaining active inputs from all attendees, generating consensus via a facilitated process, and working on issues within the meeting to produce some specialised output such as a register or schedule.

While some agenda items were discussed only once at one meeting, with no need to follow up at subsequent meetings, other agenda items involved more protracted issues that recurred over time and were also repeated in different contexts in a range of meetings. It was possible to identify and track the recurrent agenda topics over time in a longitudinal manner to see how they were discussed in a series of meetings. It became apparent looking at these repeat agenda items that there was a pattern comprising four main phases. In the early phase the issue were emergent and parameters were not well understood, and discussions and information searching were perhaps slightly superficial. In the second phase the issue had become important because of some constraint and the agenda item moved into collective searching for solutions and action-taking to progress things before the next meeting. This stage could comprise several meetings. In the third phase there was some resolution in which the issue had been substantially resolved and reports of solutions and resolutions were made in the
meetings. The final phase was verification, in which the agenda item remained on the agenda and minutes from previous meetings, and was discussed at the meeting to verify that matters had now been closed out. These phases are illustrated diagrammatically in Figure 7-15.

![Diagram of the life cycle of an agenda item](image)

**Figure 7-15: Observed Typical Pattern of Repeat Agenda Items**

### 7.6.2 Findings from Particularly Pertinent Agenda Items

During the meetings the researcher took notes of agenda items and highlighted those with particular interest with a special note in which some issue pertinent to information flow was observed. Of the 539 agenda items observed, 75 (14%) were identified as having some special interest. Content analysis of the notes for these items was undertaken using NVivo10 software, which identified 15 key themes relating to information flow and productivity. These themes are discussed in the following sections.

**Qualitative Theme 1: Good information sharing during meetings leads to effective decision-making**

It was apparent from the observations that good sharing of information between participants during the meeting often resulted in effective decision-making and useful actions. Often the meeting would be the place where people from different disciplines would update each other on information to which they would not otherwise have ready access. The sharing of information in meetings enabled people to better coordinate efforts and resources. Examples include the following:

- Meeting 21: Information sharing between participants about consenting and archaeological investigation approvals led to a series of decisions around scheduling of design packages and submission of packages for approvals with a forward-looking view to meeting the project programme.
• Meeting 35: The sharing of information about a design change led to realisation of significant impacts on foundation piles and a need to expedite some other design elements to meet the construction programme. This led to the appointment of an additional design resource as an action point to expedite the matter.

Generally, participants were proactive in sharing information in a spirit of mutual trust and cooperation, which helped to make all the observed meetings productive.

**Qualitative Theme 2: Importance of up-front information for improving the efficiency and effectiveness of future design, construction and maintenance of the physical assets**

Having the right information, structured in an appropriate format and made accessible to information users is vitally important for the efficiency and effectiveness of the users, including, but not limited to, designers, constructors and asset owners and maintainers. While this is a somewhat obvious finding, two examples illustrate the point well:

• Meeting 24: Discussion regarding the asset numbering system identified a need to set up a numbering system early; otherwise, it could result in a large amount of abortive work for the drafting team. This led to identification of an opportunity for suppliers to use the same numbering system in the asset management system for operation and maintenance manuals, to make it easier to manage the asset following completion.

This was a very good example of the importance of planning for information flow as it does not happen just by chance, but rather some prior planning can lead to good information systems. Having an asset management system containing all the operating and maintenance manuals will be a powerful resource for the owners and operators. The process starts before design and documentation, and requires a paradigm shift from one of designing a physical asset to one of designing an integrated system that includes some value for human users.

• Several meetings: Discussions relating to a buried casing abandoned in a previous project identified the impacts not only of extracting the buried casing (i.e., physical works) but also of gaining access to an existing sports field used by the local community. Information about the buried casing was sparse as the as-built records from the previous project were poor. However, during a series of meetings in which different disciplines of engineers collaborated, an alternative option was developed that avoided the need to remove the buried casing, which in turn meant that the sports field did not need to be used for construction activities, and hence the scope of physical works relaying the field after construction was reduced.

In this second example it was apparent that the lack of good information from a previous project had a significant impact upon the current project, but good information sharing and innovation on construction techniques found a novel solution to the problem, saving significant resources and money. The identified solution was acknowledged with an innovation award.

While the finding would probably be accepted by most people as common sense, that does not necessarily mean it is easy to implement in practical ways. Effort is needed to coordinate
information upfront. Sometimes the benefits of the additional effort accrue to others, such that the cost of the effort of improving information flow is borne by one group but the benefit reaped by another group. In the case study the project alliance includes designers, constructors and owner, and the project alliance is also responsible for maintenance of the asset for a defined period. Hence, there is an incentive for the project team as a whole to improve information flow for the benefit of the wider project. It is not clear from the meeting observations the extent to which the alliance procurement model helped facilitate good collaboration and information flow, as it is not possible to observe how the same participants would have behaved with the same problems under a different procurement regime. However, the importance of upfront information flow for improving the efficiency and effectiveness of future design, construction and maintenance of the physical assets is demonstrably illustrated in these two examples and the principle was common in numerous other meeting discussions observed.

Qualitative Theme 3: Waste caused by poor information flow
Evidence was observed of wasteful use of resources either due to a lack of information at the right time or arising from duplication of effort caused by a lack of coordination of information. Such waste was observed in different contexts, including wasteful use of people’s time in meetings, and wasteful use of design and construction resources outside of the meetings, with the latter probably being of greater commercial significance. Examples of waste include standing time of construction equipment, rework and unnecessary redeployment of resources, all of which are typical of wastes commonly identified in lean thinking (Womack & Jones, 1996). Examples from the meetings include:

- Meeting 32: A lack of information in a design package was identified as the cause of piling rigs being put on standby. Labour was redeployed to other parts of the works, but plant and equipment could not be redeployed and therefore was a direct wasteful cost to the project.

- Meeting 33: A package of drawings had been issued to the peer reviewer but the turnaround time for the peer review was likely to be two to three weeks, with a knock-on effect on the issue date for construction status drawings. This had a potential impact upon the critical path for manufacture of moulds for the tunnel pre-cast units. A solution was proposed to issue the draft construction status drawings before the return of peer review comments to allow for small manufacture, but at risk for potential abortive works pending possible comments from the reviewers.

- Meeting 49: A delay to the programme was reported at four weeks due to lack of construction status drawings. A mitigation strategy was in hand to work collaboratively with approving authority to expedite the consenting process, which if successful would reduce the delay to two weeks.

Other examples include numerous times when information needed in the meeting for decision-making was not readily available, leading either to a pause while somebody went to obtain the information or identification of an action for a further meeting to address the issue later.
This theme is somewhat the reciprocal of Qualitative Theme 2, outlined previously. Factors include having the information at the right time (timeliness), completeness of the information, and availability. This finding concurs with the findings in Chapter 4 relating to waste (Key Findings 22, 26 and 29 in Section 4.5). It is interesting to note that despite being the cause of waste, information flow work-around solutions are used as mitigation strategies in these examples. It is possible that the only solution to poor information flow in the general case is to improve the qualitative elements of the information flow. Poor information flow results in uncertainty and associated risks, whereas good information flow reduces uncertainty. It would appear that the purpose of good information in a design and construction setting is to provide sufficient certainty to proceed with construction, and associated deployment of resources, with a sufficient level of confidence within commercial norms of risk tolerance.

**Qualitative Theme 4: Small errors and omissions in information can have major implications and impacts**

Information has major leveraging power. During the series of meetings a number of examples were observed in which small errors or omissions in information had major impacts, including the following:

- Meeting 49: One error in a spreadsheet cell formula resulted in an error in the financial model for the project, resulting in a negative impact on annual operating costs (major financial sum).
- Meeting 32: During a discussion about the schedule programme it became apparent that one input in the Microsoft Project network model using standard S curves was not reliable, as it was based on an old assumption that was no longer valid. In the meantime the crane platform works had become critical path works with an overall impact upon the programme for the project as a whole.

Clearly the accuracy of information is vitally important, as one small error can have significant impact. This is perhaps another finding that most would accept as being premised on common sense. However, in engineering and construction the potential scale of the impact is accentuated because of the nature of projects and their deployment of significant levels of resources based on bespoke information produced for the particular project (i.e., one-of-a-kind production). Information has to be accurate and correct, as there is little opportunity to refine the information later during prototyping, which is in contrast to some other sectors such as manufacturing.

**Qualitative Theme 5: Reviews of information can lead to new discoveries**

Sometimes reviews of information lead to new insights and discoveries that create value. This is akin to the innovation process. During meetings there were several occasions when a fairly routine discussion or review of information led to a deeper understanding of the problem or issue, or led to fresh realisation of a solution or way forward. Sometimes such fresh ideas would appear as something of a eureka moment, leading to breakthrough. Examples include the following:
• Meeting 5: After a routine review of design information in a safety in design facilitated workshop, the facilitator was about to move on in the agenda when one of the participants challenged a point of detail in the design. This led to realisation that the design was somewhat flawed and after further analysis a new solution was found.

• Meeting 34: In discussions about interfaces with external stakeholders a new suggestion was made by a meeting participant to resolve a difficult interface with a statutory services provider, which led to a breakthrough in a challenging interface issue. In the previous theme it was noted how information has major leveraging power. In this theme the leveraging power can be applied for positive benefit, but human intelligence is also required to identify and capture the positive value-creating potential of the information.

**Qualitative Theme 6: Impact of information flow with external stakeholders**

Information flow with external stakeholders is the foundation upon which trust and relationships are built. In a number of examples this finding was demonstrated for either positive or negative effect. The importance of such impacts varies upon the influence of the external stakeholder, but nevertheless information is arguably the most important ingredient for stakeholder engagement. Examples observed from the meeting discussions include the following:

• Meeting 21: The issue discussed was about managing expectations of local residents living close to the construction works regarding blasting for the groundworks. Initially residents were informed there would be three blasts per week, but it became necessary to increase blasting to five blasts per week. Initial management of stakeholder expectations was not done as well as it could have been, and when the information was amended, stakeholders felt that they had been misinformed, which had a negative impact upon the relationship of trust with the local residents.

• Meeting 35: An agenda item relating to consultation with Housing New Zealand referred to the production of a report for the external stakeholder regarding the impacts of construction works. If accepted by the stakeholder it would enable the construction team to implement an alternative construction methodology for trenching works that promised a significant improvement in construction productivity.

It is interesting to note how significant the impact of external stakeholders can be as a constraint on engineering and construction works, a finding identified in this research in Section 6.6. We identified in Chapter 6 that a key means of improving productivity is to reduce (or address) the constraints on the decision-making, and hence the importance of information flow with external stakeholders cannot be overestimated.

**Qualitative Theme 7: Currency of information and need for timely sharing and dissemination to information users**

Information needs to be timely; late information is usually of little or no use, as the opportunity for decision-making has passed and events may have moved on. Likewise, information shared with one group needs to be disseminated to other information users in a timely manner in order to make effective use of the information. In engineering and construction this is particularly
pertinent as multiple decisions are being made concurrently by numerous parties, and events can move quickly. There is a saying that a week is a long time in politics, and likewise in a design and construction project, in which design and construction efforts overlap, time is often of the essence. Examples observed from the meetings include the following:

- Meeting 42: The peer reviewer for one of the design packages, who was participating in the design coordination meeting, referred to one of the design issues that had not yet been addressed. The issue was somewhat complex as it needed inputs from several works packages. Initial request for information had been made previously but information flow was slow and becoming a matter of concern.
- Meeting 43: One of the construction managers identified a need to improve the process for purchasing. The current system was too slow and cumbersome, with internal processing of information for purchase orders. An improved system with sharing of information on rates in a database with preferred suppliers was identified and actions agreed for implementation.

Information has a time value, and has to be managed to be ready in advance for effective decision-making.

**Qualitative Theme 8: Using a defined process aids information flow in meetings**

On several occasions it was apparent that when people in meetings follow a defined or facilitated process it improves the information flow in the meetings. Examples in general include risk reviews, health and safety in design review processes and Last Planner workshops. Also, in traditional or free-style meetings, on occasions when the chair prepared and facilitated a process within the normal meeting, it was observable how the efficiency and effectiveness of information sharing and decision-making was improved. For example:

- Meeting 24 (which was a free-style meeting): The chairperson successfully involved all 21 people in active participation by using sticky notes, affiliation grouping and a whiteboard to brainstorm an issue.
- Meeting 48 (which was a traditional style meeting): The chairperson facilitated a process by which all managers gave a brief update against deliverables and identified proposed actions, which enabled efficient use of time, constructive dialogue and effective decision-making. This enabled all 22 people at the meeting to participate effectively in what was a large meeting of senior people.

Meetings represent a significant resource, and managers commonly comment on how much of their time is spent in meetings of one sort or another. Some indications from the literature indicate that construction project planners spend the majority of their time in decision-making (Winch & Kelsey, 2005). Hence, making good use of people’s time in meetings is vital for effective use of their expertise and energy.
Qualitative Theme 9: Having the right people at meetings is important for information flow and decision-making

On several occasions it was apparent that a key person was missing from a meeting, which hindered the information flow and subsequent decision-making. Sometimes this resulted in a need to arrange another future meeting. On other occasions the chairperson was notified in advance and had taken the time to catch up in advance with the person giving apologies in order to mitigate the impact. Examples include:

- Meeting 22: An action from a previous meeting came up for review relating to pressing access arrangements for construction works. However, the person with responsibility for the action was missing without apologies. Nobody present at the meeting had up-to-date information on the status of the action and therefore no decisions could be made and the only action available was to arrange another meeting with the relevant person.
- Meeting 38: Apologies were received from one of the design discipline leads. The chairperson had taken the time to meet in advance with the engineer and obtain an update for the meeting.
- Meeting 24: Several design package meetings were being held concurrently this week, each with separate meetings. In meeting 24 a representative from one of the other design coordination meetings attended this meeting and was able to give an update on the current designs for an important interface component. Therefore, it was possible for all designers to assess the impact of the design upon other packages.

The last example above is a good example of information flow between concurrent engineering teams via meetings. This was achieved by prior planning to ensure that the right people were attending the meetings.

Qualitative Theme 10: Prior planning of information for the meeting is important and improves meeting outcomes

It was very noticeable when the chairperson or others prepared some information in advance for use in the meeting. Without exception, any information prepared in advance for a meeting was helpful to some degree, often making a significant impact. Examples include the following:

- Meeting 20: Examples of KPIs were collected from other alliance projects and shared at the meeting to enable the participants to develop suitable metrics for the current project. This was a good example of knowledge transfer from previous projects.
- Meeting 42: The chairperson prepared copies of drawings and circulated them during the meeting. The drawings were then used to structure a series of discussions, including on the rationale for the designs, implications arising and alternative options. This facilitated a very focused series of technical discussions. It was one of the few times that a series of drawings was systematically used in any of the meetings observed.

It was apparent from the observations of all the meetings that a high degree of dependency was placed upon verbal updates from participants, as these were the main method of sharing information in the meetings (see results in Figure 7-6). However, on the occasions when
deliberate effort was made to use multiple information sources during a meeting via some prior preparation, these meetings would be more focused.

**Qualitative Theme 11: Use of standardised informational documents in meetings is helpful for structuring decision-making and also subsequent dissemination of information**

Some of the chairpersons drafted their minutes using a highly structured tracked changes format, which is somewhat different from traditional tracking of actions, and includes notes from consecutive meetings in a colour coded system. This was a format adopted from a previous alliance project that proved to be rather effective at capturing issues and keeping them up to date. It enabled participants and others not attending the meetings to see the development and resolution of issues over a series of meetings. Often people in meetings were able to refer back not just to the previous actions but to a more complete series of development. Not all chairs used this system, as it required more careful structuring of the information in the minutes, but those that did invariably had access to better information. The prevalence of minutes being used as an information source shown in Figure 7-5 and the means of dissemination shown in Figure 7-11 highlight the importance of minutes of meetings. Other examples from specific agenda items that illustrate this theme include the following:

- Meeting 3: Use of risk register and safety in design registers during the workshop meeting and collected at the end of the meeting to enable them to be attached to minutes for subsequent dissemination.
- Meeting 33: Use of a standardised issues register identifying the people who need to be involved in actioning the issues.

Although the use of standardised documents is a simple idea, it was not always undertaken; however, some simple ordering and structuring of information is worth the effort. In a similar vein to a previous theme about prior planning of information for the meeting, some planning into the structuring of information during and subsequent to dissemination is also important.

**Qualitative Theme 12: Impact of time pressure during meetings on information flow**

In general, meetings lasted approximately one hour (mean 69 minutes, min 27 minutes, max 125 minutes), and some chairs allowed plenty of time for issues to be explored, but other chairs were more time conscious. The time scheduled was usually limited to one hour, and hence some time pressure was imposed on participants. The effect of having some time pressure was noticeable on occasions and it made participants more focused on matters of substance, but at the risk of missing something potentially important that was not immediately apparent. Examples include the following:

- Meeting 5: The meeting was under some time pressure and the chairperson was about to move onto the next agenda item when one of the participants challenged a point of detail relating to safety. This led to discussions of some complex considerations that needed to be explored in depth and a further meeting was taken as an action point.
• Meeting 7: The meeting was starting to run overtime with some outstanding agenda items. In an effort to finish on time, the chairperson quickly talked to the remaining agenda items but without discussion from other participants and no action points were identified for the remaining items.

For effective decision-making there needs to sufficient time allocations for each agenda item. This is not to say that the agenda item has to be fully resolved, but there should at least be some effective progress forward. It was noticeable that some agenda items would take several meetings to resolve, but on each occasion some forward progress was made. In the first example given above (Meeting 5), at least an action was taken to find a suitable future time. There needs to be sufficient time in meetings to enable participants to process the information. Some time pressure may be beneficial, but too much can destroy any opportunity to add value.

Qualitative Theme 13: Decision-making and turning decisions into actions with responsibilities and informational outputs

A common theme for all meetings was a focus on making decisions and turning them into actions. While meetings were usually action oriented, with a good degree of assigning responsibilities, it was notable on some occasions under moments of crisis that extraordinary numbers of actions were agreed by participants, for example:

• Meeting 32: After identification of an issue causing standing time of plant on site, with significant cost and resource allocation implications, there was a series of rapid decisions on actions needed to mitigate the problem, including multiple actions for different staff members.

• Meeting 33: An oversight on a matter came to light needing corrective action, leading to rapid allocation of actions and responsibilities.

There were occasions when people were needed to be seen to be particularly proactive. It would appear that the rate of decision-making increases when people are under pressure or at a point of crisis.

Qualitative Theme 14: Role of the chairperson in facilitating information flow

A key role of the chairperson is to facilitate information flow during meetings. Obviously, the chairperson has a number of other roles, including setting of agendas, assigning actions, facilitating agreements and so on; however, the skill in facilitating information exchanges should not be underestimated. During meetings it was observed that the most effective chairpersons did not necessarily do most of the talking, but rather focused on ensuring the participation of people, steering discussions, asking the right questions and progressing agenda items towards conclusions and action points. Examples from the meetings include the following:

• Meeting 34: A design manager reported in a design coordination meeting that there were no issues worthy of reporting for his/her discipline, at which point the chairperson interjected that he/she imagined there must be some important updates on a particular element of the design package. This led to some constructive discussions and an action
point for other interfacing design packages. Without the quick interjection of the chairperson, the opportunity to share information would probably have been lost.

- Meeting 43: A monologue by the chairperson for a significant portion of the meeting prevented effective participation and resulted in no actions being taken.

It was observed that each chairperson had a different style, and while no effort was made by the researcher to measure the effectiveness of individual chairpersons, it was apparent from observations that facilitation of good information flows with contributions from all (including naturally more quiet participants) requires skill and emotional intelligence on the part of the chairperson.

**Qualitative Theme 15: Explicit reference to the need for information and good communications helps improve information flow**

While nobody would dispute the need for information and communications in a project in order to progress matters forward, the benefits are often implicit rather than being made explicit. However, a number of explicit references during the meetings to the need for better information and communications resulted in actions to improve the information flow. Examples include:

1. Meeting 49: Reference was made to the formal request for information (RFI) process. It was noted that to date 153 RFIs had been issued and processed, 60 of which were from one subcontractor alone. A comment was made that if the project was not being procured as an alliance, the number would likely be in the thousands and this was a good indication that queries were being resolved informally. However, the project director pointed to a downside in that lack of implementing a rigorous RFI process leads to potential for information to be missed. Following a discussion, it was agreed by all that the RFI process should be implemented more rigorously.

2. Meetings 21 and 32: The need for an incident reporting system was discussed. Options were brainstormed, including paper-based and technology solutions using short message service (SMS). Actions were agreed for an escalation process to be implemented, with upward escalation of incidents to people on a need-to-know basis.

These examples illustrate that explicit reference to information flow can help to improve information systems.

The qualitative findings of the meeting observations are summarised in Table 7-7.
<table>
<thead>
<tr>
<th>Observation</th>
<th>Impact upon Meeting Itself</th>
<th>Impact upon Meeting Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Good information sharing during meetings leads to effective decision-making.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2 Upfront information is important for improving the efficiency and effectiveness of future design, construction and maintenance of the physical assets.</td>
<td>-</td>
<td>Primarily with respect to life cycle of the asset</td>
</tr>
<tr>
<td>3 Waste is caused by poor information flow.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4 Small errors and omissions in information can have major implications and impacts.</td>
<td>-</td>
<td>Primarily on outcomes of the meeting</td>
</tr>
<tr>
<td>5 Reviews of information can lead to new discoveries.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6 Information flow affects external stakeholders.</td>
<td>-</td>
<td>Primarily on outcomes of the meeting</td>
</tr>
<tr>
<td>7 Currency of information and timely sharing and dissemination to information users are necessary.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>8 Using a defined process aids information flow in meetings.</td>
<td>-</td>
<td>Primarily on the meeting itself</td>
</tr>
<tr>
<td>9 Having the right people at meetings is important for information flow and decision-making.</td>
<td>Primarily on the meeting itself</td>
<td>-</td>
</tr>
<tr>
<td>10 Prior planning of information for the meeting is important and improves meeting outcomes.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>11 Use of standardised informational documents in meetings is helpful for structuring decision-making and also subsequent dissemination of information.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>12 Time pressure during meetings affects information flow.</td>
<td>Primarily on the meeting itself</td>
<td>-</td>
</tr>
<tr>
<td>13 Decision-making and turning decisions into actions with responsibilities and informational outputs improves effectiveness.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>14 The chairperson has the role of facilitating information flow.</td>
<td>Primarily on the meeting itself</td>
<td>-</td>
</tr>
<tr>
<td>15 Explicit reference to the need for information and good communications helps improve information flow.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

On two occasions references were made to how to make the meetings more effective. At the end of one meeting, the chairperson asked for feedback from the participants on how well the meeting had gone. A consensus score of 8/10 was agreed by the participants. Some time was...
spent reflecting and brainstorming on how future meetings could be improved and the following was agreed:

- All participants must come to meetings having prepared their action points and identified issues that need to be addressed in the meeting.
- All design disciplines must attend to enable coordination between the different design disciplines. If the discipline lead is not able to attend because of pressing other matters, the lead must delegate a representative empowered with information and the ability to made decisions.
- Participants must actively participate during the meetings.

On another occasion the project director referred to the importance of optimising the benefits from meetings via being fully prepared for meetings, using data in meetings and adopting exception reporting to identify significant implications.

In overall summary, meetings are a vital form of communication and the key means of coordinating efforts towards successful project outcomes. In observing the meetings, the researcher also made subjective assessments on aspects contributing towards good meetings, which are listed as follows:

- A clear purpose is set for the meeting and achieved, or at least significant progress is made towards the purpose.
- A positive and constructive atmosphere is facilitated by the chairperson.
- Contributions are made by all attending.
- Relevant and purposeful actions are agreed and responsibilities assigned.
- New insights or discoveries are identified during the meeting.
- Problems and issues are resolved and agreements are made.
- Actions from previous meetings are taken and acted upon in accordance with previous agreements.

Successful meetings add future value and far from being a necessary burden are the vital lifeblood of decision-making and creating value.

7.7 Quantitative Findings and Analysis

7.7.1 Meeting Productivity Metrics

As we are interested in the relationships between information flow and productivity, we generated a number of productivity metrics relating outputs from the meetings to the inputs available and used during the meetings. While it was possible to measure the outputs of the meetings with a range of data types (i.e., numbers of decisions, actions, responsibilities and information outputs), it was not possible to observe or measure the subsequent outcomes or impacts of the meetings. For example, an agenda item might consider a particular design interface challenge, which resulted in some resolution on a preferred method of treatment, an action to report to others, with responsibilities for documenting the preferred solution in drawings. However, it was not possible to observe the extent to which these agreed actions
were subsequently implemented to effect, or the impact of the preferred design solution on the design and construction of the physical asset. Hence, the metrics developed relate primarily to the productivity of the meetings, and not the overall engineering and construction of the project. Nevertheless, the metrics are useful in giving an indication of the efficiency of use of both labour and information resources.

Three meaningful inputs and four outputs (see Figure 7-2) were identified as shown in Table 7-8.
Table 7-8: Input and Output Metrics for Meetings

<table>
<thead>
<tr>
<th>Input/Output Type</th>
<th>Description</th>
<th>Means of Calculating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input 1</td>
<td>People resource: Total labour resource committed to the meeting</td>
<td>(\left[\frac{(\text{Total number of people attending meeting}) \times (\text{Overall duration of the meeting})}{\text{Units = Man-hours}}\right])</td>
</tr>
<tr>
<td>Input 2</td>
<td>Informational resource: Information resource applied into the meeting</td>
<td>(\sum_{i=1}^{n} (\text{Number of Information Inputs}) i)  (n = \text{number of agenda items})  (\text{Units = Number})</td>
</tr>
<tr>
<td>Input 3</td>
<td>Information-seeking resource: Effort applied by people to seeking to understand and solve issues</td>
<td>(\sum_{i=1}^{n} (\text{Info. Seeking})(\text{AgendaPeople})(\text{AgendaDuration})i)  (n = \text{number of agenda items})  (\text{Info. Seeking} = \text{number of information-seeking methods used in an agenda item})  (\text{AgendaPeople} = \text{number of people contributing to the specific agenda item})  (\text{AgendaDuration} = \text{time duration of the specific agenda item})  (\text{Units = Man-hours (search effort). Number (search types)})</td>
</tr>
<tr>
<td>Output 1</td>
<td>Decisions: Number of agenda items addressed effectively with a decision</td>
<td>(\sum_{i=1}^{n} (\text{Number of Agenda Item Decisions}) i)  (n = \text{number of agenda items})  (\text{Units = Number})</td>
</tr>
<tr>
<td>Output 2</td>
<td>Actions: Number of specific actions agreed</td>
<td>(\sum_{i=1}^{n} (\text{Number of Actions Agreed}) i)  (n = \text{number of agenda items})  (\text{Units = Number})</td>
</tr>
<tr>
<td>Output 3</td>
<td>Responsibilities: Number of specific responsibilities assigned to people</td>
<td>(\sum_{i=1}^{n} (\text{Number of Responsibilities Assigned}) i)  (n = \text{number of agenda items})  (\text{Units = Number})</td>
</tr>
<tr>
<td>Output 4</td>
<td>Informational/data outputs: Number of specific information or data deliverables identified and attached to actions</td>
<td>(\sum_{i=1}^{n} (\text{Number of Information Outputs}) i)  (n = \text{number of agenda items})  (\text{Units = Number})</td>
</tr>
</tbody>
</table>

These inputs and outputs were used to create several productivity metrics, each of which measured a slightly different aspect of productivity, as detailed in Table 7-9.
### Table 7-9: Productivity Metrics for Meetings

<table>
<thead>
<tr>
<th>Output 1 (Decisions)</th>
<th>Productivity Series A&lt;br&gt;<strong>Input 1</strong>&lt;br&gt;(Meeting Labour Resource)</th>
<th>Productivity Series B&lt;br&gt;<strong>Input 2</strong>&lt;br&gt;(Meeting Information Resource)</th>
<th>Productivity Series C&lt;br&gt;<strong>Input 3</strong>&lt;br&gt;(Meeting Search Effort Resource)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity</strong>.1.1 = (\frac{\text{Output 1}}{\text{Input 1}})</td>
<td>Efficiency of collective decision-making during the meeting</td>
<td>Efficiency of generating agreed decisions from the informational inputs</td>
<td>Efficiency of decision-making from search efforts to understand the problem and find solutions</td>
</tr>
<tr>
<td>Units = Number of decisions / Man-hour</td>
<td>Units = Ratio (dimensionless)</td>
<td>Units = Number of decisions / Man-hour × Number of Search types</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output 2 (Actions)</th>
<th>Productivity Series A&lt;br&gt;<strong>Input 1</strong>&lt;br&gt;(Meeting Labour Resource)</th>
<th>Productivity Series B&lt;br&gt;<strong>Input 2</strong>&lt;br&gt;(Meeting Information Resource)</th>
<th>Productivity Series C&lt;br&gt;<strong>Input 3</strong>&lt;br&gt;(Meeting Search Effort Resource)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity</strong>.2.1 = (\frac{\text{Output 2}}{\text{Input 1}})</td>
<td>Efficiency of collective action-taking during the meeting</td>
<td>Efficiency of generating agreed actions from the informational inputs</td>
<td>Efficiency of action-taking from search efforts to understand the problem and find solutions</td>
</tr>
<tr>
<td>Units = Number of actions / Man-hour</td>
<td>Units = Ratio (dimensionless)</td>
<td>Units = Number of actions / Man-hour × Number of Search types</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output 3 (Responsibilities)</th>
<th>Productivity Series A&lt;br&gt;<strong>Input 1</strong>&lt;br&gt;(Meeting Labour Resource)</th>
<th>Productivity Series B&lt;br&gt;<strong>Input 2</strong>&lt;br&gt;(Meeting Information Resource)</th>
<th>Productivity Series C&lt;br&gt;<strong>Input 3</strong>&lt;br&gt;(Meeting Search Effort Resource)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity</strong>.3.1 = (\frac{\text{Output 3}}{\text{Input 1}})</td>
<td>Efficiency of generating agreed responsibilities for actions during the meeting</td>
<td>Efficiency of generating agreed responsibilities from the informational inputs</td>
<td>Efficiency of generating agreed responsibilities from search efforts to understand the problem and find solutions</td>
</tr>
<tr>
<td>Units = Number of responsibilities / Man-hour</td>
<td>Units = Ratio (dimensionless)</td>
<td>Units = Number of responsibilities / Man-hour × Number of Search types</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output 4 (Information)</th>
<th>Productivity Series A&lt;br&gt;<strong>Input 1</strong>&lt;br&gt;(Meeting Labour Resource)</th>
<th>Productivity Series B&lt;br&gt;<strong>Input 2</strong>&lt;br&gt;(Meeting Information Resource)</th>
<th>Productivity Series C&lt;br&gt;<strong>Input 3</strong>&lt;br&gt;(Meeting Search Effort Resource)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity</strong>.4.1 = (\frac{\text{Output 4}}{\text{Input 1}})</td>
<td>Efficiency of generating informational outputs</td>
<td>Efficiency of generating informational outputs from informational inputs</td>
<td>Efficiency of generating informational outputs from search efforts to understand the problem and find solutions</td>
</tr>
<tr>
<td>Units = Number of informational outputs / Man-hour</td>
<td>Units = Ratio (dimensionless)</td>
<td>Units = Number of informational outputs / Man-hour × Number of Search types</td>
<td></td>
</tr>
</tbody>
</table>

Results of the analyses of the productivity metrics show that some meetings were much more productive than others, but the meetings were not uniformly productive across all the productivity metrics. The results are presented in three graphs, given in Figure 7-16, Figure 7-17 and Figure 7-18. Note that the results are presented with the meeting numbers rearranged.
in each case to give a decreasing rank order of productivity (the order of the meetings is different in each case).

![Productivity Series A for Outputs for Man-hour Inputs](image)

**Figure 7-16: Productivity Series A for Outputs / Man-hour Inputs**

In Figure 7-16 the productivity of the four metrics is generally in alignment. The relationship between Productivity.1.1, Productivity.2.1, Productivity.3.1, and Productivity.4.1 was investigated using the Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. A statistically significant and strong positive correlation was found between the four metrics; \( r = .89, .77 \) and \( .78 \) respectively \( n = 49, p < .001 \), with higher Productivity.1.1 being associated with a higher productivity in all other Productivity Series A metrics.

The productivity of generating actions, responsibilities and informational outputs follows the trend in productivity of decision-making. There are some exceptions, however, notably Meeting 38, with a spike in informational producing productivity, which can be accounted for by the fact that it was a relatively short meeting in which one agenda item generated a lot of informational outputs. Also, Meeting 45 has a significant decline in actions and responsibility decision-making, which can be accounted for by the fact that it was a design coordination meeting in which most of the design packages were now complete and therefore the number of actions were low.

The analyses also indicate that some meetings are much more productive than others. Examination of the features of the top 10 meetings (20% to total) indicates that these meetings were generally shorter in duration than average, generally of the traditional system (8 out of 10), with a less than average number of participants and lower than average apparent complexity,
and chaired by the same person (7 out of the 10 chaired by the same chairperson). Examination of the features of the bottom 10 meetings (20% to total) indicates that these meetings were invariably longer in duration than average, a mix of meeting types, with a more than average number of participants (7 out of 10) and average apparent complexity, and chaired by a range of people. These relationships were used to generate a number of hypotheses and tested using statistical analyses, reported in a later section.

![Productivity Series B of Outputs for Information Inputs](image)

**Figure 7-17: Productivity Series B for Outputs / Information Inputs**

In Figure 7-17 we again find that the productivity of the metrics generally follows the productivity of the decision-making, but the productivity of the information outputs/inputs (Productivity.4.2) is less closely correlated with the other metrics. The relationship between Productivity.1.2, Productivity.2.2, Productivity.3.2, and Productivity.4.2 was investigated using the Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. A statistically significant and strong positive correlation was found between the four metrics; $r = .75$, $.57$ and $.49$ respectively $n = 49$, $p < .001$, with higher Productivity.1.2 being associated with a higher productivity in all other Productivity Series B metrics.

Again, there are some outliers. Meeting 10 was very efficient at generating responsibilities, and this can be accounted for by the fact that it was a Last Planner style meeting that involved the formation of a number of subgroups for a part of the meeting. Also, Meeting 20 has a spike in information outputs/inputs that can be accounted for by the fact that the meeting involved updating of numerous KPI results.
Examination of the features of the top 10 meetings (20% to total) indicates that these meetings were generally of average duration, generally of a free-style meeting system (9 out of 10), with a less than average number of participants and higher than average apparent complexity, and chaired by three people (5 meetings by 1 chairperson, 4 by another, 1 by another). Examination of the features of the bottom 10 meetings (20% to total) indicates that these meetings were of a random mix of durations, mostly of traditional style (7 out of 10), with a random number of participants and above average apparent complexity, and chaired by a range of people.

![Productivity Series C for Outputs for Search Effort Inputs](image)

**Figure 7-18: Productivity Series C for Outputs / Search Effort Inputs**

In Figure 7-18 the productivity of the metrics again generally follows the productivity of the decision-making, indicating that a good strategy for maximising the productive benefit of meetings is to focus on optimising the number of decisions made against agenda items. The relationship between Productivity.1.3, Productivity.2.3, Productivity.3.3, and Productivity.4.3 was investigated using the Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. A statistically significant and strong positive correlation was found between the four metrics; \( r = .92, .85 \) and \( .80 \) respectively \( n = 49, p < .001 \), with higher Productivity.1.3 being associated with a higher productivity in all other Productivity Series C metrics.

Again, there are some outliers. Meeting 7 was particularly productive at generating information outputs, which can be explained by the fact that the agenda items were all pre-existing mature issues that were easily resolved with actions and agreed informational outputs. Likewise,
Meeting 38 has a spike in information-producing productivity, which can be accounted for by the fact that it was a relatively short meeting in which one agenda item generated a lot of informational outputs.

Examination of the features of the top 10 meetings (20% to total) indicates that these meetings were generally shorter in duration than average, generally of a traditional system (8 out of 10), with a random number of participants and lower than average apparent complexity, and chaired by a range of people. Examination of the features of the bottom 10 meetings (20% to total) indicates that these meetings were invariably longer in duration than average, a mix of meeting types, with a more than average number of participants (8 out of 10) and greater than average apparent complexity, and chaired by a range of people.

A summary of the findings for each series of productivity metrics is given in Table 7-10.

### Table 7-10: Key Factors for the Upper and Lower 20% of Productive Meetings

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting duration</td>
<td>Shorter than average</td>
<td>Average</td>
<td>Shorter than average</td>
</tr>
<tr>
<td>Style of meeting</td>
<td>Traditional (8 of 10)</td>
<td>Free style (9 of 10)</td>
<td>Traditional (8 of 10)</td>
</tr>
<tr>
<td>Number of agenda items</td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>Numbers of participants</td>
<td>Less than average</td>
<td>Less than average</td>
<td>Less than average</td>
</tr>
<tr>
<td>Apparent complexity</td>
<td>Lower than average</td>
<td>Higher than average</td>
<td>Lower than average</td>
</tr>
<tr>
<td>Chairperson</td>
<td>Limited to 4 chairs (7 meetings by 1 chair, other 3 by 3 different chairs)</td>
<td>Limited to 3 chairs (5 meetings by 1 chair, 4 by another, 1 by another)</td>
<td>Range of chairs</td>
</tr>
<tr>
<td>Meeting duration</td>
<td>Longer than average (high variability)</td>
<td>Longer than average (high variability)</td>
<td>Longer than average (high variability)</td>
</tr>
<tr>
<td>Style of meeting</td>
<td>Random mix</td>
<td>Traditional (7 of 10)</td>
<td>Random mix</td>
</tr>
<tr>
<td>Number of agenda items</td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>Numbers of participants</td>
<td>Higher than average (high variability)</td>
<td>Average</td>
<td>Higher than average</td>
</tr>
<tr>
<td>Apparent complexity</td>
<td>Average</td>
<td>Higher than average</td>
<td>Higher than average</td>
</tr>
<tr>
<td>Chairperson</td>
<td>Range of chairs (6 different chairs)</td>
<td>Range of chairs (7 different chairs)</td>
<td>Range of chairs (8 different chairs)</td>
</tr>
</tbody>
</table>

From these findings it is possible to conclude that there is a wide range of variation in meeting productivities. The causal factors for the variations appear to be multifactorial. However, key factors in influencing the productivity are the rate of decision-making (resulting in shorter meetings), the number of participants, the style of meeting and the chairperson.
It should be noted that there is a very low correlation between the meetings that appear in the top 20% and the different productivity series, as illustrated in Figure 7-19:

![Figure 7-19: Matrix for Upper 20% of Productive Meeting for Each Productivity Series](image)

There is only one meeting (Meeting 4) that features in the upper 20% band of all three productivity series. There is a slightly greater correlation between Productivity Series A and C, with four meetings common in the upper 20% band. This indicates that each productivity series measures different facets of the meetings and that there are trade-offs to be made for the different kinds of meeting productivity.

A similar examination of the lower 20% of productive meetings for each series is given in Figure 7-20.

![Figure 7-20: Matrix for Lower 20% of Productive Meeting for Each Productivity Series](image)

Here we find a higher degree of correlation of meetings that feature in the lower band, with four meetings featuring in all three of the productivities series (namely, Meetings 14, 20, 47 and 49). There appears to be a trade-off between Productivity Series A (outputs / man-hour inputs) and Productivity Series B (outputs / information inputs). Productivity Series A metrics indicate that the traditional style of meeting (chaired with a set agenda) is more productive at generating outputs than other styles of meeting. However, this finding may be skewed by one particularly effective chairperson who chaired a number of the most productive meetings. Productivity Series B metrics indicate that free-style meetings are better at generating outputs with less informational inputs than traditional or facilitated meetings. These findings can be accounted for rationally, as a free-style meeting uses time at the beginning to brainstorm hot topics and does not follow any set agenda, and therefore has less informational inputs than other more planned meetings. Hence, there is a trade-off, with free-style meetings allowing more freedom and
spontaneity, addressing current (hot) issues, but at the expense of traditional efficiency in terms of use of human resources. In other words, there is a trade-off between creative productivity and labour productivity.

7.7.2 Patterns within Meetings

The patterns of discussion during meetings were investigated by examining the lengths of time taken to discuss each agenda item, and plotting them against the apparent complexity score (Likert 1–5 scale). Plots indicate that within any one meeting there is a random pattern, as illustrated in Figure 7-21.

![Figure 7-21: Typical Example of a Time Series Graph for Agenda Item and Apparent Complexity](image)

Reviewing all of the patterns for all of the meetings failed to identify any typical pattern for the meetings other than randomness. The relationship between agenda item duration and apparent complexity was investigated using the Spearman’s rank-order correlation, which revealed a statistically significant and strong positive correlation between the two variables, $r_s = .56$, $n = 562$, $p < .001$, with long agenda item duration associated with a higher apparent complexity.

However, examination of the more productive meetings and comparing them with less productive meetings revealed that the patterns in the most productive meetings had much less variability of agenda item duration, and a decoupling of the agenda item duration with the apparent complexity. The pattern in Meeting 4 (the one meeting that appears in the top 20% of all three productivity series) reveals a somewhat different pattern, as illustrated in Figure 7-22.
If we contrast this with the pattern for one of the meetings that featured poorly in all three productivity series, we see a rather different pattern, with much greater variability in the agenda durations.

A method of ensuring meetings remain productive could therefore be to set a time limit for discussion on each agenda item, and for the chairperson to keep an eye on the clock to maintain a steady pace for decision-making. Obviously, there is a need for judgement and a balance to give sufficient time to understand the agenda item issue, consider options, constraints and so on, but if discussion can remain focused towards quick decision-making on all agenda items, it should help optimise meeting productivity.

### 7.7.3 Statistical Testing of Hypotheses

A number of hypotheses were generated and tested for statistical significance and relationship using SPSS software. In this section we present our hypotheses together with the results of the statistical analyses. An alpha level of 0.05 was identified as appropriate for the exploratory nature of this research. As a number of tests were undertaken on the same data set, a Bonferroni adjustment to the alpha level was applied to protect against Type 1 errors (Pallant,
As 20 tests were undertaken, a more stringent alpha was set using Bonferroni adjustment calculated at $0.05/20 = 0.0025$. Significance levels are reported with exact levels of $p$ values, except where results returned $p < 0.001$. Statistically significant results are highlighted in bold text.

Assumptions of normality, linearity and homoscedasticity were tested by examining histograms, normal probability plots of residuals and scatter diagrams of residuals versus predicted residuals. Variables were also tested for normality using the Kolmogorov-Smirnov statistic. Some of the variables indicated skewed distributions deviating from normality. Examination of the histograms for the distributions indicated a square root, logarithm or inverse distributions, which were transferred using mathematical functions (Pallant, 2013) and subsequently retested for normality.

Given the high level of correlations between productivity metrics within each productivity series, it was unnecessary to test relationships for all of the productivity metrics. Therefore, only productivity metrics across the series for decision-making were used for testing hypotheses. The relationships between productivity metrics within each series were not investigated in order to keep the number of statistical tests to a reasonable limit and hence to limit the potential for Type 1 errors.

The relationships between variables are summarised in Figure 7-24.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Scale</th>
<th>Modified Variable (if applicable)</th>
<th>Modified Scale (if applicable)</th>
<th>Type of meeting</th>
<th>Chairperson</th>
<th>Number of people attending meeting</th>
<th>Duration of Meeting</th>
<th>Number of agenda items</th>
<th>Number of people contributing to agenda items (mean)</th>
<th>Duration of agenda items (mean)</th>
<th>Productivity.1.1</th>
<th>Productivity.1.2</th>
<th>Productivity.1.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of meeting</td>
<td>Categorical: 1) Facilitated 2) Free-style 3) Last Planner 4) Traditional</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Chairperson</td>
<td>Categorical (anonymised with 1-16 numbers)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Number of people attending meeting</td>
<td>Scale (skewed distribution)</td>
<td>Reflect and square root of 'Number of people attending meeting' = SqRt (k-old variable), where k = maximum value +1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Duration of meeting</td>
<td>Scale (normal distribution)</td>
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<tr>
<td>Number of agenda items</td>
<td>Scale (normal distribution)</td>
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<tr>
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<td>Scale (skewed distribution)</td>
<td>Log10 of 'Number of people contributing to agenda items'</td>
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</tr>
<tr>
<td>Duration of agenda items (mean)</td>
<td>Scale (skewed distribution)</td>
<td>Inverse of 'Duration of agenda items (mean)'</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Productivity.1.1</td>
<td>Scale (skewed distribution)</td>
<td>Square root of 'Productivity.1.1'</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Productivity.1.2</td>
<td>Scale (normal distribution)</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Productivity.1.3</td>
<td>Scale (normal distribution)</td>
<td>Square root of 'Productivity.1.3'</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Hypothesis 08: Pearson $r = -.57$, $n = 49$, $p < .001$
Hypothesis 09: Pearson $r = .49$, $n = 49$, $p < .001$
Hypothesis 10: Pearson $r = .28$, $n = 49$, $p = .053$
Hypothesis 11: Pearson $r = .54$, $n = 49$, $p < .001$
Hypothesis 12: Pearson $r = .67$, $n = 49$, $p < .001$
Hypothesis 13: Pearson $r = -.60$, $n = 49$, $p < .001$
Hypothesis 14: Pearson $r = -.67$, $n = 49$, $p < .001$

Relationship explored in regression analysis

Key: ANOVA (F, p) Two-way ANOVA (F, p) Test for correlation (Pearson $r$, n, p) Bold text in results indicates statistical significance at $p < .0025$ level

Figure 7-24: Summary of Statistical Tests for Meetings Variables
We formulated 14 hypotheses generated from reviews of the preliminary analyses presented in previous sections. We also explored relationships between productivity metrics and variables using regression analysis. The findings of the hypothesis testing and regression analysis are reported in the following sections.

**Null Hypothesis H01**: There is no difference in ‘durations of meetings’ for different ‘styles of meeting’ and different ‘chairpersons’.

**Alternative Hypothesis H01**: There is a difference in ‘durations of meetings’ for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings being of shorter durations than other styles of meeting.

In Hypothesis H01 we made a conjecture that there would a difference in ‘durations of meetings’ for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings being of shorter durations than other styles of meeting. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that traditional meetings appeared to be more compact in duration and some chairpersons were more skilled at chairing their meetings than others.

A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, n = 5; Gp2, free style, n = 19; Gp3, Last Planner, n = 2; Gp4, traditional, n = 23) and chairperson for the durations of meetings. The interaction effect between style of meeting and chairperson was not statistically significant, $F(1, 29) = 0.94, p = .34$. There was no statistically significant main effect for type of meeting at the $p < .0025$ level: $F(3, 29) = 5.05, p = .006$. However, at $p < .05$ this would become significant. The size effect, calculated using partial eta squared, was .34, which is a large effect on the Cohen classification. Post-hoc comparisons indicated that the mean score for traditional was the lowest (Gp1, facilitated, $M = 102$; Gp2, free style, $M = 67$; Gp3, Last Planner, $M = 82$; Gp4, traditional, $M = 62$), with Tukey’s HSD test indicating significance between Gp1 and Gp2, and between Gp1 and Gp4, but with differences between other groups not differing significantly. There was no statistically significant main effect for chairperson at the $p < .0025$ level: $F(15, 29) = 2.07, p = .045$.

Hence, there was a failure to reject the Null Hypothesis H01 (but is worthy of further study given that $p = .006$).

**Null Hypothesis H02**: There is no difference in ‘number of agenda items’ for different ‘styles of meeting’ and different ‘chairpersons’.

**Alternative Hypothesis H02**: There is a difference in the ‘number of agenda items’ for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings covering more agenda items than other styles of meeting.

In Hypothesis H02 we made a conjecture that there would be a difference in the ‘number of agenda items’ for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings addressing more agenda items than other styles of meeting. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that traditional meetings appeared to often be more efficient and some chairpersons were more skilled at chairing their meetings than others.
A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, n = 5; Gp2, free style, n = 19; Gp3, Last Planner, n = 2; Gp4, traditional, n = 23) and chairperson for the durations of meetings. The interaction effect between style of meeting and chairperson was not statistically significant, $F(1, 29) = 1.78, p = .19$. There was no statistically significant main effect for type of meeting at the $p < .0025$ level: $F(3, 29) = 1.72, p = .19$. There was no statistically significant main effect for chairperson at the $p < .0025$ level: $F(15, 29) = 1.76, p = .093$.

Hence, there was a failure to reject the Null Hypothesis $H_{02}$.  

Null Hypothesis $H_{03_0}$: There is no difference in the average (mean) ‘number of people contributing to agenda items’ of meetings for different ‘styles of meeting’ and different ‘chairpersons’.

Alternative Hypothesis $H_{03_a}$: There is a difference in the average (mean) ‘number of people contributing to agenda items’ of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings enabling fewer people to contribute than other styles of meeting.

In Hypothesis $H_3$ we made a conjecture that there would be a difference in the average (mean) ‘number of people contributing to agenda items’ of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings enabling fewer people to contribute than other styles of meeting. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that traditional meetings were more highly structured and some chairpersons were more skilled at chairing their meetings than others.

A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, n = 5; Gp2, free style, n = 19; Gp3, Last Planner, n = 2; Gp4, traditional, n = 23) and chairperson for the average (mean) number of people contributing to agenda items. The interaction effect between style of meeting and chairperson was not statistically significant, $F(1, 29) = .82, p = .19$. There was no statistically significant main effect for type of meeting at the $p < .0025$ level: $F(3, 29) = 5.17, p = .006$. However, at $p < .05$ this would become significant. The size effect, calculated using partial eta squared, was .35, which is a large effect on the Cohen classification. Post-hoc comparisons indicated that the mean score for traditional was the lowest (Gp1, facilitated, $M = .78$; Gp2, free style, $M = .65$; Gp3, Last Planner, $M = .87$; Gp4, traditional, $M = .58$), with Tukey’s HSD test indicating significance between Gp1 and Gp4, and between Gp12 and Gp4, but differences between other groups were not significant. There was no statistically significant main effect for chairperson at the $p < .0025$ level: $F(15, 29) = 2.27, p = .029$.

Hence, there was a failure to reject the Null Hypothesis $H_{03_0}$ (but is worthy of further study given that $p = .006$).
Null Hypothesis H04: There is no difference in the average (mean) ‘duration of agenda item discussions’ for different ‘styles of meeting’ and different ‘chairpersons’.

Alternative Hypothesis H04: There is a difference in the average (mean) ‘duration of agenda item discussions’ for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings having shorter duration discussions than other styles of meeting.

In Hypothesis H04 we made a conjecture that there would be a difference in the average (mean) ‘duration of agenda item discussions’ for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings having shorter duration discussions than other styles of meeting. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that traditional meetings appeared to often be more efficient and some chairpersons were more skilled at chairing their meetings than others.

A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, n = 5; Gp2, free style, n = 19; Gp3, Last Planner, n = 2; Gp4, traditional, n = 23) and chairperson for the durations of meetings. The interaction effect between style of meeting and chairperson was not statistically significant, $F(1, 29) = .39, p = .57$. There was no statistically significant main effect for type of meeting at the $p < .0025$ level: $F(3, 29) = 2.53, p = .077$. There was no statistically significant main effect for chairperson at the $p < .0025$ level: $F(15, 29) = .97, p = .51$.

Hence, there was a failure to reject the Null Hypothesis H04.

Null Hypothesis H05: There is no difference in ‘Productivity.1.1’ (labour productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’.

Alternative Hypothesis H05: There is a difference in ‘Productivity.1.1’ (labour productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings being more productive against the Productivity.1.1 metric than other styles of meeting.

In Hypothesis H05 we made a conjecture that there would be a difference in ‘Productivity.1.1’ (labour productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings being more productive for use of human resources for decision-making than others. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that traditional meetings were more highly structured and some chairpersons were more skilled at chairing their meetings than others.

A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, n = 5; Gp2, free style, n = 19; Gp3, Last Planner, n = 2; Gp4, traditional, n = 23) and chairperson for labour productivity (Productivity.1.1). The interaction effect between style of meeting and chairperson was not statistically significant, $F(1, 29) = 0.21, p = .65$. There was a statistically significant main effect for type of meeting at the $p < .0025$ level: $F(3, 29) = 7.9, p = .001$. The size effect, calculated using partial eta squared, was .45, which is a large effect on the Cohen classification. Post-hoc comparisons indicated that the mean score for traditional was the highest (Gp1, facilitated, $M = .61$; Gp2, free style, $M = .83$; Gp3, Last Planner, $M = .52$;
Gp4, traditional, $M = .98$), with Tukey’s HSD test indicating significance between Gp1 and Gp4, and between Gp2 and Gp4, and between Gp3 and Gp4, but differences between other groups were not significant. There was also a main effect for chairperson: $F(15, 29) = 5.5, p < .001$. The size effect, calculated using partial eta squared, was .74, which is a large effect on the Cohen classification. Post-hoc comparisons indicated differences in mean scores for different chairpersons, but did not reach statistical levels for difference between any two particular chairpersons.

Hence, the Null Hypothesis $H_{05a}$ was rejected.

Null Hypothesis $H_{05a}$: There is no difference in ‘Productivity,1.2’ (information productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’.

Alternative Hypothesis $H_{05a}$: There is a difference in ‘Productivity,1.2’ (information productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with free-style meetings being more productive against Productivity,1.2 metric than other styles of meeting.

In Hypothesis H06 we made a conjecture that there would be a difference in ‘Productivity,1.2’ (information productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with free-style meetings being more productive for use of information for decision-making than others. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that free-style meetings were more open and creative and some chairpersons were more skilled at chairing their meetings than others.

A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, $n = 5$; Gp2, free style, $n = 19$; Gp3, Last Planner, $n = 2$; Gp4, traditional, $n = 23$) and chairperson for information productivity (Productivity,1.2). The interaction effect between style of meeting and chairperson was not statistically significant, $F(1, 29) = 0.42, p = .52$. There was no statistically significant main effect for type of meeting at the $p < .0025$ level: $F(3, 29) = 1.13, p = .35$. There was no statistically significant main effect for chairperson at the $p < .0025$ level: $F(15, 29) = 2.07, p = .045$.

Hence, there was a failure to reject the Null Hypothesis $H_{06a}$.

Null Hypothesis $H_{07a}$: There is no difference in ‘Productivity,1.3’ (search effort productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’.

Alternative Hypothesis $H_{07a}$: There is a difference in ‘Productivity,1.3’ (search effort productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with traditional meetings being more productive against Productivity,1.3 metric than other styles of meeting.

In Hypothesis H07 we made a conjecture that there would be a difference in ‘Productivity,1.3’ (search effort productivity) of meetings for different ‘styles of meeting’ and different ‘chairpersons’, with traditional style meetings being more productive for use of search effort for decision-making than others. The rationale for the hypothesis, based on observations during meetings and preliminary analysis presented in Section 7.7.1, was that traditional meetings
were more highly structured and some chairpersons were more skilled at chairing their meetings than others.

A two-way between-groups ANOVA was conducted to explore the impacts of types of meeting (Gp1, facilitated, \( n = 5 \); Gp2, free style, \( n = 19 \); Gp3, Last Planner, \( n = 2 \); Gp4, traditional, \( n = 23 \)) and chairperson for search effort productivity (Productivity). The interaction effect between style of meeting and chairperson was not statistically significant, \( F(1, 29) = 0.21, p = .65 \). There was no statistically significant main effect for type of meeting at the \( p < .0025 \) level: \( F(3, 29) = 2.11, p = .12 \). There was no statistically significant main effect for chairperson at the \( p < .0025 \) level: \( F(15, 29) = .78, p = .79 \).

Hence, there was a failure to reject the Null Hypothesis \( H_{07} \).

\[ \text{Null Hypothesis } H_{07}: \text{There is no correlation between the ‘number of people attending meetings’ and the ‘duration of meetings’}. \]

\[ \text{Alternative Hypothesis } H_{07}: \text{There is a positive correlation between the ‘number of people attending meetings’ and the ‘duration of meetings’}. \]

In Hypothesis \( H_{07} \) we made a conjecture that there would be a positive correlation between the ‘number of people attending meetings’ and the ‘duration of meetings’, the rationale being that it would take longer to discuss issues and make decisions as the number of participants increased.

The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a statistically significant and strong positive correlation between the two variables, \( r = .57, n = 49, p < .001 \), with higher numbers of people participating in the meetings being associated with longer duration meetings.

Hence, the Null Hypothesis \( H_{07} \) was rejected.

\[ \text{Null Hypothesis } H_{08}: \text{There is no correlation between the ‘number of people attending meetings’ and the average (mean) ‘number of people contributing to agenda items’}. \]

\[ \text{Alternative Hypothesis } H_{08}: \text{There is a positive correlation between the ‘number of people attending meetings’ and the average (mean) ‘number of people contributing to agenda items’}. \]

In Hypothesis \( H_{08} \) we made a conjecture that there would be a positive correlation between the ‘number of people attending meetings’ and the average (mean) ‘number of people contributing to agenda items’. This is not necessarily trivial, as some agenda items attract contributions only from small numbers of people irrespective of the numbers of people attending a meeting, and it is not necessarily the case that more people can contribute to discussion on any particular agenda item. However, the rationale for hypothesising a positive relationship was that the more people involved in a meeting the more likely there will be more diversity and a greater number of contributions to each agenda item.
The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a statistically significant and strong positive correlation between the two variables, \( r = .49, n = 49, p < .001 \), with higher numbers of people participating in the meetings being associated with higher numbers of people contributing to discussions on average to individual agenda items.

Hence, the Null Hypothesis H09 was rejected.

\[ \text{Null Hypothesis H10: There is no correlation between the ‘duration of meetings’ and the ‘number of agenda items’.} \]

\[ \text{Alternative Hypothesis H10: There is a positive correlation between the ‘duration of meetings’ and the ‘number of agenda items’.} \]

In Hypothesis H10 we made a conjecture that there would be a positive correlation between the ‘duration of meetings’ and the ‘number of agenda items’, the rationale being that the greater the number of agenda items for discussion the longer it would take to conclude a meeting.

The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a small positive correlation between the two variables, but it failed to reach statistical significance at the \( p < .0025 \) level: \( r = .28, n = 49, p < .053 \).

Hence, there was a failure to reject the Null Hypothesis H10.

This finding was somewhat surprising. However, a possible explanation could be that meetings are generally allocated one hour in people’s diaries, perhaps without too much thought being given to the amount of time needed, and hence discussions fill the time allocated to the meeting regardless of the number of agenda items.

\[ \text{Null Hypothesis H11: There is no correlation between the ‘duration of meetings’ and the average (mean) ‘number of people contributing to agenda items’.} \]

\[ \text{Alternative Hypothesis H11: There is a positive correlation between the ‘duration of meetings’ and the average (mean) ‘number of people contributing to agenda items’.} \]

In Hypothesis H11 we made a conjecture that there would be a positive correlation between the ‘duration of meetings’ and the average (mean) ‘number of people contributing to agenda items’, the rationale being that the greater the number of people contributing to agenda item discussions the longer the discussion period is likely to be.

The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a statistically significant and strong positive correlation between the two variables, \( r = .54, n = 49, p < .001 \), with longer duration meetings being associated with higher numbers of people contributing to discussions on average to individual agenda items.
Hence, the Null Hypothesis H₁₀ was rejected.

Null Hypothesis H₁₂₀: There is no correlation between the ‘duration of meetings’ and the average (mean) ‘duration of the agenda item discussions’.

Alternative Hypothesis H₁₂ₐ: There is a positive correlation between the ‘duration of meetings’ and the average (mean) ‘duration of the agenda item discussions’.

In Hypothesis H₁₂ we made a conjecture that there would be a positive correlation between the ‘duration of meetings’ and the average (mean) ‘duration of the agenda item discussions’, the rationale being that the longer the average duration of discussion for each agenda item in a meeting the longer the overall duration of the meeting. Although this may be somewhat trivial, the strength of any relationship would help to explain the findings in Hypothesis H₁₀.

The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a statistically significant and strong positive correlation between the two variables, \( r = .67, n = 49, p < .001 \), with longer duration meetings being associated with longer durations of individual agenda items.

Hence, the Null Hypothesis H₁₂₀ was rejected.

This finding helps explain in conjunction with H₁₀ that the overall relationship between duration of meetings and agenda items is correlated much more strongly with the duration of the agenda item discussions rather than the number of agenda items.

Null Hypothesis H₁₃₀: There is no correlation between the ‘number of agenda items’ and the average (mean) ‘duration of the agenda item discussions’.

Alternative Hypothesis H₁₃ₐ: There is an inverse correlation between the ‘number of agenda items’ and the average (mean) ‘duration of the agenda item discussions’.

In Hypothesis H₁₃ we made a conjecture that there would be an inverse correlation between the ‘number of agenda items’ and the average (mean) ‘duration of the agenda item discussions’, the rationale being that the greater the number of agenda items the shorter the average duration of discussion on each agenda item. This is a logical hypothesis given the findings of H₁₀ and H₁₂.

The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a statistically significant and strong negative correlation between the two variables, \( r = -.60, n = 49, p < .001 \), with larger number of agenda items associated with shorter durations of individual agenda items.

Hence, the Null Hypothesis H₁₃₀ was rejected.

This finding helps explain in conjunction with H₁₀ and H₁₂ the overall relationship between duration of meetings, the number of agenda items and the average duration of discussion of
It would appear that the number and duration of agenda items tend to flex to fill the available time set for the meeting.

**Null Hypothesis H14:** There is no correlation between the average (mean) ‘number of people contributing to agenda items’ and the average (mean) ‘duration of the agenda item discussions’.

**Alternative Hypothesis H14:** There is a positive correlation between the average (mean) ‘number of people contributing to agenda items’ and the average (mean) ‘duration of the agenda item discussions’.

In Hypothesis H14 we made a conjecture that there would be a positive correlation between the average (mean) ‘number of people contributing to agenda items’ and the average (mean) ‘duration of the agenda item discussions’.

The relationship between the variables was investigated using Pearson product-moment correlation coefficient. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. There was a statistically significant and strong positive correlation between the two variables, $r = .67$, $n = 49$, $p < .001$, with larger average (mean) number of people contributing to discussions on agenda items being associated with longer durations for discussion on agenda items.

Hence, the Null Hypothesis H14 was rejected.

### 7.7.4 Relationships between Meeting Agenda Items and Productivity Using Multiple Regression Analysis

The productivity metrics identified provide a measure of outputs over inputs, and thus each metric is dependent upon its output and input variables; therefore, there is no reason to use statistical techniques to test these metrics for relationships between the output-input variables. For example, Productivity$_{1,1}$ is a metric of number of decisions, number of people attending the meeting, and duration of the meeting, and as such will naturally be correlated with these three variables. However, the effects of the meeting agenda factors as variables upon the productivity metrics are not immediately apparent. Multiple regression techniques were therefore used to investigate the relationships between the meeting agenda factors and productivity metrics. Factors from Figure 7-2 were reviewed and a model was designed for regression analysis as given in Figure 7-25.
A summary of the meeting agenda item used as independent factors in the regression modelling is given in Table 7-11.

Table 7-11: Summary of Meeting Agenda Items as Independent Factors in Regression Analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people contributing to agenda item</td>
<td>4.58</td>
<td>2.63</td>
<td>11.33</td>
<td>49</td>
</tr>
<tr>
<td>Duration of agenda item discussions</td>
<td>433</td>
<td>180</td>
<td>1881</td>
<td>49</td>
</tr>
<tr>
<td>Apparent complexity factor</td>
<td>2.29</td>
<td>1.38</td>
<td>4.33</td>
<td>49</td>
</tr>
<tr>
<td>Apparent age factor</td>
<td>2.84</td>
<td>1.33</td>
<td>3.70</td>
<td>49</td>
</tr>
<tr>
<td>Information-seeking approach to agenda item</td>
<td>1.60</td>
<td>1.00</td>
<td>4.33</td>
<td>49</td>
</tr>
<tr>
<td>Number of constraints to agenda item</td>
<td>1.36</td>
<td>1.00</td>
<td>2.83</td>
<td>49</td>
</tr>
</tbody>
</table>

Hierarchical multiple regression was performed between the dependent variable (Productivity) and the independent variables (meeting agenda factors given in Figure 7-25). Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity occurred. The two variables ‘number of people contributing to agenda item’ and ‘duration of agenda item discussions’ were entered at Step 1, followed by ‘apparent complexity factor’ and ‘apparent age factor’ in Step 2, with the variables ‘information-seeking approach to agenda item’ and ‘number of constraints to agenda item’ in the final Step 3. These regressions were performed in hierarchy to assess the relationships of agenda people and duration (Step 1), the apparent complexity and age factors (Step 2) and agenda item.
searches and constraints (Step 3) respectively in the hierarchy on theoretical grounds and in order to compare between the different productivity metrics.

**Regression Model Analysis and Results for Productivity,.1, Metric**

Regression analysis revealed that the model explains with statistical significance the productivity of meetings as measured by Productivity,.1, metric, as indicated by the results given in Table 7-12.

**Table 7-12: Summary of Hierarchical Multiple Regression Results for Productivity,.1**

<table>
<thead>
<tr>
<th>Step</th>
<th>F</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>$R^2$ Change</th>
<th>$p (R^2$ Change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>$F (2, 46) = 47.72$</td>
<td>.68</td>
<td>.65</td>
<td>.68</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Step 2</td>
<td>$F (4, 44) = 33.73$</td>
<td>.75</td>
<td>.73</td>
<td>.08</td>
<td>.002</td>
</tr>
<tr>
<td>Step 3</td>
<td>$F (6, 42) = 24.25$</td>
<td>.78</td>
<td>.74</td>
<td>.02</td>
<td>.141</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

Step 1 explains 68% of the variance in the model, and Step 2 explains 73% of the variance of the model, with the two variables of ‘apparent complexity factor’ and ‘apparent age factor’ accounting for an additional 8% at a statistically significant confidence level. The final Step 3, including the variables for ‘information-seeking approach to agenda item’ and ‘number of constraints to agenda item’ makes no statistically significant difference to the model. In the final model, only the ‘number of people contributing to agenda item’, ‘duration of agenda item discussions’, ‘apparent age factor’ and ‘information-seeking approach to agenda item’ variables were statistically significant, with the ‘apparent age factor’ recording the highest Standardised $\beta$ value, as given in Table 7-13.

**Table 7-13: Final Model Results from Multiple Regression for Productivity,.1**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>Std. Error</th>
<th>Standardised $\beta$</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people contributing to agenda item</td>
<td>-.845</td>
<td>.233</td>
<td>-.432</td>
<td>-3.621</td>
<td>.001</td>
</tr>
<tr>
<td>Duration of agenda item discussions</td>
<td>78.985</td>
<td>25.956</td>
<td>.324</td>
<td>3.043</td>
<td>.004</td>
</tr>
<tr>
<td>Apparent complexity factor</td>
<td>.049</td>
<td>.053</td>
<td>.120</td>
<td>.928</td>
<td>.359</td>
</tr>
<tr>
<td>Apparent age factor</td>
<td>.230</td>
<td>.062</td>
<td>.441</td>
<td>3.681</td>
<td>.001</td>
</tr>
<tr>
<td>Information-seeking approach to agenda item</td>
<td>-.290</td>
<td>.143</td>
<td>-.194</td>
<td>-2.027</td>
<td>.049</td>
</tr>
<tr>
<td>Number of constraints to agenda item</td>
<td>.103</td>
<td>.166</td>
<td>.055</td>
<td>.620</td>
<td>.538</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

The ‘apparent age factor’ refers to how new or old the agenda item was to the meeting participants, with lower scores being associated with new emerging issues, and higher ‘apparent age factor’ being associated with longer-standing issues.
Regression Model Analysis and Results for Productivity,1.2 Metric

Regression analysis revealed that the model explains a moderate level of the productivity of meetings as measured by ‘Productivity,1.2’ metric, as indicated by the results given in Table 7-14.

Table 7-14: Summary of Hierarchical Multiple Regression Results for Productivity,1.2

<table>
<thead>
<tr>
<th>Step</th>
<th>F</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>R² Change</th>
<th>p (R² Change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>F (2, 46) = .97</td>
<td>.04</td>
<td>−.011</td>
<td>.04</td>
<td>.39</td>
</tr>
<tr>
<td>Step 2</td>
<td>F (4, 44) = .65</td>
<td>.06</td>
<td>−.03</td>
<td>.02</td>
<td>.71</td>
</tr>
<tr>
<td>Step 3</td>
<td>F (6, 42) = 3.81</td>
<td>.35</td>
<td>.26</td>
<td>.30</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

Steps 1 and 2 make no material contribution to the model. Only in the final step, Step 3, including the variables for ‘information-seeking approach to agenda item’ and ‘number of constraints to agenda item’ contributes to the prediction of the Productivity,1.2 model. In the final model only the ‘information-seeking approach to agenda item’ and ‘number of constraints to agenda item’ variables were statistically significant, both with similar Standardised β value, as given in Table 7-15.

Table 7-15: Final Model Results from Multiple Regression for Productivity,1.2

<table>
<thead>
<tr>
<th>Variable</th>
<th>β</th>
<th>Std. Error</th>
<th>Standardised β</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people contributing to agenda item</td>
<td>−.014</td>
<td>.336</td>
<td>−.008</td>
<td>−.041</td>
<td>.967</td>
</tr>
<tr>
<td>Duration of agenda item discussions</td>
<td>15.665</td>
<td>37.406</td>
<td>.076</td>
<td>.419</td>
<td>.678</td>
</tr>
<tr>
<td>Apparent complexity factor</td>
<td>−.013</td>
<td>.076</td>
<td>−.036</td>
<td>−.165</td>
<td>.870</td>
</tr>
<tr>
<td>Apparent age factor</td>
<td>.027</td>
<td>.090</td>
<td>.061</td>
<td>.297</td>
<td>.768</td>
</tr>
<tr>
<td>Information-seeking approach to agenda item</td>
<td>.665</td>
<td>.206</td>
<td>.524</td>
<td>3.223</td>
<td>.002</td>
</tr>
<tr>
<td>Number of constraints to agenda item</td>
<td>−.913</td>
<td>.239</td>
<td>−.578</td>
<td>−3.818</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

This contrasts markedly with the regression model for Productivity,1.1, indicating that the factors that are associated with the two productivity metrics are rather different. Productivity,1.1 is a measure of the efficiency of using labour resource for decision-making, whereas Productivity,1.2 is a measure of the efficiency of using information sources for decision-making. It is therefore reasonable to find that different independent variables contribute to the models to contrasting degrees, as each productivity metric is measuring a different type of efficiency. In terms of efficiency of using information sources for decision-making, we found that productivity is not dependent upon the number of people contributing to the agenda items or the duration of the agenda items, but rather on the depth of enquiry undertaken during discussions to use a range
of information-seeking methods and to gain an understanding of the constraints to the problem or issue being discussed.

**Regression Model Analysis and Results for Productivity \(_{1.3}\) Metric**

Regression analysis revealed that the model significantly explains the productivity of meetings as measured by Productivity \(_{1.3}\) metric, as indicated by the results given in Table 7-16.

**Table 7-16: Summary of Hierarchical Multiple Regression Results for Productivity \(_{1.3}\)**

<table>
<thead>
<tr>
<th>Step</th>
<th>(F)</th>
<th>(R^2)</th>
<th>Adjusted (R^2)</th>
<th>(R^2) Change</th>
<th>(p (R^2) Change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>(F(2, 46) = 47.72)</td>
<td>.70</td>
<td>.69</td>
<td>.70</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Step 2</td>
<td>(F(4, 44) = 33.73)</td>
<td>.72</td>
<td>.70</td>
<td>.02</td>
<td>.154</td>
</tr>
<tr>
<td>Step 3</td>
<td>(F(6, 42) = 24.25)</td>
<td>.80</td>
<td>.77</td>
<td>.07</td>
<td>.002</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

Step 1 explains 69% of the variance in the model, and Step 2 makes no statistically significant difference to the model with the two variables of ‘apparent complexity factor’ and ‘apparent age factor’ added. The final step, Step 3, including the variables for ‘information-seeking approach to agenda item’ and ‘number of constraints to agenda item’, makes a statistically significant difference to the model, accounting for an additional 7% to the predictability of the model towards Productivity \(_{1.3}\). In the final model, only the ‘number of people contributing to agenda item’ and ‘information-seeking approach to agenda item’ variables were statistically significant, with the ‘number of people contributing to agenda item’ recording the highest Standardised \(\beta\) value (based on magnitude and ignoring the direction of effects), as given in Table 7-17.

**Table 7-17: Final Model Results from Multiple Regression for Productivity \(_{1.3}\)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>(\beta)</th>
<th>Std. Error</th>
<th>Standardised (\beta)</th>
<th>(t)</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people contributing to agenda item</td>
<td>-.558</td>
<td>.119</td>
<td>-.533</td>
<td>-4.688</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Duration of agenda item discussions</td>
<td>20.331</td>
<td>13.234</td>
<td>.156</td>
<td>1.536</td>
<td>.132</td>
</tr>
<tr>
<td>Apparent complexity factor</td>
<td>.033</td>
<td>.027</td>
<td>.152</td>
<td>1.237</td>
<td>.223</td>
</tr>
<tr>
<td>Apparent age factor</td>
<td>.055</td>
<td>.032</td>
<td>.197</td>
<td>1.726</td>
<td>.092</td>
</tr>
<tr>
<td>Information-seeking approach to agenda item</td>
<td>.281</td>
<td>.073</td>
<td>.350</td>
<td>3.844</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Number of constraints to agenda item</td>
<td>-.058</td>
<td>.085</td>
<td>-.058</td>
<td>-.685</td>
<td>.497</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

This contrasts with the models for the other productivity metrics. Productivity \(_{1.3}\) measures the efficiency of decision-making from search efforts to understand the problem and find solutions. Hence, it is reasonable to find that the variables that contribute significantly to this productivity metric relate to the intensity of effort by those engaged in the agenda item.
7.8 Discussion

A comparison of the regression models for the different productivity metrics is informative for understanding the issues relating to measuring productivity and understanding productivity drivers, as given in Table 7-18.

Table 7-18: Final Model Results from Multiple Regression Comparing the Three Productivity Metrics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Productivity,1,1</th>
<th>Productivity,1,2</th>
<th>Productivity,1,3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard-ised β</td>
<td>p</td>
<td>Standard-ised β</td>
</tr>
<tr>
<td>Number of people contributing to agenda item</td>
<td>-.432</td>
<td>.001</td>
<td>-.008</td>
</tr>
<tr>
<td>Duration of agenda item discussions</td>
<td>.324</td>
<td>.004</td>
<td>.076</td>
</tr>
<tr>
<td>Apparent complexity factor</td>
<td>.120</td>
<td>.359</td>
<td>-.036</td>
</tr>
<tr>
<td>Apparent age factor</td>
<td>.441</td>
<td>.001</td>
<td>.061</td>
</tr>
<tr>
<td>Information-seeking approach to agenda item</td>
<td>-.194</td>
<td>.049</td>
<td>.524</td>
</tr>
<tr>
<td>Number of constraints to agenda item</td>
<td>.055</td>
<td>.538</td>
<td>-.578</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance

Clearly, each productivity metric is giving us different insights into the productivity of meetings. Each metric is useful, although Productivity,1,1 metric is probably the most straightforward to measure accurately and to interpret.

It should be noted that ‘apparent complexity factor’ and ‘apparent age factor’ are subjective estimates, made by the researcher during observations. Hence, repeatability of the findings of the specific regression models is unlikely and results are useful only as indicative of factors rather than as proofs of any particular relationships. The results will not be generalisable and observations of meetings within just the one case study project is a limitation, which means that the results need to be interpreted with care. However, the comparisons of the productivity metrics and of the regression models for each are useful and indicate the following:

- Each productivity metric, although similar, measures different aspects of efficiency, and the influencing factors are divergent for the contrasting productivity metrics.
- Productivity Series A measures labour productivity and here the key to optimising productivity is managing the number of people and the duration of discussion for agenda items. This concurs with logic. Age of agenda items is also important, and while it may not be possible to directly control the agedness of agenda items, it is important not to let agenda items sit unaddressed between meetings.
Productivity Series B measures efficiency of using information and here the key to improving efficiency is to reduce the constraints applicable to the agenda item being discussed and finding the most appropriate way to unlock the constraints.

Productivity Series C measures the efficiency of search efforts to understand the problem and find solutions. The key to optimising productivity here is to limit the number of people contributing to the discussion. However, caution should be expressed as a focus on efficiency may be to the detriment of effectiveness, and contributions by greater numbers of people may improve the quality of the decision-making and action-taking.

In our findings it would appear that the number of people contributing to the agenda items is the most significant factor in general upon productivity of meetings. This would suggest that a means of improving productivity of meetings could be to limit the number of contributions on each agenda item. While this might help with obtaining quick and efficient decisions, thereby optimising productivity, it brings into question the risk such an approach could have on the effectiveness of the discussion and hence the subsequent effectiveness and value of having the meeting in the first place. It could be possible to hold a meeting in which agenda items are forced to quick but simplistic decisions without giving sufficient time for contributions from all relevant participants, risking a poor understanding of the issues, poor buy-in to the decisions by participants, and ultimately poor outcomes.

Our productivity metrics only give a one-dimensional view and tell us very little about the effectiveness of the meetings. There are no metrics of effectiveness that can be identified, as such effectiveness metrics would need to collect extensive data about the impact of the meetings and the decisions taken upon subsequent implementation of actions. This concept concurs with key findings of Chapters 4 and 5 in that effectiveness of decision-making is potentially more important than simplistic efficiency, but it is worth mentioning here to place the regression analyses in context, and to acknowledge that the main value of these findings is not so much in the specific models for each productivity metric, but rather in gaining a deeper understanding of what productivity metrics are actually showing us. There are some important intrinsic limitations to productivity as a measure of value creation and really productivity just gives a limited insight into efficiency (not effectiveness) of one subsystem component of a wider overall system. The productivity metric tells us nothing of the effectiveness of the subsystem, or the efficiency of the wider system.

7.9 Limitations of this Research Stage (Industry Observations)

This research is based on data generated in the context of a single case study project. Although the case study project was large and complex, providing a suitable environment for observing information flow, the alliance nature of the project is not typical of more traditional project delivery methods normally used in NZ. Nevertheless, it does provide real context for a multidisciplinary engineering and construction project, with the appropriate level of complexity in which to collect meaningful data relevant for the research objectives. Also, the single large
project allowed for analyses without having to control for possible influencing factors that might have been problematic if a range of smaller projects, under differing delivery methods, had been used for data collection. The single case study, however, means that results are not generalisable to all types of engineering and construction projects or to meetings in other contexts.

A further limitation is the reliance upon just one observer for the data collection in that the perceptions of the single observer may be skewed by personal subconscious biases. In contrast, an advantage of having a single observer is consistency of approach in the observations. Repeatability of the findings of the specific regression models is unlikely and results are useful as indicative of factors rather than as proofs of any particular relationships.

Although meetings were observed over a period of time for the case study project, they all related to a particular phase of design and construction, with overlap of the design with early stages of construction on site. This was a good period to observe information flow in engineering and construction, but the limitation should also be noted of the project stage, as other stages such as feasibility, initial scheme design and tendering had already concluded before the meeting observations commenced. Likewise, ongoing detailed design and the bulk of the construction works were still being progressed after the end of the research observations, and these different phases may have had different patterns of information flow.

An important limitation of the observation method of data collection is the Hawthorne effect, through which individuals modify or improve aspects of their behaviour in response to their being observed (McCambridge, Witton, & Elbourne, 2013; Parsons, 1974). While the researcher made deliberate efforts not to influence the meetings by not participating in any discussions, inevitably, the simple presence of an observer will have influenced participants’ behaviours. It is not possible to account for the degree of impact of this known phenomenon, other than to recognise it exists. However, at no point during the observations did the researcher sense any degree of censoring of discussions.

7.10 Conclusions for This Research Stage

Overall, the information flow occurring in the meetings was substantial. While it was possible to measure a number of factors, such as number of agenda items, decisions taken and participants contributing, the quantum of the semantic value of the information shared at the meetings vastly overshadowed the quantum of raw data. It was apparent that the meetings achieved in general the following:

- collective understanding of problems and issues, leading to better definitions of matters before finding solutions and taking actions;
- collective problem-solving, in which specialists from a diverse range of technical competencies contribute to effective solutions;
- consensus building towards actions and allocation of responsibilities;
- coordination of resource effort;
• keeping abreast of issues via information sharing and responding to breaking issues appropriately;
• keeping to commitments and ensuring actions are taken between meetings to monitor and control progress;
• building and maintaining relationships between individuals.
All of these factors lead to value-creating effort, and all are dependent upon information flow via meetings. It would be difficult to achieve the above without holding regular meetings with appropriate people. There are no substitutes that would be even nearly as effective in achieving the above outcomes: face-to-face information flow is the lifeblood of meetings.

Hence, there is a strong link between information flow between people working jointly towards a common goal of a project and the wider effectiveness and efficiency of the project to which the meetings refer. The direct relationship between information flow and productivity may be hard to quantify, but it is more evident via the process of information sharing leading to decision-making, followed by actions, which then affect the use of resources. This is a clear pattern from the meetings and concurs with the findings in Chapter 4, and specifically with our model proposed in Figure 4-17.

We can make a number of qualitative and quantitative conclusions from our findings and analyses as outlined in the next section.

7.10.1 Qualitative Conclusions
It is possible to observe the information flow during meetings and there is a strong link between the quality of the information flow and the outcomes on the wider project or system. The qualitative findings given in Table 7-7 are very pertinent in linking the quality of information with the productivity outcomes, particularly how information sharing during meetings leads to effective decision-making, the potential for information to affect design and construction (and subsequent asset life cycle), avoidance of waste via good information sharing, and the avoidance of possible harm via minimisation of errors from good-quality information. Also, the potential impact of new ideas and innovations stemming from the exchange of information should not be underestimated. The value-creating impact of the innovation process is itself founded on sharing of ideas via exchanges of information. Information shared in meetings is also the foundation for allocation of responsibilities, and clarity of roles and responsibilities enhances coordination of effort and deployment of resources. All of these factors undeniably contribute or hinder the subsequent efficiency and effectiveness of engineering and construction.

While these findings are strongly evident from the meetings and can be backed up with numerous examples, it is hard to measure the quantum of the impact. Suffice to say that the leverage potential of information to create value is very large. One small piece of vital information shared at the right time with the right people via a meeting can release a solution to a problem and create significant value for the project and wider system.
Information flow within meetings follows typical patterns around agenda items, as summarised in Figure 7-14 with three typical stages. After an initial briefing stage, there is often a second exploration stage involving questions and answers, debate and constructive dialogue, followed by a final third stage of decision-making and action-taking. The second stage of exploration is critical for value creation, and involves simultaneous information searching and dissemination between multiple participants. It is this simultaneous search and dissemination between several intelligent agents that is particularly valuable, and is something that is hard, if not impossible, to achieve in alternative forms of communication. The quality of the information flow at this stage typically appears to influence the quality of the subsequent decision-making.

7.10.2 Quantitative Findings

It is possible to measure the productivity of the meetings with a range of different productivity metrics. While such metrics are useful for measuring the efficiency of the meetings, they do not give any insight into the effectiveness of the meetings.

From a labour efficiency point of view, some styles of meetings are more productive than others, with traditional style meetings affording the most efficient use of labour resource within meetings, as measured by our Productivity₁,₁ metric. A regression model for our Productivity₁,₁ metric shows that 74% of the metric can be explained by six input variables, namely, (i) ‘number of people contributing to agenda items’, (ii) ‘duration of agenda items’, (iii) ‘apparent age factor’ of the issues, (iv) ‘apparent complexity factor’ of the issues, (v) ‘information-seeking approach to agenda item’ and the (vi) ‘number of constraints to agenda item’. Of these items, (i), (ii), (iii) and (v) are statistically significant at a confidence level of $p < .0025$. We also found, using the Productivity₁,₁ metric, that the chairperson makes a statistically significant difference to the productivity of meetings.

However, from an information efficiency point of view as well as a search effort efficiency point of view, a different perspective was provided from productivity metrics Productivity₁,₂ and Productivity₁,₃. Here we found different styles of meeting were more productive, with Productivity₁,₂ metric indicating the free-style meetings afforded a greater degree of productivity. Regression analysis indicated that the variables (v) ‘information-seeking approach to agenda item’ and (vi) ‘number of constraints to agenda item’ were of statistical significance for making contributions to information productivity as measured by Productivity₁,₂. In contrast, for Productivity₁,₃ metric the variables (i) ‘number of people contributing to agenda items’ and (v) ‘information-seeking approach to agenda item’ were of statistical significance for making contributions to search effort productivity.

In comparing the contrasting conclusions for the productivity metrics, it is possible to conclude that productivity is not a single dimensional phenomenon, but rather there are different facets of productivity as metrics of output/input, each of which are sensitive to different independent variables. It is therefore important to understand the metric being used and to interpret the results with care. Therefore, it is useful to have the three series of productivity metrics and to compare and contrast the results rather than relying on just one metric. The implications of this
conclusion should be applied to the use of productivity metrics elsewhere. We should therefore always ask “What are we really measuring with this productivity metric and what other metrics should we be using in tandem to gain a better understanding of the underlying issues and causation factors?”

We also found that, in general, for all meetings there is a high degree of correlation between the number of people participating in the meeting, the number of people contributing to agenda items, the duration of the discussion on agenda items and the overall duration of the meeting. Correlations are statistically significant at a confidence level of $p < .0025$. The duration of meetings is not correlated to the number of agenda items at a statistically significant confidence level.

These findings indicate that an important consideration is the number of participants at meetings, not just the number of agenda items and time allocated. A greater number of attendees will naturally lead to a greater number of participants discussing agenda items, longer durations, longer meetings and lower meeting productivity (Productivity$_{1,1}$ metric). However, these quantitative findings and conclusions say nothing of the implications that the number of participants have for the quality of the subsequent outcomes of the meetings and subsequent impact upon the project.

7.10.3 Final Conclusions

Combining the qualitative and quantitative conclusions leads to an overall conclusion that the impact of information flow within meetings is very significant within engineering and construction. Projects could not be progressed effectively without mutual exchanges of information and decision-making in meeting settings. The quantification of the impact is hard to measure, and while our productivity metrics are useful for giving an indication of the efficiency of the meetings themselves, the effectiveness dimension of meetings is arguably of more significance.

7.11 Recommendations

7.11.1 Recommendation for Using Meetings to Facilitate Project Productivity Outcomes

We make two key recommendations for the use of meetings to help ensure excellent outcomes on projects:

- Use project meetings to help build shared understanding and consensus building around the solving of problems, the making of decisions, the negotiation of actions and the allocation of responsibilities, as these will in turn determine the quality of outcomes on projects.
- Hold regular meetings to facilitate a regular information flow and assist with resolving issues.
7.11.2 Recommendations for Productive Meetings

For anybody wishing to take recommendations on our findings relating to meetings in engineering and construction, we propose the following:

- Select the type of meeting (traditional, free style or facilitated) to suit the objectives you wish to achieve.
- Ensure the right people are involved to make the meeting effective, but not too many people because of the risk of reducing the efficiency of the meeting for decision-making.
- The role of the chairperson is important and he/she needs to focus on facilitating effective information flow during agenda item discussions.
- Set a clear purpose for the meeting and ensure that it is achieved, or at least that significant progress is made towards the purpose.
- Tone of the meeting is important; set a positive and constructive atmosphere.
- Positively solicit contributions from all attending.
- Ensure that relevant and purposeful actions are agreed, with responsibilities assigned.
- Look for new insights or discoveries during the meeting.
- Seek to resolve problems and issues that arise and make agreements wherever possible.
- Insist that actions from previous meetings are taken and acted upon in accordance with previous agreements.
- Evidence shows that the duration of agenda items will flex to fill the available time; therefore, seek to maximise the benefit of the meeting by planning and controlling the agenda item discussions.
- Focus on the qualitative value of the discussions, not just getting through the agenda quickly.

7.11.3 Recommendations for Further Research

Recommendations for future directions of research include the following:

- Undertake similar data collection and analysis on other engineering projects to expand the data set and make comparisons. This could enable assessment of contextual influences, and start to indicate some patterns leading to more generalised models and conclusions.
- Explore possible metrics for measuring the effectiveness of meetings. A possible direction is to interview some participants in periods following key meetings, and obtaining some subjective scoring on effectiveness.
- Track the extent to which actions agreed during meetings are subsequently completed and add value to the project or wider system to which the decision relates.

7.12 Further Conclusions Combining Chapters 4, 5, 6 and 7

In the conclusions to Chapter 4 we proposed an information flow productivity causality model showing the linkage between information stations to productivity outcomes via intermediate
stations of decision-making, action-taking and contextual issues. In Chapter 5 we decomposed the contextual issues relating to productivity in task, teams, project, organisation and industry and proposed a more detailed model, based on the initial model, but enhanced to provide more contextual matters in engineering and construction. In Chapter 6 we enhanced our understanding of information stations and also identified the iterative nature of decision-making and its impact upon productivity performance. In this chapter we have explored the information flow and productivity issues across all the stations, from information, through decision-making, actions, context and outcomes. The focus has been at the level of meetings within a single case study project, and hence at the level of team and project, as illustrated in Figure 7-26.

**Figure 7-26: Annotated Generic Information Flow and Productivity Causality Model with Objectives of This Chapter**

The findings of this chapter have deepened our understanding of information flow in all aspects of the model, summarised as follows:

- **Information station:** Quality of information is paramount. People, rather than documents, are the preferred source of information as people are able to filter data to bring pertinent information into the decision-making forum of a meeting.

- **Decision-making station:** Information is the basic ingredient for decision-making. The better the quality of information the better, in general, the quality of the decision-making. The value-creating impact of the innovation process is itself founded on sharing of ideas via exchanges of information. Information flow within meetings follows typical patterns
around agenda items, with three typical stages. After an initial briefing stage, there is a second exploration stage involving questions and answers, debate and constructive dialogue, followed by a final third stage of decision-making and action-taking. The second stage of exploration is critical for value creation, and involves simultaneous information searching and dissemination between multiple participants. The sharing of information is also required for building shared understanding within meetings, which is necessary as a precursor to finalising decisions and agreeing on actions. Shared understanding also enables allocation of responsibilities based on mutual trust and cooperation, so that responsibilities can be shared or allocated appropriately.

• Action station: Information has the potential to affect actions taken following decisions. In the context of engineering and construction this is particularly relevant in consideration of design and construction (and subsequent asset life cycle). Numerous examples were evident throughout the observations. These are often most evident in terms of avoidance of waste via good information sharing, and the avoidance of possible harm via minimisation of errors from good-quality information.

• Context station: The context of the case study, an alliance of seven organisations working in partnership to achieve delivery of NZ’s largest roading infrastructure project, illustrated the importance of project coordination, integration and teamwork. Reducing the constraints from contextual issues is a good strategy for improving productivity, as indicated by the regression model on metric Productivity1.2, which also concurs with our findings in Chapter 6. We found that productivity of the project is dependent upon the effectiveness of the team, and that a focus on the effectiveness of team decision-making can unlock greater efficiency at the project level, which confirms our stratified model of productivity at task, team, project, organisation and industry level.

• Outcome station: In comparing the contrasting conclusions for the productivity metrics it is possible to conclude that productivity is not a single dimensional phenomenon, but rather there are different facets of productivity as metrics of output/input, each of which is sensitive to the factors that contribute to the output and/or input criteria. The opportunity to improve performance is more significant by focusing on effectiveness rather than efficiency.

Overall, the model is useful for understanding the nature of the complex relationships between information flow and productivity.
8 A New Theory of Information: An Information Semantic Theoretical Model

8.1 Introduction

In this chapter we present a new theory of information, drawing upon existing literature and the findings of previous chapters.

No previous authors appear to have linked information with the concept of future subjective expected utility or subjective expected value. Information theories to date appear to concentrate on quantification of the signal content, rather than the quantification of the semantic value of information. A measure of the value of information is needed in order to investigate linkages between information as an input to a process and value created from the information as an output or outcome. The impact of information flow on productivity is a case in point (productivity being a measure of output against input). The development of this hypothesis has arisen from ongoing research investigating information flow and productivity improvement, but our hypothesis may be applicable to other information fields.

Our theory explains and quantifies the semantic value of information. The concept is that information is the medium that connects the present with the future expected utility. Information is anything that has an impact on the future value of an expectation held by an intelligent agent in receipt of the information signal. Future value is subjective from the viewpoint of the information receiver, and may be tangible (e.g., monetary, time) or intangible (e.g., quality of life, social standing). The subjective value gradually converts to real value with the natural progression of time, but at the point of receipt of information the value is an expectation and is subjective.

8.2 Objectives and Goals of This Research Stage

The purpose of this stage of the research was to develop a new definition for information. This was identified as needed in order to clarify the concept of information, which has many different definitions in the existing literature. Also, we perceived that it would be helpful to have a clearer distinction between information as a general concept, comprising elements of data, knowledge, signals and so on, and real information, being information with semantic value. The focus of this chapter therefore has one main objective:

- Objective 1: Generate a new definition and theory of information with respect to the semantic value of information.

This objective is illustrated with reference to our model in Figure 8-1, which indicates that the focus of this chapter is the development of our understanding of the concept of information as a philosophical concept. Having a deeper understanding of the concept of information will help with future research into the field, and potentially for wider fields that also draw on concepts of information theories.
Rather than collect any new data for this stage of the research, we developed a theory based on existing theories of information and philosophical argument, while also drawing upon some of the data and results from previous chapters.

Before presenting our information theory, we refer the reader to Section 2.2 in the literature review, as our theoretical discussion and development picks up from the discussion presented in this section. None of the existing theories define information from the perspective of the receiver, and it is in this regard that our theory provides a new perspective by reference to information-seeking (i.e., pull) patterns.

### 8.3 Scenario Proposition and Consideration

Consider a common scenario: applying for a job. At the beginning of the search the job seeker has no information pertaining to, or knowledge of, the future job he/she will eventually be offered. However, let us assume that at some point in the future the seeker will eventually be offered a job. There is value derived from having a job, which can be expressed in monetary terms (income) and other intangible terms (sense of purpose, self-worth, etc.). This is illustrated in Figure 8-2.
For this discussion we ignore considerations of discounting future monetary incomes into today’s value of money, as we wish to focus on the nature of information flow in the employment search. Also, for the time being we show the slope of the value line on the graph as increasing on a simple linear basis, indicative of ongoing income and benefits to be derived from the future job that accrues with time once the job is secured. The line is shown in this example on a simple linear basis as a simplified illustration, and the shape of value lines may differ depending upon the scenario.

A typical sequence of events for the job search (from an information flow view) might involve numerous information stages as shown indicatively in Figure 8-3, and described as follows:

1. At time \( T = 0 \) information (and data and knowledge) relating to the future job is nil.

2. An initial information search through company websites identifies a shortlist of companies that have jobs advertised, and providing details of the positions they are advertising. These state the qualifications and experience the potential employers are looking for. These findings are useful information. There has been an information flow, which has occurred because the receiver (job seeker) has obtained some indication of which companies are advertising roles that he/she is potentially qualified to do.

3. Having made job applications, the job seeker is called to an interview. A letter received inviting the seeker to an interview is a flow of information, as again, there is a change in the recipient’s future expected value. Other letters received that decline the applicant are also flows of information; these have reduced the likelihood of the job seeker receiving a job offer and the effect has been to reduce possible future value (perceived by the recipient). However, for this illustration we will follow the positive letter inviting the seeker to interview.

4. At the interview the job seeker finds that the company is looking for somebody with very specific experience and skills, which the seeker happens to have. The interview goes
well and at the end there is a discussion on salary expectations and the interviewer gives very positive signs. Again, there has been a flow of information, which has increased the expected future value. At this point the job seeker becomes relatively confident he/she will receive an employment offer.

5. Next day the seeker receives a formal job offer, and the salary offered is in alignment with expectations. Again, there has been an information flow, and the offer letter makes the future value ‘bankable’.

We can plot each of these information flows on the diagram as shown in Figure 8-3.

![Time Value Graph for Scenario of a Future Job Offer Showing Information Flow Stages](image)

Let us continue with our consideration of the scenario and assume that the overall process occurs much more quickly than initially expected. At Point 5 (receipt of firm employment offer) the future expected value is almost fully released, and the job seeker now has a contract and can use the offer of employment to apply for things like a mortgage (even though he/she has not yet drawn the first pay package). Hence, each stage of information flow in this example pulls forward in time the future expected value, and while doing so releases value (from the perspective of the recipient).

Our example illustrates a generally positive information flow and hence is an example of receipt of good news. By contrast, in the contrary direction, receipt of negative information (or bad news) destroys future expected value (that is, expected future value from the perspective of the recipient). Value is destroyed either by reducing the quantum of future value or by delaying the outcome.

Information usually precedes the outcome, although sometimes they can happen in close succession or even simultaneously. For example, scoring the winning goal in a sports game in the last seconds of the match secures the outcome of the match.
Note that the accuracy of information may be unknown, and hence, subjective expected value may be inaccurate, leading to ‘shocks’ when the matter pertaining to the prior information eventuates contrary to expectations. Returning to the job offer scenario, the seeker could, for example, accept the offer on certain expectations of the nature of the role based on discussions at the interview, only to find out after acceptance and starting the job that such assessment was incorrect.

In this scenario the job seeker is using his/her intelligence to anticipate the future and draw from the data received relevant and useful information that helps move from the present into the future. So, more generally, we argue that intelligent agents are able to use judgement to anticipate the future. Therefore, intelligent agents are constantly scanning the future horizons and making estimations of possible outcomes.

All current knowledge held by an intelligent agent with memory is already factored into the future expected value. Information, in contrast to knowledge, can be described as something new or novel, and is synonymous with the change (either positive or negative) in future expected value.

Information works on the recipient’s knowledge base. Knowledge has the feature of retention over time, although it may diminish or be lost through the processes of forgetting. In a perfect information and knowledge system (in which all information is factually correct and true, and all knowledge is retained exactly and completely), only new information has value. In such a system ‘information’ that is repeated or replicated through multiple channels has zero value and becomes useless. However, human knowledge retention is not perfect; hence, some repetition of information constitutes information flow between human agents, even though the information may not be truly new. Also, information typically contains degrees of equivocation and noise (inaccuracies), and hence, intelligent beings continuously scan the horizons for confirming or refuting data.

### 8.4 Development of Hypothesis into New Theory of Information

Information is anything received through an intelligent agent’s senses that has the potential to create or destroy future value, as determined in the subjective judgement of the recipient. In this context an increase in value relates to a reduction in uncertainty of potential future outcomes.

Therefore, we bring a definition to information, which does not define it from the viewpoint of a signal sent by a sender, but rather from the viewpoint of the impact of the signal from the perspective of the recipient. This leads to a definition of information as follows:

\[
\text{Information} = \Delta \text{SEFV}_r
\]

Our definition hence classifies information in the subjective domain according to the classification system given by Zins (2007a), and hence fits with Models 2–5, but contrasts with
the most common Model 1 (see Table 2-4 in the literature review, Section 2). Our definition also addresses the argument advanced by Boisot and Canals (2004) that information only becomes knowledge if it is internalised and becomes part of the recipient’s expectation structure, taken as a disposition to act. Other theories of information typically model a flow from a sender to a receiver, for example, those of Shannon and Weaver (1949) and Dretske (1983); however, only data and instructions can flow in this manner. We argue that information is a phenomenon that can only be detected, perceived and measured from the opposite perspective, that is, that an intelligent recipient perceives information from a source. The source could be data, natural phenomena or other intelligent beings. Information is not ‘pushed’ by a sender, but rather ‘pulled’ by the recipient (even though a recipient may not be actively seeking, as information may be extracted by casual observation). Even in cases of a signal being sent as an instruction or command, in which an attempt is made to disseminate information by a sender, it is the information as perceived by the recipient that is of significance. The information received may differ from what the sender intended. Hence, the information flow diagram should be drawn the opposite way round to the traditional MTI flow diagram, as indicated in Figure 8-4.

Figure 8-4: Information Flow: Information Is Pulled by Intelligent Recipient

This pull feature of information is one of the differentiating features between information and data. Data can be disseminated, whereas information is extracted from the available data. The senses of the human body receive a constant stream of stimuli every day from numerous sources. The capabilities of the receptors determine the data that is received from the available
signals, and the understanding of the intelligent agent determines the information that can be extracted from such data. The information received is tuned by experience and knowledge. Wisdom and judgement are exercised in selecting subsequent courses of action upon receiving information. The linkages between data, information, value and knowledge are illustrated in Figure 8-5:

![Figure 8-5: Relationships between Data, Information, Value and Knowledge](image)

Note that whilst the value graphs here and elsewhere in this Chapter indicate notional end points, that the value generated from information may be ongoing ad infinitum, (depending upon the nature of the information), and hence the end points on the graphs are indicative only.

### 8.5 Detailed Development of New Theory of Information

There are two main scenarios in which information is exchanged and can potentially flow:

- **Type 1:** In which an intelligent agent is able to extract information from data (e.g., through observation or analysis of data) on an ongoing basis. Examples include monitoring of a gauge on a machine such as a speedometer in a car, or reading a daily newspaper.
• Type 2: In which two or more intelligent agents engage in activities to generate some value or benefit. Examples include an architect and engineer working together on a design of a building, or information exchanges between an apprentice and a master to develop expertise in a field. Often such interactions are accompanied with some degree of apportionment of the mutual value created from the interaction between the actors, but two or more actors are needed in order to create value.

In both of these main scenarios there is a stream of information, which flows with the passage of time.

In the case of Type 1 Information Flow some simple deductions can be made as follows:

Total Information Extracted over time period \( p \) = \[ \sum_{t=0}^{p} (\Delta SEFV (t)) \]

Average rate of Information Flow = \[ \frac{\sum_{t=0}^{p} (\Delta SEFV (t))}{p} \]

Where \( p \) = period of time

The problem with stating an average rate of information flow, however, is obvious in that typically information extracted is not at a constant rate. In the example of a speedometer in a car perhaps the rate is fairly regular at, say, once a minute, for an average driver, which is used to maintain a speed below the road speed limit. But in the example of reading a daily newspaper there will be news that has greater value on some days than other news on other days.

In the case of information flow between two or more intelligent agents the information flow is much more complex, as the sender may attempt to appropriate some of the value created and vested in the recipient via:

• negotiation;
• exercising command and control (if the sender is in a position of power over the recipient);
• collaborative actions leading to reciprocity (e.g., sharing of information to build a relationship of trust for future mutually beneficial exchanges).

Contracts are a formal way of apportioning the value between a sender and a recipient.

8.5.1 Information for Use in Negotiations

Negotiation is the classic scenario in which information is used to apportion future value pertaining to the issue of the negotiation between actors in the negotiation. Information flow is the means by which intelligent agents conduct their negotiation. Our information hypothesis allows development of an information theoretic model of negotiation, as follows:

• Human agents engage in a process of making offers and counter-offers, and the rejection or acceptance of such offers and counter-offers.
• Value extracted from data released during the interactions is information and is vested in the recipient.
• However, if one of the agents can accurately anticipate the potential value that the other recipient will place on data exchanged in the process, then that first agent can potentially extract a greater portion of the value at stake. However, if that agent cannot accurately anticipate the value of the information exchange, then the agent will either give away too much value (without realising it), or attempt to extract too much value, leading to a stalemate or breakdown of negotiations.

• Data exchange acts upon the knowledge base of the individual agents to create information; hence; sharing of existing knowledge should lead to better information exchange and therefore more equitable negotiation outcomes.

We can develop this information theoretic model of negotiation further as follows:

The objective for a successful negotiation is to increase $\Delta \text{SEFV}(r)$ for both parties.

$$\text{Total value} = \Delta \text{SEFV}(r_1) + \Delta \text{SEFV}(r_2).$$

However, there is a cost to parties in a negotiation. The cost is a real present cost, which is the cost incurred to date entering into the negotiation, and is unlike information. Thus, to reach a successful conclusion to negotiations, the following criteria must be satisfied:

$$\Delta \text{SEFV}(r_1) > \text{Present Costs}(r_1)$$

and

$$\Delta \text{SEFV}(r_2) > \text{Present Costs}(r_2).$$

Now let us assume that Agent 1 can accurately assess $\Delta \text{SEFV}(r_2)$ and Present Costs$(r_2)$, whereas Agent 2 cannot accurately assess $\Delta \text{SEFV}(r_1)$ and Present Costs$(r_1)$, then Agent 1 is at an advantage and can potentially extract some of the value represented by $(\Delta \text{SEFV}(r_2) - \text{Present Costs}(r_2))$. So in a negotiation the party with better information is therefore more likely to 'win'. If there is a mutual objective to find the most equitable outcome for both parties, then they should focus on maximising the information flow between parties. Sharing of knowledge may be a way of maximising $\Delta \text{SEFV}(r_1) + \Delta \text{SEFV}(r_2)$ at minimum cost, leading to win-win negotiation outcomes.

This is an example of information flow leading to improved productivity, and hence, this information theoretic model is useful in making the linkage between information flow and productivity.

8.5.2 Information for Command and Control

Having the power to command another agent allows the human agent with the power to extract value from the information recipient. Information flow is likely to be in the form of instructions, or in a manner that is highly directive. Our hypothesis allows development of an information theoretic model of command and control as follows:

• In the context of a commander with the necessary supporting system comprising a strong command and control structure, directives can be issued that have a high degree
of likelihood of being obeyed. The classic examples are the military and hierarchical organisations.

- The information sender can only extract value up to the point of the commander’s skill in being highly directive or to the point of compliance enforced by the supporting system. Goodwill from the recipient is not assured. For example, in the military setting a commander can issue instructions to attack the enemy knowing that the system will enforce compliance, ultimately with court martial for those who disobey. In a less extreme example, a boss can issue reasonable instructions to a subordinate with an expectation of compliance within the bounds of the subordinate’s job role and employment contract.
- The value generated by an instruction is limited to the degree it is understood, and complied with, by the recipient.

Value can only be extracted by a commanding agent when the information flow results in some action by the recipient. An uncompleted instruction results in another information flow, as the future expected value of the action (from the perspective of the sender) is destroyed.

The value extracted by the information sender will usually be less than $\Delta \text{SEFV}_{(r)}$. A recipient may receive and fully understand an instruction, but may also have better knowledge than the sender. A recipient may elect to respond with a minimum complying response and hence there may be a residual.

Hence:

$$\text{Value of instruction given by a sender} \leq \Delta \text{SEFV}_{(r)}$$

$$\text{Value of instruction given by a sender} = (\Delta \text{SEFV}_{(r)} - \text{Reserved SEFV}_{(r)})$$

Where Reserved SEFV$_{(r)}$ is the Reserved Subjective Expected Future Value from the perspective of the recipient

The Reserved SEFV$_{(r)}$ is the difference between the value extracted by an instruction and $\Delta$SEFV$_{(r)}$. It is retained, or set aside, by the information receiver. The information receiver may elect to share the reserve or set it aside, or use it in some other way. An example could be a boss who instructs a subordinate to undertake an engineering design in a certain manner, not appreciating that there is a better technique available in which the subordinate has some skill, but the subordinate elects not to share because he/she has been instructed to comply with an inferior technique and is fearful to challenge the instruction.

Information flow is optimised as Reserved SEFV$_{(r)}$ tends towards zero. This can be achieved either by ensuring that the commander has the best possible up-to-date data and information upon which to base his/her instructions, or by capturing the goodwill of the recipient in some manner, such as providing incentives or an excellent workplace culture. A culture of minimal compliance will inevitably lead to loss of some of the value that could be realised and hence lead to suboptimal productivity.
This is another example of how our information theoretic model is useful in making the linkage between information flow and productivity.

8.5.3 Information for Facilitating Collaboration and Reciprocity

Value is created through information flow, but it is ‘cemented’ by the subsequent actions of people. In a business setting, value is created by employees working for the organisation. In other settings there is a range of interactions, from those with casual social acquaintances to the most intimate, interpersonal relationships such as those with family. In the latter example, people collaborate to create a home and conducive family setting in order to raise children.

In a collaborative relationship information is willingly shared to create value for the other human agent, often without an explicit expectation of appropriating value from the other agent. Hence, information is used to ‘give away’ value, but in doing so it builds a relationship of trust. Our hypothesis allows development of an information theoretic model of collaboration as follows:

- A repeated information flow, on a reciprocal basis, builds trust between agents.
- Total value = $\Delta SEFV(r_1) + \Delta SEFV(r_2)$.
- Knowledge of the other person’s interests allows the information sender to send more succinct signals and data to affect the same information flow. With relationships of collaboration and reciprocity there is a process of information exchange between agents to establish a shared knowledge base, which usually only occurs over a period of time. There is a cost incurred in establishing the shared knowledge, but the potential future total $\Delta SEFV(r)$ may be optimised and realised much more efficiently. An example might include a communication between two people who know each other well comprising just one word, or a certain facial gesture, which can communicate a significant amount of information, because it draws on a shared knowledge base.

Reciprocity means both parties gain from mutual information exchanges. Lack of reciprocity may diminish trust, and lead to the breakdown of the collaborative relationship. Good relationships will lead to a stream of positive $\Delta SEFV(r)$, which further builds trust, enabling sharing of knowledge and more effective and efficient future communications. A poor relationship built on secrecy, misinformation and lies will result in a stream of negative $\Delta SEFV(r)$. Human agents have the power to forgive pain caused by negative $\Delta SEFV(r)$, but this requires the goodwill of the injured party.

This leads us to identify an efficiency metric for the information flow itself, being a metric of the data input of the signal and the value of information content. If we let the quantum of data contained in a communication signal be $D$, then:

$$\text{Efficiency of the information flow from a communication perspective} = \frac{\Delta SEFV(r)}{D}$$

Here $D$ is related to the shared knowledge of the parties to the communication.

Here again we can see a link between information flow and productivity, where the $\Delta SEFV(r)$ can be optimised by minimising $D$ and maximising the shared knowledge base between agents.
8.6 Semantic Parameters of Information

Gitt (2006) formulated some theoretical quantitative evaluations of semantics, and in doing so identified six parameters. These are summarised and critiqued in Table 8-1.

<table>
<thead>
<tr>
<th>Parameter of semantics</th>
<th>Gitt’s evaluation</th>
<th>Critique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic quality (q): a subjective concept, which mainly concerns the recipient.</td>
<td>A measure of the importance of the meaning of information. For inane or nonsensical information ( q = 0 ), while for the best possible information ( q = 1 ).</td>
<td>This is not particularly helpful as a quantitative evaluation of semantics of information, as it is rather inwardly circular, measuring something by essentially itself. Semantics is about the meaning of information. Something that is meaningful is full of significance, and conversely, something of low meaning is of no significance or of no import. An alternative parameter would be more useful.</td>
</tr>
<tr>
<td>Relevance (r): a subjective concept, which mainly concerns the recipient.</td>
<td>Reflects individual interests and it includes its relevance for achieving some purpose.</td>
<td>This is a good parameter.</td>
</tr>
<tr>
<td>Timeliness (t): a subjective concept, which mainly concerns the recipient.</td>
<td>A measure of the time dependency. ( t = 0 ) for yesterday’s news, and ( t = 1 ) for information received at the right moment.</td>
<td>This implies a continuous linear scale between 0 and 1. However, information can only be timely or not from the perspective of the recipient. If information is received in time to create a ( \Delta SEFV_r ), then it is timely and value is created. If information is received after the event, then facts of the event are already known and ( \Delta SEFV_r ) is zero.</td>
</tr>
<tr>
<td>Accessibility (a): a subjective concept, which mainly concerns the recipient.</td>
<td>A measure of the ease of access. ( a = 0 ) when there is no access, and ( a = 1 ) when the recipient has full access to the information transmitted by the sender.</td>
<td>Issues relating to accessibility result from lack of differentiation between data, knowledge and information. A measure of ease of access can relate to data and knowledge, where the data or knowledge may exist independently of the information recipient. Such data or knowledge may be easy or hard to find depending upon the accessibility of the database or knowledge base systems. However, as soon as the data (or knowledge) is sourced it may become information and is now fully accessed.</td>
</tr>
<tr>
<td>Existence (e): an objective concept, which mainly concerns the sender.</td>
<td>Concerns whether the information exists at all. ( e = 0 ) for questions that are completely open and ( e = 1 ) is something is fully known.</td>
<td>The question as to whether a piece of data or a signal exists is not of particular import. For an information seeker who does not know whether an answer to his/her question already exists, then the question of existence within a body of knowledge is relevant, but applies more to knowledge than information. What is more important is the truthfulness of the data or signal or existing knowledge.</td>
</tr>
<tr>
<td>Comprehensibility (c): a subjective concept, which concerns both the sender and the recipient.</td>
<td>Describes the intelligibility of information. ( c = 0 ) when the information cannot be understood, ( c = 1 ) when completely understood.</td>
<td>This is the extent to which the receiver is able to apply understanding to the information received to make a correct estimate of the change in expected future value/utility. It is therefore a subjective concept concerning the receiver.</td>
</tr>
</tbody>
</table>
In our information theoretic theory we offer alternative quantitative evaluations of semantics, as shown in Table 8-2, and then subsequently link them to our definition of information.

**Table 8-2: Evaluations of Semantic Parameters of Information**

<table>
<thead>
<tr>
<th>Parameter of semantics</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected future value (utility) = EFV.</td>
<td>May be measured in $ terms or some other utility of worth.</td>
</tr>
<tr>
<td>Integrity of information (i): an objective concept primarily, which mainly concerns the information source.</td>
<td>Relates to reliability, trustworthiness, truthfulness, factual correctness of the information. All relate to the degree to which the information source can be relied upon. For people sources this is typically referred to in terms of words such as reliability and trustworthiness. For documentary sources it might be referred to in terms of being factually correct. Intermediate values may apply that will result in lower ΔSEFV until more reliable information can be obtained to either confirm or refute the initial information. A reciprocal of this integrity parameter is equivocation. ( i = 0 ) for information with no semantic integrity, ( i = 1 ) for information which is the truth, the whole truth and nothing but the truth. Negative for lies and misinformation.</td>
</tr>
<tr>
<td>Timeliness (t): an objective concept, which mainly concerns the recipient.</td>
<td>Late information has zero ΔSEFV (as the event has already occurred and cannot therefore affect the future value/utility). ( t = 0 ) for late news, and ( t = 1 ) for information received in timely manner. No intermediate values.</td>
</tr>
<tr>
<td>Relevance (r): a subjective concept, which mainly concerns the recipient.</td>
<td>Reflects recipient’s interests and it includes its relevance for achieving some purpose. Similar to Gitt’s analysis. ( r = 0 ) for irrelevant information, and ( r = 1 ) for directly relevant information that readily affects future expected value. Intermediate values on continuous range from 0 to 1.</td>
</tr>
<tr>
<td>Understanding (u): a subjective concept, concerns both the sender and the recipient.</td>
<td>This is the extent to which the receiver is able to apply understanding to the information received to make a correct estimate of the change in expected future value/utility. It is therefore a subjective concept concerning the receiver, but is also dependent upon the comprehensibility of the information source, such as how well it is structured, presented, etc. Hence, this is similar to Gitt’s parameter comprehensibility c, but is framed more from the perspective of the understanding of the recipient, which is what determines the subjectivity of ΔSEFV. ( u = 0 ) for information which is not understood, and ( u = 1 ) for readily understood information that affects future expected value. Intermediate values on continuous range from 0 to 1.</td>
</tr>
<tr>
<td>Cognisance (c): a subjective concept, which mainly concerns the recipient.</td>
<td>Cognisance relates to the degree to which the recipient has knowledge about something and is aware of the implications. It is a measure of ready access to the knowledge memory bank, rather than a measure of the transmitted information. Memory in human agents has a tendency to decline, and therefore there is a degree of subjectivity in making the linkages between a message received and prior knowledge. This parameter is shaped by the cognitive processing capability of the recipient and upon personal taste or opinion on matters that may be lacking impartiality. ( c = 0 ) for information that is not cognitively linked to existing knowledge and/or is completely biased from a faulty frame of reference, and ( c = 1 ) information that is cognitively linked to a sound reference frame. Intermediate values on continuous range from 0 to 1.</td>
</tr>
</tbody>
</table>
Applying these parameters to our definition of information, we develop a series of quantitative evaluations as follows:

Information = Delta (i.e., the change in) subjective expected future value, from the perspective of the recipient.

Information = ΔSEFV(t)

Breaking this down into the component parts we postulate the following:

Information = Δ(SEFV(r))

Where:

Delta Expected Future Value $\Delta(\text{EFV}) = \text{Function of } \Delta(\text{FV})_{\text{actual}} \cdot (i) \cdot (t)$

$\Delta$ is the change arising as a result of the informational signal (or group of signals).

Future Value $(\text{FV})_{\text{actual}}$ is the real (i.e., actual) future value from events to which the information relates that are eventuated in due course.

Integrity $(i)$ is a factor to reflect the integrity, reliability, truthfulness, factual correctness of information.

Timeliness $(t)$ is a factor to reflect the need for information be received in a timely manner.

Information from a highly reliable (truthful) source is therefore more valuable than that from an inconsistent source. Where $(i)$ is less than 1, confirming information is needed to verify the source. Where $(i) = 0$ (i.e., factually incorrect) and is known by the recipient to be unreliable, such information has zero value. Where $(i) = 0$ and is not known to the recipient and is assumed to be $> 0$, there is a high residual risk. Integrity $(i)$ may be a negative number for deliberate lies and ‘misinformation’.

If information is received late for decision-making, then $(t)$ will be zero as the decision will have been taken by the time information is received. There may be occasions when information is received somewhat late, but still in time to affect some smaller $\Delta\text{SEFV}_(r)$ than would have been the case if that same information had been received earlier. It might be argued, therefore, that $(t)$ could be an intermediate value between 0 and 1 in such scenarios. However, $(t)$ is still equal to 1, not an intermediate value; it is just that earlier receipt of the same information might have generated a greater increment for Future Value $(\Delta)\cdot(\text{FV})$. There may also be occasions when information is received somewhat late, but still in time to enable the decision-maker to revise or modify a decision made prior to receipt. However, on such occasions the informational signal generates a new incremental $\Delta\text{SEFV}_(r)$, and should not be confused with an intermediate value of $(t)$.
Where also:

Subjectivity (S) is a function of: Relevance (r), Understanding (u) and Cognisance (c) and each of these varies between 0 and 1;

\[ S = \text{Function of } (r).(u).(c) \]

Hence:

\[ \text{Information} = \Delta SEFV(r) = \text{Function of } \Delta(FV)_{\text{actual}}(i).(t).(r).(u).(c) \]

Or we can restate this more qualitatively as:

Information is a function of the future value, integrity and timeliness of a signal, and the relevance, understanding and cognisance from the perspective of the recipient.

This is a new model of semantic value of information flow, which is useful for conceptualising information and also quantifying the semantic value of any particular piece of information.

An examination of the equations indicates the fragile nature of information. It is easy to destroy informational value, because of lack of timeliness or integrity or inappropriate subjective assessment. This is supported by our research findings from our survey presented in Chapter 6, in which participants rated the importance of all the different factors to a high degree, as all parameters are needed to provide really useful (valuable) information.

### 8.6.1 Further Elaboration of Model Relating to Creative and Operational Information Flows

We elaborate further on the nature of information using our model. Not all information is equal; some information is incremental, and only makes a small difference, whereas other information is highly valuable and effective in making a very substantial difference. For example, the informational content of the discovery of penicillin by Alexander Fleming in 1928 revolutionised the treatment of bacterial infections, or the publication of Einstein’s theories of relativity opened up whole new areas of scientific discovery and understanding of the nature of the universe. These major discoveries and others like them have added major contributions to human knowledge, and at the point of being communicated, represented informational flows with major \( \Delta SEFV \). If we contrast other information flows that are much more operationally oriented, such as monitoring the traffic on road networks, there is evidently some value but it has a very different kind of value from the more creative information in the previous examples. Gitt (2006) identified three types of information, namely, ‘creative’, ‘operational’ and ‘other’. We have built on Gitt’s theory and propose that the difference between ‘creative’ and ‘operational’ information lies primarily in the size and timing of the \( \Delta SEFV \) factor, as outlined in Table 8-3 and Figure 8-6.
Table 8-3: Types of Information

<table>
<thead>
<tr>
<th>Type</th>
<th>Gitt (2006)</th>
<th>Our Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative</td>
<td>All information that is used for purposes of producing something.</td>
<td>Creative process is associated with large ΔSEFV, as indicated in Figure 8-6.</td>
</tr>
<tr>
<td>Operational</td>
<td>All information used for maintaining some industry.</td>
<td>Maintenance process is associated with small ΔSEFV and is more immediately associated with implementation, as indicated in Figure 8-6.</td>
</tr>
<tr>
<td>Other</td>
<td>All other information in which there is no apobetic aspect of construction or maintaining a process.</td>
<td>This is not really information as it serves no purpose.</td>
</tr>
</tbody>
</table>

Figure 8-6: Time Value Graphs for Different Types of Information

Operational information is more immediately associated with receipt of actual Future Value (FV) from the process (i.e., with relatively small time horizons) than is the case for creative information. For example, consider the scenario of planning a car journey. If we have information on road conditions and all other road users in advance, we can plan our journey with an optimal solution, which will give us the most effective route and quickest journey time. Given complete information of this type, the journey could be subject to automation in a deterministic manner. However, we can only collect information slightly in advance, through news bulletins, satellite navigation systems, word of mouth and so on. This allows us to fine-tune the journey, but only slightly in advance. During the journey, information is continuously processed by the driver, who is in constant receipt of stimuli (e.g., traffic light changes from green to red). The receipt of such stimuli complies with our semantic definition of information, and such information is valuable for preventing accidents and allowing us to arrive at the destination safely. Hence, we can see in this example how operational information is more immediate and actionable. In general, operational information follows the dotted line only slightly in advance of the actual value line, as indicated in Figure 8-6.
By contrast, the more creative information is associated with something new, which has a longer time horizon (typically) and represents a significant change in future value, even if that future value is not immediately fully recognised. The exact shape of the value curve is not of material import for our theory here, but could be, as indicated in in Figure 8-6, S curved, of even notionally a vertical increment for full and perfect information. Further, the shape of the actual value graph may also differ depending upon the nature of the scenario, as illustrated in Figure 8-7 by a range of different possible value graphs.

Figure 8-7: Range of Different Information and Actual Value Graph Shapes

8.6.2 Further Elaboration of Model Relating to Optimistic and Pessimistic Views

An optimistic interpretation of an informational signal will see things on the bright side, with a more confident outlook on the future. By comparison, a pessimistic view takes a more cautionary view of the future (i.e., lower future expected value of outcomes).

Taking a pessimistic view ascribes a lower ΔSEFV_{(r)} than an optimistic view, such that it avoids the risk of disappointments later should actual Future Value (FV) < ΔSEFV_{(r)}. A pessimistic view will tend to apply a lower value of the subjective parameters of relevance (r), understanding (u) and cognisance (c), which will have the effect of lowing the quantum of ΔSEFV_{(r)} below the real Future Value (FV), which will result in more cautious decision-making, sometimes missing the opportunity to capitalise on the information, but at the advantage of avoiding disappointment of negative shocks in the future. By contrast, an optimistic view will tend to apply a higher value of subjective parameters of relevance (r), understanding (u) and cognisance (c), which will have the effect of increasing the quantum of ΔSEFV_{(r)} above the real Future Value (FV). This will give the optimist the motivation and enthusiasm to pursue the opportunities beyond that justified by the real value. A realistic attempt to estimate the value of an informational signal requires intelligence and knowledge, and a skilled decision-maker fine-tunes estimates of ΔSEFV_{(r)} using...
experience and other feedback systems to build realistic reference frames. We suggest such ability is akin to wisdom.

### 8.6.3 Information Flow and Productivity with Reference to Our Semantic Definition of Information

Our model gives some direction to explaining the relationship between information flow and productivity. The linkage is evident from analysis of information, defined as $\Delta \text{SEFV}_{\text{pr}}$, and actual production value, defined as $\Delta \text{FV}_{\text{actual}}$. We also have time intervals $\Delta T_{\text{info}}$, being the time taken to produce the information, and $\Delta T_{\text{prod}}$, being the time taken for the physical production of the valuable product or service, as illustrated in Figure 8-8. An example is the production of a set of design drawings for a new infrastructure project, which is given as information to a contractor from which to start construction of the physical works.

\[
\text{Figure 8-8: Timing of Information Flows towards Productive Outcomes}
\]

We also need to define the cost of production, differentiating between cost for generating the information and cost for producing and delivering the product or service, which we define as $\Delta C_{\text{info}}$ and $\Delta C_{\text{prod}}$ respectively. If we accept that information has to flow before producing a product or service (e.g., design of product before manufacturing), then we can optimise our productivity by the following considerations.

Firstly, we wish to achieve as close a match between $\Delta \text{SEFV}$ and $\Delta \text{FV}_{\text{actual}}$ as possible. In the information graph presented in Figure 8-8 they eventually match, at which point $\Delta \text{SEFV}_{\text{final}}$ equals $\Delta \text{FV}_{\text{actual}}$. However, at the point of starting the production $\Delta \text{SEFV}$ is less than the $\Delta \text{FV}_{\text{actual}}$ but is sufficiently along the information curve to give the decision-maker confidence to proceed. Poor information at this stage will lead to mismatch between the value expected and the value actually delivered and generally leads to outcomes. For example, in Figure 8-8 it would be unwise to finalise the decision to move to production at the first point $\Delta \text{SEFV}_{T_1}$ on the information curve, as the decision-maker would have a high degree of uncertainty of the outcome. Hence, at this stage the focus should be on exploring the information curve and
seeking to maximise the $\Delta SEFV$ by focusing on integrity (i), relevance (r), understanding (u) and cognisance (c) parameters of the information. This stage, therefore, is about maximising the value of the impact rather than the efficiency of generating the information. Or putting it another way, it is about focusing on effectiveness rather than efficiency. The decision-maker should be seeking to push the envelope of the information production stage towards $\Delta SEFV_{T1}$ and $\Delta SEFV_{T2}$.

Secondly, we wish to maximise $\Delta SEFV$ while also minimising $\Delta T_{info}$ and $\Delta C_{info}$ but without jeopardising the realisation of $\Delta FV_{actual}$. As the $\Delta C_{info}$ is usually much less than $\Delta C_{prod}$, judgement needs to be exercised as to the amount of effort to expend on the information creation stage before moving to the production stage. Given that $\Delta SEFV$ and $\Delta T_{info}$ are usually positively correlated, it is generally unwise to curtail the information production stage. Depending upon the shape of the information curve, it may in fact be preferable to allow greater time at $\Delta T_{info}$ in order to maximise $\Delta SEFV$.

Optimise $\Delta SEFV / \Delta C_{info}$ and $\Delta SEFV / \Delta T_{info}$

Thirdly, we wish to maximise $\Delta SEFV$ while also minimising $\Delta T_{prod}$ and $\Delta C_{prod}$, but without jeopardising the realisation of $\Delta FV_{actual}$. Given that $\Delta C_{prod}$ is usually much greater than $\Delta C_{info}$, there is usually greater potential to optimise costs by minimising $\Delta C_{prod}$ rather than $\Delta C_{info}$. Hence, the smart thinking at the information stage applied to minimising costs of the production stage has the potential to improve productivity from an overall system efficiency point of view. However, this must be done without jeopardising $\Delta FV_{actual}$, and hence, quality of information is paramount.

Hence, we can state some objectives as follows:

Objective 1: Maximise $\Delta SEFV \rightarrow \Delta FV_{maximum}$

Objective 2: Optimise $\Delta SEFV / \Delta C_{info}$

Objective 3: Optimise $\Delta SEFV / \Delta T_{info}$

Overall, we are seeking to pursue Objectives 1 and 2 simultaneously without jeopardising $\Delta FV_{actual}$ recognising that the greater $\Delta T_{info}$ the greater the integrity (i) of the information and the subjective parameters (r), (u), (c) are likely to be for the recipient, and also recognising that if information is late it may destroy the potential value.

This is akin in the engineering and construction context to value engineering, in that we are seeking to apply smart thinking to find better ways of production before committing to the production process. In our example of producing a set of drawings for a new infrastructure project it is synonymous with design for constructability. The key is to achieve as high a degree of information quality as possible with smart thinking applied to the production process. It is wise to spend a little more or take longer at the $\Delta T_{info}$ stage before committing to production.
Finally, we wish to maximise $\Delta F_{\text{actual}}$ while also minimising $\Delta T_{\text{total}}$ and $\Delta C_{\text{total}}$. There are multiple trade-offs that require the application of skill, experience and judgement by an intelligent agent to optimise parameters against relevant contextual considerations. On occasion, it may be possible to easily achieve an optimised $\Delta F_{\text{actual}}$ with a minimal $\Delta T_{\text{total}}$ and $\Delta C_{\text{total}}$, for example, in routine, low-risk decisions based on straightforward operational information. However, often the creative process requires a focus initially on generating creative information that is actualised only later through the physical production process.

Hence, we can state some objectives as follows:

Objective 1: Maximise $\Delta \text{SEFV} \rightarrow \Delta F_{\text{maximum}}$

Objective 2: Optimise $\Delta \text{SEFV} / \Delta C_{\text{info}}$

Objective 3: Optimise $\Delta \text{SEFV} / \Delta T_{\text{info}}$

Objective 4: Optimise $\Delta F_{\text{actual}} / (\Delta C_{\text{info}} + \Delta C_{\text{prod}})$

Objective 5: Optimise $\Delta F_{\text{actual}} / (\Delta T_{\text{info}} + \Delta T_{\text{prod}})$

Overall, we are seeking to pursue these five objectives simultaneously, recognising that the greater $\Delta T_{\text{info}}$ the greater the integrity ($i$) of the information and also the greater the subjective parameters ($r$).($u$).($c$) are likely to be for the recipient. Also, we are seeking to maximise value without jeopardising $\Delta F_{\text{actual}}$, recognising that if information is late, it may destroy the potential value. Furthermore, there is typically a relationship between $\Delta C_{\text{info}}$ and $\Delta C_{\text{prod}}$, and often a small investment in $\Delta C_{\text{info}}$ generating better information can yield greater savings in $\Delta C_{\text{prod}}$ production costs.

These parameters can be linked to MFP. We can restate MFP as follows (using our annotations for value):

$$\text{Multifactor Productivity} = \frac{\Delta F_{\text{actual}}}{(\Delta \text{Labour Input} + \Delta \text{Capital Input})}$$

Where:

$$\text{Output} = \Delta F_{\text{actual}}$$

$$\text{Labour Input} = \Delta C_{\text{prod(labour)}}$$

$$\text{Capital Input} = \Delta C_{\text{prod(capital)}}$$

So, now we can make an equation for MFP incorporating information as follows:

$$\text{Informational Multifactor Productivity} = \frac{\Delta \text{SEFV}}{(\Delta C_{\text{info}} + \Delta C_{\text{prod(labour)}} + \Delta C_{\text{prod(capital)}})}$$

$$\text{Multifactor Productivity} = \frac{\Delta F_{\text{actual}}}{(\Delta C_{\text{info}} + \Delta C_{\text{prod(labour)}} + \Delta C_{\text{prod(capital)}})}$$

Note that:

Informational Multifactor Productivity $\rightarrow$ Multifactor Productivity, when $\Delta \text{SEFV} \rightarrow \Delta F_{\text{actual}}$

And $\Delta \text{SEFV} \rightarrow \Delta F_{\text{actual}}$ when all the factors ($i$).($t$).($r$).($u$).($c$) $\rightarrow$ 1.0
We have introduced a new input in the denominator for productivity recognising the cost for producing information before moving to the production stage with associated labour and capital costs. The advantage of recognising information as an input is that smart use of information can reduce both labour and capital production costs, and therefore drive productivity improvements.

**8.6.4 Information Flow in Sequential Activities**

Let us now consider a linear sequence of informational task activities A-B-C. Different human agents undertake each activity. An example could be design elements of a new building by an architect (Task A), structural engineer (Task B) and building services engineer (Task C). There are many other examples of the sequential information production process. Each agent is reliant upon information received from the person undertaking the prior activity, with the exception of the initiator in the process. Upon completion of all the information, production of the physical product can commence, but let us assume this can only occur upon completion of full and final information. In our example the physical value creation would be construction of the building by a contractor upon receipt of full and final drawings. Such a system can be formed into an idealised information flow diagram as illustrated in Figure 8-9.

![Figure 8-9: Time Value Graph for Sequential Activities](image)

Now suppose that each agent is able to make some initial estimates and issue preliminary or partial information in advance. On each occasion the subsequent agent is able to make an early start on the creation of his/her information in order to shorten the overall time span from conception to completion. However, working on partial information has some inherent risks and leads to some errors that have to be corrected, resulting in rework in one of the later information production tasks. Our information flow diagram could look like Figure 8-10.
Task C now starts early, but the value creation rate is slower than first anticipated because the Task C agent does not yet have complete information. Nevertheless, progress is made up to the point when the Task B agent issues final and complete information. At this point there may be a surprise: the provisional information issued by Task B agent may not have been accurate, resulting in rework for the Task C agent (indicated by downward vertical line and subsequent new value creation curve). Let us consider this scenario from each agent's perspective:

- From the perspectives of the agents for Tasks A and B, there is a marginal cost in releasing provisional information early. Such cost is likely to be associated with some effort to produce initial estimated information and the costs of additional communications, but in general is likely to be small.
- From the perspective of agents for Tasks B and C, there is increased uncertainty as they are now working on incomplete information. This increased risk leads to greater likelihood of having to undertake rework when more complete information becomes available. If the risk eventuates, the cost of rework could be anywhere between modest and substantial. From the perspective of the agent for Task C in our example, there is a resultant reduction in productivity.
- From the perspective of the complete system, the overall production rate is increased. While $\Delta V$ remains constant in this example, the early release of preliminary information has facilitated a reduction in $\Delta T_{info}$ and hence the rate of production has improved. If there is also an associated reduction in the cost of generating the information, then productivity will also have improved. Other benefits may also be realised such as early entry into markets with the finalised product or service. From the overall system perspective, our arguments relating to information flow and productivity are similar to

![Time Value Graph for Sequential Activities with Prior Information Flow](image)
those presented in Section 8.7.3. Ultimately, we wish to maximise $\Delta F_{V_{\text{actual}}}$ while also minimising $\Delta T_{\text{total}}$ and $\Delta C_{\text{total}}$. There is therefore a trade-off, in which early release of preliminary information may be beneficial, but it should not jeopardise the $\Delta F_{V_{\text{actual}}}$ or increase the risk of rework to an extent greater than the potential benefit of fast-tracking the process.

In engineering and construction there is often a cyclical design process in which information outputs need to feed back to the original designer in order to coordinate and finalise designs. In relation to our example of architect, structural engineer and building services engineer, we often find that the building services engineer needs to produce layout designs for heating and ventilation before the architect can finalise detailed floor designs. Hence, the process is not linear but cyclical or iterative. In such scenarios there is no alternative to recycling through the information production process. Hence, a systems thinking approach is necessary to optimise the productivity of the system. A siloed approach would run the risk of optimising one component to the detriment of others in the system. A focus on maximising $\Delta SEFV$ for each signal, seeking a high level of fidelity in integrity (i), relevance (r), understanding (u), cognisance (c) and timeliness (t), will help to optimise information flow and productivity.

8.7 Evidence to Support Our Information Theoretic Model from Our Research

We compare our model with the findings from our primary research data presented in previous chapters. In Chapter 4 we presented the findings of qualitative research in which we asked participants to discuss the attributes of information that are important and why, results of which are presented again in Figure 8-11 for ease of reference.

![Figure 8-11: Histogram of attributes of information](image)
The key findings from this stage of the research were identified as:

- Accuracy of information is vital for decision-making and subsequently for efficiency and performance.
- Timeliness of information is a significant factor from a productivity perspective.
- Information has an intangible and illusive nature. Coupled with this, people have a wide range of personal preferences on how they like to receive information, in terms of format and attributes ranging from completeness to summarised, and transparency to fitness for purpose.

Also in Chapter 6 we presented the findings of quantitative research in which we asked participants to rate the importance of a range of different parameters of information, results of which are presented in Figure 8-12 and Figure 8-13.

![Figure 8-12: Importance Ratings of Parameters for People Sources of Information](image-url)
We see from these results that parameters that relate to the integrity of the information using the descriptions of reliability and trustworthiness (people sources) and true, factually correct and reliable (documentary sources) are particularly important and valuable. These findings concur with the earlier results from qualitative research and show that there is a cluster of parameters of information that relate to integrity (accuracy, truth, reliability), which supports our definition of the semantic value of information being $\Delta \text{SEFV}_{(i)}$, being a function of integrity ($i$) and reflecting the reliability, truthfulness and factual correctness of the informational signal.

We also see from our primary data that timeliness of information is highly important, which is commonly identified by participants in the qualitative research, and also ranked third in our quantitative data collection in Chapter 6 for ratings of both people and documentary sources of information. In the interviews in Chapter 4 we found multiple references to timeliness, currency, up-to-datedness, rapidity, speed and pace, particularly in the context of information for decision-making for improving productivity. Again, the results support our definition of the semantic value of information being $\Delta \text{SEFV}_{(t)}$, being a function of timeliness ($t$).

The other factors such as relevance, accessibility and comprehensibility are rated as relatively less important compared with integrity and timeliness factors, but nevertheless were identified as still being important. In the qualitative research there was a wider range of descriptors, each with slightly different emphasis, such as form, order, transparency and appropriateness. These were all descriptors of information that relate to the subjective nature of information, which we have identified in our definition of the semantic value of information as comprising subjectivity as a function of relevance ($r$), understanding ($u$) and cognisance ($c$). There is a challenge in selecting the words with the most appropriate meaning for these subjective parameters, but we offer a classification supported by our findings as given in Table 8-4.
We also observed evidence of the information value curve in the case study observations of meetings presented in Chapter 7. In these meetings we noted that there were usually a number of information checkpoints, the first one relating to the initial sharing of the idea or proposal. The information would typically be reviewed in a subsequent meeting in order to scrutinise the options and matters arising. Invariably, there would then be further scrutiny until reaching a point of consensus and verification of the validity of the information. We add these points illustratively to our information value diagram as given in Figure 8-14.
We observed in repeat agenda items a number of information checkpoints, the first being early in the process of the information flow, with at least one scrutinising checkpoint (but possibly more) and a final verification checkpoint.

In summary, our theory provides a new definition of information that provides a means by which to measure the semantic value of an informational signal. It builds on the works of others, notably Shannon and Weaver (1949; 1948), Dretske (1981) and Gitt (2006). It is also supported by our current qualitative and quantitative research. Further research is needed to test our hypothesised model. Possible directions of future research could include

- controlled experiments in which there is release of data to participants making decisions in competition with each other or where there is a degree of financial risk – such experiments under controlled conditions could attempt to measure the extent to which participants measure and evaluate ΔSEFV against the actual value at stake;
- application to games, such Cluedo or similar, in which data and information is released gradually to build knowledge about the situation until sufficient information exists to solve the problem set;
- direct observations of decision-makers such as traders in financial markets.

### 8.7.1 Objections to Our New Theory of Information

An objection could be levelled against our hypothesis, namely, that effect is placed before cause, or in other words, we are using the effect (change in future expected value) to define the cause (information). This may be a valid criticism; however, an attempt to defend the hypothesis is made on the basis that cause and effect are synonymous. From the view of the recipient of information, it is the change in future expected value perceived that differentiates information
from data (or stimuli). The cognitive process is illustrated in Figure 8-15 (the process runs from left to right across the page).

**Figure 8-15: Cognitive Process for Information Flow**

It is the cognitive processing (change in expected future value) that registers data and/or stimuli as information when there is a change in future expectations. The cognitive $\Delta SEFV(r)$ may be wrong, and actual value may never be realised in the real world; however, at the point of receipt it is still perceived as information, which might be revised later. This is a highly active process, and hence information may flow continuously until some outcome is achieved in the real world. Intelligent agents constantly estimate outcomes in advance, based upon existing knowledge and the flow of incoming information obtained. While the signal upon which information is carried is an objective commodity, the information itself is subjective (until acted upon to generate value) and relative based on the prior knowledge and perceptions of the recipient. Hence, measuring the semantic value of information from this perspective is justified.

The above model may be simplistic, naïve or even wrong. However, even if information is something more tangible, with inherent properties in itself (which can be used to describe the cause of information independently from the recipient), we are still interested in a measure of the impact of information. For this study, having a means to quantify the value of information is needed and $\Delta SEFV(r)$ is a useful measure.

### 8.8 Conclusions for This Research Stage

We make the following hypotheses developed from the philosophical arguments presented in this chapter and supported by findings and analyses of primary data taken from Chapters 4 to 7.

Information can be defined with respect to semantic value of an informational signal in a new way as:
Information = Delta (i.e., the change in) Subjective Expected Future Value, from the perspective of the recipient

Information = $\Delta \text{SEFV}(r)$

Which in turn can be expanded to the following:

Information = $\Delta \text{SEFV}(r) = \text{Function of } \Delta (\text{FV})_{\text{actual}}(i).(t).(r).(u).(c)$

Or we can restate this more qualitatively as:

Information is a function of the future value, integrity and timeliness of a signal, and the relevance, understanding and cognisance from the perspective of the recipient.

This definition allows us to explore the relationship between information flow and productivity in meaningful ways. Using this definition, we can make a link between information and an equation for informational MFP, incorporating information as follows:

Informational Multifactor Productivity = $\Delta \text{SEFV} / (\Delta \text{C}_{\text{info}} + \Delta \text{C}_{\text{prod(labour)}} + \Delta \text{C}_{\text{prod(capital)}})$

Multifactor Productivity = $\Delta \text{FV}_{\text{actual}} / (\Delta \text{C}_{\text{info}} + \Delta \text{C}_{\text{prod(labour)}} + \Delta \text{C}_{\text{prod(capital)}})$

Note that:

Informational Multifactor Productivity $\rightarrow$ Multifactor Productivity, when $\Delta \text{SEFV} \rightarrow \Delta \text{FV}_{\text{actual}}$

8.9 Further Conclusions Combining Chapter 8 with Chapters 4 to 7

In the conclusions to Chapter 4 we proposed an informal flow causality model for productivity showing the linkage between information and productivity via intermediate stations of decision-making, action-taking and contextual issues. In Chapter 5 we decomposed the contextual issues relating to productivity in task, teams, project, organisation and industry, and proposed a more detailed model, based on the initial model, but enhanced to provide more contextual matters in engineering and construction. In Chapter 6 we enhanced our understanding of information stations and also identified the iterative nature of decision-making and its effect upon productivity performance. In Chapter 7 we explored the information flow and productivity issues across all the stations from information, through decision-making, actions, context and outcomes. In this chapter we developed a new theory of the semantic value of information, defining information from the perspective of the recipient and as a change to future expected value.

Our new definition of information makes the philosophical link between information and productivity. If we consider productivity as simply the metric that indicates the quantum of value that is captured by a system collectively (within the boundaries of the defined system), then information becomes the underlying foundation for value creation and hence also for productivity outcomes.

In this chapter we offered our arguments from a philosophical perspective for our theory of information, building upon theories of others, and supported in part by our findings in previous
chapters. It may therefore be helpful to recast our information flow and productivity causality model making the linkage more explicit with information being the precursor to value, as illustrated in Figure 8-16.

Here we have indicated that information is the foundation for value generation (bottom box on diagram) as information precedes decision-making and action-taking. Information is the generator of future value, as no decisions can be made without information, and no actions can be taken without a decision to act. As soon as information is received and generated, a change in expected future value from the viewpoint of the recipient; the degree to which that perceived value is actually achieved and captured in the system is dependent upon the quality of the decision-making, action-taking and constraints and enablers within the context.

Figure 8-16: Developed Information Flow and Productivity Causality Model Incorporating Our Theory of Information
9 Information Flow and Making the Linkage to Industry Productivity Performance at the Macroeconomic Level

9.1 Introduction

In this section we draw together the main themes from the various stages of our research and address the central issue of information flow with respect to the aggregate productivity in the NZ construction sector. We review the productivity performance results, drawing on SNZ data, and make reference to these results with linkages to our research findings from previous chapters and recommendations for improving productivity performance.

9.2 Objectives and Goals of This Research Stage

As outlined in Chapter 1, the overall objective of this research was defined as:

To gain an understanding of the linkages between information flow and productivity in the engineering and construction sector; and thereby to identify future directions for improving productivity.

The specific objectives of this stage of the research were to advance the findings from previous stages and make a linkage to the overall productivity performance of the construction sector at the aggregate level in NZ. They link with our research goals as outlined in Table 9-1.

Table 9-1: Goals for This Research Stage (Productivity Performance at Aggregate Level)

<table>
<thead>
<tr>
<th>#</th>
<th>Overall Research Goals</th>
<th>More Specific Goals for This Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To investigate the linkages between information flow and productivity within the sector and determine the extent to which productivity outcomes are dependent upon information flow inputs.</td>
<td>To make the linkage between productivity performance and findings from previous chapters, with a focus on performance at the aggregate industry level.</td>
</tr>
<tr>
<td>2</td>
<td>To understand the mechanisms by which information flow affects productivity and thereby build a framework or causality model linking information flow with productivity.</td>
<td>To understand the causal factors for the apparently poor performance of the construction sector productivity performance at a macro level.</td>
</tr>
<tr>
<td>3</td>
<td>To identify the impact of information flow upon the quality of problem-solving and decision-making within the engineering and construction context.</td>
<td>To understand how macroeconomic decision-making might influence productivity performance, if at all, at the aggregate level.</td>
</tr>
<tr>
<td>4</td>
<td>To investigate the relative effectiveness of different information search strategies for decision-makers.</td>
<td>Not addressed in this chapter.</td>
</tr>
<tr>
<td>5</td>
<td>To identify the relative effectiveness of a range of information dissemination and transfer systems, including new and emerging information technology and management solutions.</td>
<td>Not addressed in this chapter.</td>
</tr>
<tr>
<td>6</td>
<td>To provide some directions for productivity improvement for the engineering and construction sector in NZ.</td>
<td>To identify some recommendations for productivity performance improvement in NZ.</td>
</tr>
</tbody>
</table>
In the conclusions to Chapter 4 we proposed an informational flow causality model showing the linkage between information stations and productivity outcomes via intermediate stations of decision-making, action-taking and contextual issues. In Chapter 5 we decomposed the contextual issues relating to productivity into task, teams, project, organisation and industry, and proposed a more detailed model, based on the initial model, but enhanced to provide more contextual matters in engineering and construction. In Chapter 6 we enhanced our understanding of information stations and also identified the iterative nature of decision-making and its impact upon productivity performance. In Chapter 7 we explored the information flow and productivity issues across all the stations, from information through decision-making, actions, context and outcomes within a case study. In Chapter 8 we developed a new theory of the semantic value of information, defining information from the perspective of the recipient and as a change to subjective expected future value. In all of these chapters the evidence points consistently towards a positive relationship between information flow inputs and productivity performance outcomes, albeit the relationship is somewhat complex.

It is apparent that quality of information is of upmost importance. It is the semantic value of the information being shared that matters, not the quantity of information. Indeed, information overload (Edmunds & Morris, 2000) is to be avoided, in the interest of facilitating good decision-making. A vital piece of information shared at the right time, typically early in the design and construction process, can save considerable effort and avoid waste downstream in the process. This is similar to the classic design for constructability argument already acknowledged in the literature (O'Connor, Rusch, & Schulz, 1987). However, it is a more fundamental and pervasive issue in the sector than just designing for buildability; it is about having the intelligence, knowledge and information applied with foresight to all decision-making. This goes to the heart of engineering and the design process: to the utilisation of resources effectively and efficiently. It also goes to the heart of the innovation process: to the application of information to maximise the potential to understand and solve problems in novel ways.

It would be illogical to try to argue that information flow does not have any bearing on performance. The argument against information flow would have to conclude that productivity performance occurs by chance, and that the quality of action, based on quality of decisions, based on quality of information has no bearing on the outcomes. If this kind of thinking were to be applied to any human endeavour, the result would be chaos, with no coordination of effort, and would ultimately end in failure. Rather, information is the initial lever in a complex process, in which intelligent agents are able to wield information to add productive value.

The evidence strongly supports a simple contention that information flow matters. The extent to which it matters is rather more difficult to measure or demonstrate. While the findings of the research and conclusions of Chapters 4 to 8 all give support to our information flow productivity causality model, the extent to which it accounts for productivity performance remains. The challenge in demonstrating the linkage quantitatively is the rather indeterminate and ambiguous nature of information, which is hard to measure and define in the first instance. Our new
definition of information goes some way to providing a meaningful way of measuring the semantic value of information. The other challenge is gaining clarity on the productivity metric itself, as it is probably fair to say that productivity is not understood well. While it is a useful metric for economists, it is open to misinterpretation, and productivity performance metrics need to be understood at a fundamental level. Hence, it is worth returning to the productivity performance of the construction sector at the macroeconomic level before we finalise conclusions and recommendations.

9.3 Data Collection Methods for This Research Stage: Macroeconomic Investigations

The data used for this chapter draws on the raw statistics data published by SNZ. Independent verification of the data was not possible.

9.4 Productivity Performance of the New Zealand Construction Sector

9.4.1 Casting of the Construction Sector Productivity Performance in Context

The NZ construction sector is thought to have poor productivity, and numerous reports have flagged productivity performance as a cause for concern (Davis, 2007; Page, 2010; Tran & Tookey, 2011). Most draw upon data published by SNZ and conclude that the performance of the sector is poor compared with other sectors and/or other comparable nations. For example, Page (2010) identified a poor performance, showing results in graphical form, drawing from SNZ, as reproduced in Figure 9-1, identifying a declining trend.

![Figure 9-1: New Zealand Construction Sector Multifactor Productivity Performance](image)

Clearly, the implication here is that the productivity performance of the sector is in decline, as graphically illustrated by the linear trend line. However, more recently, SNZ have undertaken a back-casting process of historical data, which sheds new light on the performance of the construction sector, as shown in Figure 9-2. Here we have a longer time series and make comparison with the wider NZ economy (as measured by the ‘former measured sector’) and we also contrast with the manufacturing sector as a comparator within the same NZ economy. This
still shows a somewhat poor performance, with the construction sector falling behind the economy in general, but it starts to tell a rather different story.

![Figure 9-2: New Zealand Construction Sector Multifactor Productivity Performance](image)

There is limited intelligence to be gained from the raw data about the causal factors for the trend. Hence, it is useful to put the productivity performance in the context of the wider macroeconomic events that affected the NZ and global economies, which is illustrated in Figure 9-3. We can see that these major macroeconomic factors have had positive or negative impacts upon productivity performance as a whole for NZ and upon the construction sector.
Figure 9-3: New Zealand Construction Sector Multifactor Productivity Performance in Context of New Zealand and Global Major Economic Events
As can be seen in Figure 9-3, there was a period of very significant productivity decline in the two years from 1990 to 1992, during which the MFP index declined by 35% (by comparison, the decline following the global financial crisis of 2008–2009 was only 9%). This period of rapid decline far outweighs the impacts of other events such as the Asian financial crisis, the Gulf wars and the Christchurch earthquakes, while other sectors such as manufacturing were hardly affected and the productivity performance of the wider NZ economy continued to grow. The period 1990–1992 requires special consideration, as the productivity trend in general, omitting the decline in these two years, is trending in positive growth. Prior to 1990, the productivity performance of construction outperformed the economy. In the period since 1992, the sector has been slightly underperforming productivity in the wider NZ economy; however, there has been positive growth, as illustrated in Figure 9-4 and Figure 9-5.

**Figure 9-4: Construction Sector Multifactor Productivity Performance Period 1978–1990**

**Figure 9-5: Construction Sector Multifactor Productivity Performance Period 1992–2014**
This contextual analysis now shows a different story, in which overall performance was significantly affected by severe decline in a short period, followed by a period of trending growth. This leads us to ask the question “Why the very significant and rapid decline in the period between 1990 and 1992?” Either there was a major structural change in the construction sector that accounted for the decline, or a change in the means of measurement, or a change in the data collection methods. Staff at SNZ have advised in correspondence and discussions that the means of measurement of productivity during the period was consistent. If the means of measurement and data collection methods were applied consistently by SNZ, the decline in this period must be explained by events at the time.

One possible explanation is that prior to 1993 financial accounts were prepared based on series of standards published by the New Zealand Society of Accountants. Members of the society were required to exert their best efforts, but the standards did not have any legal standing in NZ (Bradbury & van Zijl, 2006). The Financial Reporting Act was introduced in 1993, setting new standards for reporting with legal backing. The impact of these standards upon data reported at the time to SNZ is uncertain, but it is noted, for example, that the Fletcher Challenge Group changed its financial accounting policies in 1992 to comply with international accounting practices (Fletcher Challenge Ltd, 1993). The notes in the accounts show that the effect of a change due to accounting policy was to reduce the reported net earnings for the group from $381.8 million to $300.9 million (i.e., a change of > 20%). The impact of such changes upon the construction sector productivity metrics warrants a deeper understanding of the data. Is the apparent poor performance of the sector due, in part, to changes in the NZ accounting methods? However, accounting standards apply to all sectors in NZ and we do not see a corresponding decline in other sectors at this time. Could it be that the performance of one major and dominant company has skewed the results in this period? Answering this question would only be possible with access to the historical raw data held by SNZ, which is not readily available. Another possible major factor was the disestablishment of the former Ministry of Works (which acted as the government client body for procurement of construction-related services and contracting works), the impact of which is not possible to estimate retrospectively.

A breakdown of the MFP into labour and capital components reveals that most of the decline in MFP during this period was due to a severe decline in capital productivity, rather than a decline in labour productivity, which can be seen by reference to the changes of the labour and capital productivity components, as given in Figure 9-6.
Note that there was a double-digit percentage decline in capital productivity in both 1991 and 1992. The decline in the capital utilisation can be explained by the fall in volume of work in the early 1990s, which had been preceded by a property boom and the disestablishment of the Ministry of Works. Also, the impact of the introduction of the RMA at this time should be considered. The RMA gained Royal Assent in July 1991 and caused a significant impact upon client investment decision-making, leading to a negative impact upon the demand flow of work (McShane, 1996). Hence, the decline in capital productivity may be explained by the impact of two compounding features: a severe recession coupled with the introduction of major new regulations. Annual company reports for the Fletcher Challenge Group indicate there was considerable market stress on the sector caused by a rapid and severe decline in demand in both the construction and the building materials segments. While it was possible to lay off labour during the recession, it was not possible to utilise or dispose of plant and equipment, which subsequently sat largely idle, and hence the significant impact upon the capital productivity component.

In conclusion, the period from 1990 to 1993 needs to be understood much more clearly, and the productivity performance metrics for the sector during this period must be treated with a degree of caution. It is arguable that the productivity performance of the construction sector was significantly damaged by this one period of rapid decline, caused by factors primarily outside of the control of the sector supply chain, and therefore, it should not reflect negatively upon the reputation of the supply side of the sector. The performance of the sector after 1993 is probably reported on a more reliable and consistent basis, which shows a trend of improving productivity. There remains an issue, however, in that productivity growth after 1993, although positive, is slower than the aggregate NZ economy.

9.4.2 Off-Site Production and Its Impact upon Productivity Metrics

Another factor to be taken into account in the interpretation of the data is that the SNZ productivity metrics for the sector are reported using a value-added metric, and therefore exclude the intermediate inputs. This means off-site production of components such as pre-cast...
concrete and fabrication of structural steelwork are excluded from the productivity metrics for the reported sector. More specifically, the following are explicitly excluded from the construction sector in the Australian and New Zealand Standard Industrial Classification (2006); rather, they are incorporated in the manufacturing sector:

- structural steelwork fabrication;
- steel pipe and tube manufacturing;
- pre-cast concrete production;
- ready mix concrete manufacturing;
- ceramic product manufacturing;
- prefabricated wood production.

These exclusions are important to note, given the general imperative to increase the amount of off-site production of components in the industry as a means of improving productivity performance (Building and Construction Sector Productivity Taskforce, 2009). So, as the volume of work undertaken off-site increases in general over time, the potential productivity benefits arising accrue to the manufacturing sector, which is to the detriment of the measured construction sector (from a purely measurement and reporting point of view). This assumes that productivity is better off site than on site, but such an assumption is generally supported well in the existing literature (Ballard et al., 2003). Also, there is a compounding effect, as increasing the amount of off-site production means that the remaining balance of work will be the riskier activities, such as earthworks, which are more susceptible to adverse impacts from weather, unexpected ground conditions and other challenging site issues. Hence, we find again that the productivity data needs to be interpreted with intelligence in order to extract useful information, if it is to be used to inform value-adding decision-making.

A revised metric for the construction sector productivity performance, making an adjustment for structural steelwork fabrication and pre-cast concrete production, shows a slightly different productivity performance. This adjustment uses simple ratio analysis, assuming that the off-site production components operate at the average productivity rates of the aggregate manufacturing sector. The findings are shown in Figure 9-7.
Figure 9-7: Revised MFP Performance for Construction Sector Adjusting for Components of Off-Site Production
This analysis indicates that the end-to-end construction process, including the off-site intermediate activities, may be more productive than was apparent in data previously reported for the ‘construction sector’. The effects of technology change for embodied technology only accrue to the productivity metric if the metric is remunerated accordingly (Organisation for Economic Co-operation and Development, 2001), and it is apparent that this is not the case here. Rather, the effects of off-site production are hidden in the NZ productivity statistics because of the classification system. However, it must be noted that our analysis is not conclusive as it is based on an assumption that the off-site components operate at the average productivity for the manufacturing sector as a whole, which might not be the case in reality. Our adjustment uses simple ratio analysis, based on relative volumes and productivities. A more accurate approach would be to construct a new productivity index for the wider construction sector, including intermediate inputs, compiled from detailed input and output tables at the subsector level, but unfortunately these are not readily available from SNZ. More detailed analysis is needed, with access to the underlying data held by SNZ, in order to prove the validity of our finding from this simple ratio approach. Suffice to say, however, that there will be an impact, although the magnitude cannot be proven at this stage.

Our analysis on the data published by SNZ in relation to the construction sector leads us to conclude that there needs to be careful interpretation of the data, to put the performance in context and ensure a thorough understanding of what the metric is actually measuring. It is too easy to make assumptions about what it is measuring without understanding how the metric is constructed. The example of the off-site components are a case in point. It would be helpful to have other performance metrics, which can be reported alongside productivity, to aid in the understanding of the results. This leads us to a recommendation to improve the reporting of the productivity performance data for the construction sector, by providing the data in context, and with greater clarity on how the data is compiled. It would also be preferable to have a range of metrics to help improve understanding. One such metric is a productivity index incorporating the extended construction supply chain, including off-site components.

9.4.3 Construction Sector Productivity Growth and Volatility Issues

One striking aspect that is apparent from analysis of the data is the high volatility of the productivity growth from year to year, in the period from 1978 to 2014, as shown in Figure 9-8.
Figure 9-8: Annual Percentage Changes in MFP, Labour Productivity and Capital Productivity for the Construction Sector

Here we see wide swings from growth to decline from one year to the next, which occur in a random manner. Also, the MFP growth does not always synchronise with the labour and capital productivity. These severe swings indicate challenges for the sector, with boom–bust cycles being prevalent rather than steady growth. We compare the construction sector with all other sectors in NZ and can see that the construction sector has a relatively high degree of volatility, particularly in the negative changes in recession years, as indicated in Figure 9-9.

Figure 9-9: Relative Volatility of Construction Sector MFP Compared with Other Sectors of the New Zealand Economy

The volatility of the sector is also illustrated by the descriptive statistics given in Table 9-2, which compares performance across sectors over the period from 1978 to 2014, indicating that construction is one of the most volatile sectors. These statistics show that the sector is characterised not only by high variability (as indicated by standard deviation), but also by having only modest average growth, and some severely negative years of declining productivity.
When we break down the results into the component parts for output, labour input and capital input, we start to gain a deeper understanding of issues. In the construction sector we see high variability in outputs, matched with a wide range of labour inputs, but with only a narrow range of capital inputs. We constructed a series of distribution curves, using the year-on-year percentage changes of the component inputs and outputs for the period from 1978 to 2014 published by SNZ. These are shown in Figure 9-10 in conjunction with the standard equation for the derivation of MFP (Organisation for Economic Co-operation and Development, 2001), in order to illustrate a deeper understanding of the productivity metric and the possible causation of the productivity performance. Note that MFP is a function of the value-added output, labour input and capital inputs. Further details of productivity definitions are given in Appendix A1. Each component of MFP has been analysed for annual percentage change and hence the distribution is an indicator of the relative volatility (all shown on the same horizontal scales range −20% to +20%).
Figure 9-10: Breakdown of MFP for the Construction Sector Showing Volatility of MFP, Outputs, Labour Inputs and Capital Inputs

The analysis shows that the sector is characterised by a very wide range of growth and decline in outputs. The sector output is determined by the quantum of work commissioned by clients, based on their investment decisions in the built environment. These decisions are made generally outside the direct control of the suppliers in the construction sector supply chain. Hence, the construction sector has to respond to increases and decreases in demand (boom–bust) on a best endeavours basis. When we look at the labour and capital inputs, we see that labour inputs have a relatively high degree of variability but capital inputs for the sector have a much narrower distribution. This is to be expected as labour is more flexible and under the control of the supply chain, albeit within parameters of employment law and human resource practices. However, capital inputs are less flexible as it is difficult to divest of plant and equipment, and there are longer lead-in periods for capital investments.
When we analyse the degree to which MFP for the construction sector is correlated with the components (i.e., output, labour input, capital input), we find that it is highly correlated with the sector outputs, as given in correlation results given in Table 9-3.

Table 9-3: Correlation of MFP with Output, Labour Input and Capital Input for the Construction Sector

<table>
<thead>
<tr>
<th>Pearson Correlation (r, p, N)</th>
<th>MFP Construction</th>
<th>Output Construction</th>
<th>Labour Input Construction</th>
<th>Capital Input Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFP Construction</td>
<td>r</td>
<td>.766</td>
<td>.186</td>
<td>.081</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>&lt; .001</td>
<td>.276</td>
<td>.640</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Output Construction</td>
<td>r</td>
<td>1</td>
<td>.767</td>
<td>.479</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>&lt; .001</td>
<td>.003</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Labour Input Construction</td>
<td>r</td>
<td>1</td>
<td>.547</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>36</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Capital Input Construction</td>
<td>r</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance at p < .05

These results show that MFP is highly correlated with output, but not with the labour input or capital input. Labour and capital inputs are correlated with each other and also output is correlated with labour input, indicating that suppliers attempt to match labour inputs to meet the output demand. However, the net effect is such that the productivity performance of the construction sector is really a function of high variability of the sector output. The key to improving productivity in the longer term is therefore to reduce the variability of the output component of the productivity function.

This point is perhaps illustrated by comparing the productivity performance with that of another sector. The sector with one of the best productivity performances on average over the period 1978 to 2014 in NZ is the ‘information media and telecommunications’ sector. A comparison is given in Figure 9-11.
Here we see an almost ideal scenario for productivity performance improvement, with output distribution skewed strongly positively (i.e., growth), with no periods of decline. This is matched with capital inputs, which follow a similar distribution pattern, skewed into the positive region, indicative of steady investment, resulting in capital deepening. As capital input is in the denominator of the productivity equation, increases in capital input would have the effect of reducing productivity if labour input were to remain constant; however, there is also a relationship between labour and capital inputs. Capital deepening improves labour productivity, with investments in technology having a leveraging effect to reduce labour input, the net effect of which is to improve MFP. The correlation of factors for the information media and telecommunications sector is given in Table 9-4, which contrasts sharply with the construction sector. We see that MFP is correlated with labour and capital inputs, whereas in the construction sector MFP is correlated with outputs.
Table 9-4: Correlation of MFP with Output, Labour Input and Capital Input for the Information, Media and Telecommunications Sector

<table>
<thead>
<tr>
<th>Pearson Correlation ( (r, p, N) )</th>
<th>MFP Info, Media &amp; Telecom</th>
<th>Output Info, Media &amp; Telecom</th>
<th>Labour Input Info, Media &amp; Telecom</th>
<th>Capital Input Info, Media &amp; Telecom</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r )</td>
<td>1</td>
<td>.389</td>
<td>-.437</td>
<td>-.438</td>
</tr>
<tr>
<td>( p )</td>
<td>.019</td>
<td>.008</td>
<td>.008</td>
<td></td>
</tr>
<tr>
<td>( N )</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Output Info, Media &amp; Telecom</td>
<td></td>
<td>1</td>
<td>.328</td>
<td>.395</td>
</tr>
<tr>
<td>( r )</td>
<td></td>
<td>1</td>
<td>.328</td>
<td>.395</td>
</tr>
<tr>
<td>( p )</td>
<td></td>
<td>.051</td>
<td>.017</td>
<td></td>
</tr>
<tr>
<td>( N )</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Labour Input Info, Media &amp; Telecom</td>
<td></td>
<td></td>
<td>1</td>
<td>.091</td>
</tr>
<tr>
<td>( r )</td>
<td></td>
<td></td>
<td>1</td>
<td>.091</td>
</tr>
<tr>
<td>( p )</td>
<td></td>
<td></td>
<td>.598</td>
<td></td>
</tr>
<tr>
<td>( N )</td>
<td>36</td>
<td></td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Capital Input Info, Media &amp; Telecom</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>( r )</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>( p )</td>
<td></td>
<td></td>
<td></td>
<td>.091</td>
</tr>
<tr>
<td>( N )</td>
<td>36</td>
<td></td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance at \( p < .05 \)

Now if we compare the components of the productivity performance for the average NZ economy in a similar manner as before using the distributions, we see a pattern as given in Figure 9-12.
Figure 9-12: Breakdown of MFP for the New Zealand Economy as a Whole (Former Measured Sector Metric) Showing Volatility of MFP, Outputs, Labour Inputs and Capital Inputs

A comparison between the construction sector, the information, media and telecommunications sector, and the NZ economy (former measured sector) shows a similar pattern between the latter two. The construction sector contrasts as being rather different, with greater extremes of boom–bust and more variability in the annual percentage change of outputs and capital inputs. For the economy as a whole, we see a consistent growth in capital inputs, similar to the information, media and telecommunications sector. Also in the economy as a whole, we see a high degree of correlation between MFP and output, similar to the construction sector; however, the relationship with capital input is markedly different, as demonstrated in Table 9-5.
Table 9-5: Correlation of MFP with Output, Labour Input and Capital Input for the New Zealand Economy as a Whole (Former Measured Sector Metric)

<table>
<thead>
<tr>
<th>Pearson Correlation (r, p, N)</th>
<th>MFP Former Measured Sector</th>
<th>Output Former Measured Sector</th>
<th>Labour Input Former Measured Sector</th>
<th>Capital Input Former Measured Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>MFP Former Measured Sector</td>
<td>1</td>
<td>.617</td>
<td>.057</td>
<td>-.361</td>
</tr>
<tr>
<td></td>
<td>&lt; .001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Former Measured Sector</td>
<td>1</td>
<td>.783</td>
<td>.248</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; .001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour Former Measured Sector</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.335</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.046</td>
</tr>
<tr>
<td>Capital Former Measured Sector</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance at p < .05

It should be noted that the correlation between MFP and output is not as strong in the NZ economy as a whole compared with the construction sector. A test to see whether the correlations for the two sectors are significantly different statistically was undertaken by comparing $z_{obs}$ values. The $r$ values for the two sectors were converted into $z$ values, returning $z_{(construction)} = 1.008$ and $z_{(former measured)} = 0.75$. This gives a $z_{obs}$ value = 4.26, which is greater than the threshold value of 1.96, indicating statistical significance. This finding shows that construction sector productivity is subject to boom–bust cycles more severely than the economy as a whole, and that the difference is statistically significant.

Our findings here reiterate the already acknowledged problem of boom–bust cycles (Allan et al., 2008; Davis, 2007; Page, 2010), but provide new compelling evidence based on official quantitative data published by SNZ. It also goes some way to quantifying the impact of the boom–bust problem, being the difference between the annual productivity growth of the construction sector and the average of the NZ economy = 0.7% (compound). While this may appear a low percentage impact, it should be seen in the context of the existing productivity improvement rates of 0.2% for the construction sector and 0.9% for the economy in general.

Other sectors show varying degrees of volatility, with different degrees of output, labour and capital inputs, and differing degrees of correlation, as illustrated in Table 9-6.
Table 9-6: Correlation of MFP with Output, Labour Input and Capital Input

<table>
<thead>
<tr>
<th>Pearson Correlation (r)</th>
<th>Output Sector</th>
<th>Labour Input</th>
<th>Capital Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFP Primary industries</td>
<td>.975</td>
<td>-.244</td>
<td>-.055</td>
</tr>
<tr>
<td>MFP Agriculture, forestry and fishing</td>
<td>.975</td>
<td>-.224</td>
<td>-.163</td>
</tr>
<tr>
<td>MFP Mining</td>
<td>.954</td>
<td>.012</td>
<td>.135</td>
</tr>
<tr>
<td>MFP Wholesale trade</td>
<td>.933</td>
<td>-.093</td>
<td>-.032</td>
</tr>
<tr>
<td>MFP Electricity, gas, water and waste services</td>
<td>.891</td>
<td>-.402</td>
<td>-.505</td>
</tr>
<tr>
<td>MFP Transport, postal and warehousing</td>
<td>.785</td>
<td>-.325</td>
<td>-.597</td>
</tr>
<tr>
<td>MFP Construction</td>
<td>.766</td>
<td>.186</td>
<td>.081</td>
</tr>
<tr>
<td>MFP Service industries</td>
<td>.697</td>
<td>-.022</td>
<td>-.293</td>
</tr>
<tr>
<td>MFP Retail trade</td>
<td>.687</td>
<td>-.276</td>
<td>-.307</td>
</tr>
<tr>
<td>MFP Goods-producing industries</td>
<td>.686</td>
<td>.102</td>
<td>-.221</td>
</tr>
<tr>
<td>MFP Manufacturing</td>
<td>.668</td>
<td>.075</td>
<td>-.325</td>
</tr>
<tr>
<td>MFP Accommodation and food services</td>
<td>.642</td>
<td>-.255</td>
<td>-.060</td>
</tr>
<tr>
<td>MFP Former measured sector</td>
<td>.617</td>
<td>.057</td>
<td>-.361</td>
</tr>
<tr>
<td>MFP Financial and insurance services</td>
<td>.489</td>
<td>-.453</td>
<td>-.538</td>
</tr>
<tr>
<td>MFP Information media and telecoms</td>
<td>.389</td>
<td>-.437</td>
<td>-.438</td>
</tr>
</tbody>
</table>

Note: Bold text indicates statistical significance at $p < .05$

It is noticeable that only the construction and mining sectors have positive correlation between MFP and capital input, albeit these are not statistically significant correlations. However, all other sectors have a negative correlation between MFP and capital input, and given that capital input is in the denominator, a strong negative correlation is arguably desirable.

Those sectors that outperform the NZ economy appear to be the sectors that have achieved a virtuous circle of improvement. Balanced growth of the output facilitates investment in productivity-enhancing technologies, which lead to lower labour input (or greater outputs for the same labour input), which in turn helps generate a healthy sector for future growth and investment. Unfortunately, the severe boom–bust nature of the construction sector makes it difficult, if not impossible, to achieve such a virtuous circle. Therefore, a strategy to improve the construction sector towards the average performance of the NZ economy must address this fundamental barrier and move towards generating an environment of steady growth and investment, as illustrated in Figure 9-13.
Let us now consider the monetary value of the productivity performance of the sector for NZ. The construction sector is worth NZ$14.1 billion per annum (Statistics New Zealand, 2016). On average, the ‘construction sector’ productivity has shown a 0.2% (compound annual growth rate) improvement over the period 1978 to 2014 compared with 0.9% for the economy as a whole and 2.2% for the ‘information media and telecommunications’ sector. An improvement of construction productivity by 2% per annum (i.e., to match the ‘information media and telecommunications’ sector performance) would be worth approximately NZ$0.28 billion per annum. If this growth rate could be achieved over the period of the next 25 years such an improvement would be worth approximately NZ$4.4 billion in net present value (NPV) terms, assuming a discount rate of 6%, which is in accordance with the NZ Treasury (2016) official discount rate.

It is unrealistic to expect construction productivity to improve to match one of the best-performing sectors of the economy, so let us compare with the average performance of all sectors in NZ. The average (unweighted) productivity growth of the NZ economy (as measured by the ‘former measured sector’ metric) over the past 36 years was 0.9% (compound average growth rate). It is a much more achievable target to improve to the average performance. If improvements could be made to the construction sector to match the average of the economy, a

**Figure 9-13: Strategy for Improving Productivity Performance of the New Zealand Construction Sector**
more realistic target, it would equate to 0.7% average improvement. This translates to approximately NZ$0.10 billion per annum, which over the next 25 years would equate to an NPV of approximately NZ$1.55 billion. To put this in context, the monetary amount is sufficient to purchase the Waterview project, which cost approximately $1.4 billion (New Zealand Transport Agency, 2016).

These monetary values are sufficiently large to justify some strategic decision-making at governmental policy-making levels. The potential monetary values from productivity improvements are achievable by reducing the variability of the demand side of the productivity equation for the construction sector. While this is simple in theory and easy to recommend, the practicalities of implementation are difficult. The construction sector is highly fragmented, with no central decision-making for managing the demand on the sector. However, some policies towards streamlining demand, and towards steady growth, could be implemented by central government, local government and major customers of the construction sector such as utility companies and significant owners of infrastructure.

Another strategy for addressing the productivity problem is for the construction sector supply chain to find ways of increasing the investment in value-adding technologies, as indicated in Figure 9-13. Ideally, the supply chain could also assist in addressing the challenge of the boom–bust cycle by finding agile ways of responding to this natural cycle. Again, such recommendations are easy to make but difficult to implement, particularly in NZ because of its geographic isolation as there is little opportunity to flex resources to meet demand via geographic diversification.

A further strategy could be to develop partnerships between construction industry clients and supply chain organisations to take a more proactive approach to smoothing supply and demand via new and novel procurement systems. Rather than procuring on a project-by-project basis, major clients could consider long-term strategic partnerships with suppliers, offering greater certainty of future workloads. Options could include procurement models incorporating supplier selection on the basis of productivity improvement track record and targets, rather than the basis of raw price, or models with some guarantees around workload levels where the client-side organisations take more of the risk of workload demand. Another option is greater use of the private finance initiative (PFI), with supplier-led consortia identifying projects and initiatives and making greater use of private finance to secure a steadier, forward-looking order book.

Hence, we have an additional four key recommendations to add to our existing recommendation made earlier in this chapter (which is repeated for the sake of clarity):

- Recommendation 1: Improve the reporting of the productivity performance data for the construction sector, by providing the data in context, and with greater clarity on how the data is compiled.
- Recommendation 2 (Client side): Implement policy directions at governmental level and leadership levels of construction sector client organisations, to reduce the demand
volatility and move towards a steady growth of demand upon the construction sector supply chain.

- Recommendation 3 (Supply side): Develop and implement new strategies to improve the agility of the supply chain to respond to shifts in demand.
- Recommendation 4 (Supply side): Improve the investment rate in capital inputs, particularly value-adding information and communications technologies applied within the industry sector.
- Recommendation 5 (Client side and supply side): Develop new partnerships and strategies to work collectively to reduce the volatility of the sector and exit from the boom–bust cycle.

We suggest that the estimate of the impact on productivity is not imaginary money. It is a real opportunity-lost $ sum. It is not theoretical, but real and tangible. If we could guarantee a 0.7% improvement in construction productivity from now and keep the level sustained until 2050, we could afford another Waterview project and still be in pocket, with $150 million change left over. NZ incurs the costs of the boom–bust impact upon the construction sector productivity in real terms. In effect, over the next 25 years NZ will incur the cost, irrespective of whether we improve productivity or not, and we will forego the potential benefit if we do not improve the sector productivity.

9.5 Conclusions and Recommendations for This Research Stage: Macroeconomic Analysis

If the demand volatility of the construction sector can be reduced, then it will allow the construction sector to improve the rate of investment in systems with confidence. This can be demonstrated by reference to our information flow causality model, annotated with our five key recommendations, as given in Figure 9-14.
Recommendation 1 relates to the reporting of the productivity performance data for the construction sector, by providing the data in context, and with greater clarity on how the data is compiled. Recommendations 2 and 3 relate to improving the effectiveness and efficiency of the construction sector by addressing the context issues and creating a healthy environment in which the industry has maximum opportunity to thrive. They also relate to creating value and reducing waste through taking actions towards improvements. Recommendation 4 relates primarily to improving knowledge bases via technology enablers. The potential for ICT to improve the management of design and construction is not yet fully realised. Recommendation 5 relates to using information we have about the situation to create shared understanding between client and supply chain sides of the industry to generate new and creative solutions and procurement delivery models. Underlying all of these is the use of information to demonstrate the case for improvement, using knowledge and information pertaining to the productivity challenge to envisage a better, more productive future.

In order to achieve a more productive sector, and generate the benefits associated with productivity improvement such as greater prosperity, there needs to be an ongoing planned programme for performance improvement. Improvements cannot be achieved simply and
quickly, but rather they require continuous effort towards superior outcomes. Hence, we need to generate a virtuous circle of ongoing betterment. Our productivity improvement circle coupled with our informational flow productivity causality model, as given in Figure 9-15, provides a future roadmap for policy makers, leaders and all decision-makers with an interest in the construction sector, for the benefit of NZ.

![Figure 9-15: Model of Virtuous Circle of Productivity Performance Improvement, with Information Flow Causality Model Applied as a Driver for Improvement](image)

We can also apply our new definition of information to the issue under consideration: the above analysis is an example of a set of data with high semantic value. According to our new definition of information, which is defined as follows:

\[
\text{Multifactor Productivity} = \frac{\text{Output}}{\text{Labour Input} + \text{Capital Input}}
\]
Information = Delta (i.e., the change in) subjective expected future value, from the perspective of the recipient

Information = $\Delta \text{SEFV}(r)$

Breaking this down into the component parts we postulate the following:

Information = $\Delta (S).\text{(EFV)}(r)$

Where:

Delta Expected Future Value $\Delta (\text{EFV}) = \text{Function of } \Delta (\text{FV})_{\text{actual}}.\text{(i)}.\text{(t)}$

$\Delta$ is the change arising as a result of the informational signal (or group of signals);

Future Value $(\text{FV})_{\text{actual}}$ is the real (i.e., actual) future value from events to which the information relates, which are eventuated in due course;

Integrity $(i)$ is a factor to reflect the integrity, reliability, truthfulness, factual correctness of information;

Timeliness $(t)$ is a factor to reflect the need for information be received in a timely manner.

Where also:

Subjectivity $(S)$ is a function of Relevance $(r)$, Understanding $(u)$ and Cognisance $(c)$ and each of these have a function that varies between 0 and 1;

$S = \text{Function of } (r).\text{(u)}.\text{(c)}$

Hence:

Information = $\Delta \text{SEFV}(r) = \text{Function of } \Delta (\text{FV})_{\text{actual}}.\text{(i)}.\text{(t)}.\text{(r)}.\text{(u)}.\text{(c)}$

It is for the recipient of this information (reader of this document) to formulate a view on the value of $(i)$, in a range from 0 (if the reader is of the opinion that our analysis has no integrity, or is factually incorrect) through to 1.0 (if the reader forms the opinion that our analysis has complete integrity, reliability and truthfulness and is factually correct). We suggest $(i)$ approaches 1.0 in this instance as it is based on reliable evidence and rigorous analysis, but it is the recipient’s estimation of $(i)$ that matters.

The message needs to be timely to be of value. We suggest that the information contained in our analysis is timely from now onwards, as the construction sector will need to improve over the next several decades. We suggest this information is timely for decision-makers looking at policy direction and strategic decision-making over the next 25 years; hence, $(t)$ should = 1.0.

Also, the value of the informational content will depend upon the extent to which it is relevant, understood and interpreted correctly by the recipient. If the message is not relevant to the reader, or not understood, or not appreciated cogitatively, then the informational value may be
close or equal to zero. Hopefully it is understood by the reader, and relevant and appreciated cognitively, in which case \((r)\) will tend towards 1.0.

We previously estimated that the NPV of a productivity improvement of the NZ construction sector to the NZ economy average productivity growth rate (i.e., from an average annual productivity growth rate of 0.2\% to 0.9\%) equates to approximately NZ$1.55 billion (NPV in 2017 time value of money). Hence:

Information contained in this analysis, interpretation and recommendation, if acted upon

\[
\Delta \text{SEFV}(r) = \text{NZ$1.55bn (NPV)}
\]

Information flow matters: it is the key to improving performance.
10 Overarching Conclusions and Recommendations

10.1 Overarching Review of the Research Objectives

In this section we return to the original objective and associated goals of the research, and assess the extent to which these have been achieved. In Chapter 1 the objective was defined as follows:

To gain an understanding of the linkages between information flow and productivity in the engineering and construction sector; and thereby to identify future directions for improving productivity.

Within this objective six goals were also identified, as follows:

- Goal 1: To investigate the linkages between information flow and productivity within the sector and determine the extent to which productivity outcomes are dependent upon information flow inputs.
- Goal 2: To understand the mechanisms by which information flow affects productivity and thereby build a framework or causality model linking information flow with productivity.
- Goal 3: To identify the impact of information flow upon the quality of problem-solving and decision-making within the engineering and construction context.
- Goal 4: To investigate the relative effectiveness of different information search strategies for decision-makers.
- Goal 5: To identify the relative effectiveness of a range of information dissemination and transfer systems, including new and emerging information technology and management solutions.
- Goal 6: To provide some directions for productivity improvement for the engineering and construction sector in NZ.

A review of the key findings for each chapter addresses the extent to which the objective and goals have been addressed. A summary is also provided in Table 10-1.
<table>
<thead>
<tr>
<th>#</th>
<th>Objective Achieved</th>
<th>Goals Achieved</th>
<th>Qualitative/Quantitative</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Objective addressed and information flow productivity causality model proposed</td>
<td>Qualitative</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantitative</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Objective addressed and information flow productivity causality model enhanced</td>
<td>Qualitative</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantitative</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Objective addressed and information flow productivity causality model fine-tuned</td>
<td>Qualitative</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantitative</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Objective addressed and information flow productivity causality model validated</td>
<td>Qualitative</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantitative</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>8</td>
<td>Objective addressed and new theory of semantic value of information proposed</td>
<td>Qualitative</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantitative</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>9</td>
<td>Objective addressed with recommendations for productivity improvement</td>
<td>Qualitative</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quantitative</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

In Chapter 4 we identified a new information flow productivity causality model, which linked information flow as an input to productivity outcomes. We identified that the linkage is via a number of intermediate stations, namely, decision-making, action-taking and context. Within each of these, we identified some important considerations such that the causality model may be used to improve the quality of the information flow, based upon knowledge, quality of decision-making and action-taking in turn, which influence productivity as a function of effectiveness and efficiency. This model provides a foundational framework to help direct performance improvements. The model is qualitative, based on a series of in-depth interviews of industry professionals working in a range of roles and subsectors of the construction industry, including clients, designers and constructors. Hence, we addressed our objective and provided a qualitative framework to help identify future directions for improving productivity. This addressed Goal 2, and also partly addressed Goals 1, 3, 4, 5 and 6, all from a qualitative perspective. We argued that the key to improving productivity is to focus on effectiveness, rather than efficiency. While we acknowledge that efficiency is also important, we contend that improvements in efficiency should not be to the detriment of effectiveness.

In Chapter 5 we developed the flow productivity causality model initially proposed in Chapter 4. We enhanced the model to identify issues in the context station, decomposing them into five levels, namely, task, team, project, organisation and industry. We identified some of the most pertinent context considerations in each of these layers to make the model more specifically applicable to the engineering and construction sector. We gave directions for the most
prominent means of translating task-level productivity improvement into team productivity improvements via focusing on communications, from team to project via integrating efforts, from project to organisational improvements via focus on human resources, and from organisations to broad industry productivity performance via organisational management. Hence, in decomposing the problem of productivity into component parts in order to provide greater understanding of the issues, we also provided a framework for integrating these component parts in a new way, not previously given in the literature. Hence, we addressed the objective, enhancing our understanding, and giving more directions for productivity improvement, thereby addressing Goals 2 and 6. We also achieved a quantitative assessment of the impact of information flow on productivity via statistical analysis on participant views of information inputs and performance of organisations. Regression analysis indicated a statistically significant linkage, with 46% of variation in organisational performance being associated with informational inputs. Institutional-knowledge-based information inputs were identified through the analysis as having the greatest impact, followed by market-focused information and operating-focused information respectively. Hence, a direction for improving performance can be taken as focusing on improvements in these aspects of information flow, as improvement in information translates to less variability in organisational performance, which in turn should improve long-term organisational productivity. This addresses our objective from a more quantitative perspective, complementing our qualitative findings. Hence, Goals 1 and 6 were also addressed.

In Chapter 6 we turned to improving our understanding of the ways in which information is used for decision-making and to identify information search strategies typically undertaken by decision-makers in the engineering and construction sector. We were able to make a meaningful comparison between information search strategies undertaken nowadays in the modern ICT world and search strategies undertaken in the early 1980s before the digital revolution, by conducting research similar to the study by Patterson and Farrant (1982). We found a dramatic change in the way decision-makers access information from documentary sources, such as previous reports, codes and regulations and standards, facilitated via database and online systems. However, of equal interest is that we also found that decision-makers much prefer people sources of information, such as colleagues and superiors, as reflected in the frequencies with which they are consulted as well as ratings of the best sources of information for both the understanding process and the solving process. In this regard, information search strategies have not changed. We also found that decision constraints influence the time spent in decision-making, and hence, that a strategy for improving the timeliness of decisions is to understand and address the constraints as a priority. We also found that decision-making in engineering and construction is a highly iterative process, with 80% of decisions taking two or more iterations, and the principal reason for such iterations was identified by participants as being emergent information issues. We found statistical significance in the correlation between the number of iterations to a decision and the overall time span of the decision-making process. Hence, a possible means of improving productivity is to focus on generating as complete and full information as possible early to enable robust decision-making
to reduce the need to reiterate, and thereby reduce time spans and improve production rates and productivity. In this chapter we therefore addressed the central objective by deepening our understanding of the interplays between information search strategies and decision-making. The findings helped to build more evidence for our information flow productivity causality model, particularly in validating the linkages between knowledge, types and channels of information, and decision-making. We addressed Goals 2, 3, 4 and 5 qualitatively and quantitatively, with some strong indicators of the impact of ICT, and a range of statistically significant relationships between elements of decision-making such as iterations and time. We developed our information flow productivity causality model further by adding the iteration loop in the decision-making process, thereby also addressing Goals 1, 2 and 6.

In Chapter 7 we undertook detailed quantitative and qualitative data collection and analyses of information flow in meetings on a major engineering and construction project in a longitudinal study over 30 weeks. This research provided a wealth of data and information that effectively served to validate the applicability of our information flow productivity model. The quality of information sharing in meetings has a direct bearing on the quality of decisions and subsequent actions. These in turn have significant impacts in the engineering and construction sector in aspects of quality of design and subsequent construction and asset life cycles, avoidance of waste, avoidance of possible harm, generation of new ideas, innovative problem-solving, allocation of responsibilities, providing clarity of roles, and the coordination of efforts towards common purpose. We also found patterns of information flow within meetings, in which the simultaneous search and dissemination of information between several intelligent agents is particularly valuable, and is hard to replicate in non-personal forms of information flow (i.e., outside of face-to-face dialogue). This helps to explain the preference for information from colleagues and superiors found in Chapter 6. We were also able to measure the productivity of the meetings quantitatively with a series of three of productivity metrics. We found that a labour productivity metric for decision-making is a function of the number of decisions and the quantum of human resources committed to the meeting. Statistical analyses indicated that 75% of the productivity of meetings is associated with six parameters, namely, number of people contributing to agenda discussion, number of agenda items, agedness of the agenda item, complexity of issues, information-seeking effort, and constraints. Hence, we were able to address our objective within the context of information flow via meetings. We also addressed Goals 1, 3, 4 and 5, and we were able to provide additional evidence to validate our model offered in Chapter 4 towards Goal 2 and provide additional recommendations towards Goal 6.

In Chapter 8 we turned our attention to a philosophical discussion and development of a new definition of the semantic value of information. This was needed in order to provide a means of quantifying the particular value of an informational signal. One of the challenges of our research subject was the rather abstract nature of information. Previous models of information from the literature focused on the quantification of the signal rather than the quantification of the value of the signal. We needed to research the linkages between informational flow and productivity from a semantic value perspective and hence a new definition was necessary in order to
attempt to quantify linkages. We identified that the semantic value of information is a function of integrity, timeliness, relevance, understanding and cognisance from the perspective of the recipient. Hence, we developed a new understanding of the fundamental nature of the semantic value of information, which is applicable to all information, but in the context of our objective, also helped to understand the linkages between information and productivity at a fundamental level. This also addresses Goals 1, 2, 3 and 6.

In Chapter 9 we turned our attention to the productivity performance of the engineering and construction sector at an aggregate level, drawing on the productivity performance of the construction sector in NZ using data for the period 1978–2014 published by SNZ. We also made comparisons with other sectors to deepen our understanding of productivity performance improvement. We were able to improve interpretation of the SNZ data from previous studies by a combination of casting the performance in the context of NZ and global market forces (shocks) and more careful analysis of the subcomponents of the construction sector productivity index. We found that the construction sector’s apparent poor performance (compared with other sectors) has been caused to a significant degree by the impact of just two years in the early 1990s. Exceptional factors that influenced these two years were introduction of the RMA, changes to accounting reporting practices and the NZ Government selling of the Ministry of Works. Also, we found that SNZ categorise off-site production as being in the manufacturing sector, which means that the performance of the construction sector is really a metric of just the on-site component of productivity, not of the industry wider supply chain. Hence, we were able to cast performance in context and also deepen the understanding of the productivity performance of the sector in NZ. We were also able to provide some new compelling analyses on the causality of the construction sector productivity performance, being the high volatility of the output demand and low investments in capital inputs (capital inputs typically being information communications technologies). We were able to quantify the monetary value of the impact on the productivity performance of the construction sector, and use our information flow productivity causality model in conjunction with our new definition of the semantic value of information to solve the key underlying productivity problem in NZ and make five compelling recommendations for productivity improvements. Hence, we believe we have answered the objective in a comprehensive and convincing way, while also addressing all six goals.

10.2 Overall Limitations

The limitations of each of the primary data sources are acknowledged in the relevant chapters, Chapters 4 to 9, and summarised as follows:

- Chapter 4: Based on qualitative data only.
- Chapter 5: While comprising a mix of qualitative and quantitative data, the data is based on the subjective estimations of participants (i.e., not independently quantified).
- Chapter 6: Similar to Chapter 5. Also, the response was dominated by participants from the professional services subsector and hence reflects the decision-making preferences primarily of designers.
• Chapter 7: While comprising a mix of qualitative and quantitative data, the data is based on one case study project. The case study project was a large infrastructure project delivered under an alliance form of procurement. Information flows in meetings in other types of projects may differ. The data collection was undertaken via observations in which the researcher was present in the meetings, and although the researcher did not contribute to the meetings, the mere presence will have influenced meeting participants’ behaviours because of the Hawthorne effect (McCambridge et al., 2013; Parsons, 1974).

• Chapter 8: Based on data from previous chapters.

• Chapter 9: Based on SNZ data only and no independent verification was undertaken.

While these limitations should be acknowledged within each chapter, the progressional approach to our research combining mixed methods, as outlined in Chapter 3, means that collectively the body of research has a greater degree of validity than any one chapter on its own. Each of the mixed research methods helps to validate the findings from other chapters. We used five independent data sets to compile our findings, summarised in Table 10-2.

Table 10-2: Summary of Data Sources Used for This Body of Research

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Data Collection Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Semi-structured Interviews</td>
<td>In-depth interviews of 24 participants with responses to 18 open-ended questions.</td>
</tr>
<tr>
<td>5</td>
<td>Industry Survey</td>
<td>Detailed questionnaire with 62 responses to a set of 16 questions.</td>
</tr>
<tr>
<td>6</td>
<td>Decision Survey</td>
<td>Detailed questionnaire with 98 responses to a set of 27 questions. Independent from previous questionnaire used in industry survey.</td>
</tr>
<tr>
<td>7</td>
<td>Observations</td>
<td>Direct observations of 49 meetings, comprising 439 agenda items, generating approx. 65,000 data points.</td>
</tr>
<tr>
<td>8</td>
<td>Drawing on data from Chapters 4 to 7</td>
<td>As above.</td>
</tr>
</tbody>
</table>

We completed our research following a mixed data collection and analyses strategy, following our research design developed in Chapter 3 (summarised in Section 3.3). We believe that the progressional research approach adopted was appropriate for our research objective and goals, and the outcomes validate the research design we developed.

Overall, the limitations of this research as a collective body of findings and conclusions relate to the fact that all data has been collected in the context of the engineering and construction sector in NZ. While our findings may be of interest to other comparable sectors and/or nations, our recommendations for productivity performance improvement should be subject to comparative studies using similar data sets to validate applicability to other contexts.
10.3 Overall Summary of Key Recommendations from Each Chapter

In this section we provide a summary of the key recommendations made in each of the chapters, as given in Table 10-3.

Table 10-3: Summary of Key Recommendations for Productivity Improvement from Each of the Chapters

<table>
<thead>
<tr>
<th>Ch</th>
<th>#</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>Seek to improve productivity performance by focusing on effectiveness foremost, without unduly affecting efficiency. Thereafter, seek to improve efficiency, but not at the expense of effectiveness.</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Improve outcomes by investing in knowledge-based informational products such as ICT solutions, as these have significant potential to improve the bottom line performance of organisations.</td>
</tr>
</tbody>
</table>
| 6  | 1 | Seek to maximise opportunities for decision-making staff to interact in direct face-to-face communications, as these are the preferred and most effective means of facilitating information flows.  
2 | Focus on generating as complete and full information as possible early to enable robust decision-making to reduce the need to reiterate, and thereby reduce time spans, and improve production rates and productivity.  
3 | Increase the quality of information sources available to staff via ICT systems, to transform data into information with intelligence and high semantic value, and make such information readily available. |
| 7  | 1 | Use project meetings to help build shared understanding and consensus building around the solving of problems, the making of decisions, the negotiation of actions and the allocation of responsibilities, as these will in turn determine the quality of outcomes on projects.  
2 | Hold regular meetings to facilitate a regular information flow and assist with resolving issues.  
3 | Twelve recommendations for holding effective and efficient meetings as given in Section 7.11. |
| 8  | 1 | Focus on optimising the semantic content of informational messages, as this is the key to realising future value, leading to effective decision-making and action-taking. Semantic value of information can be optimised via ensuring integrity and timeliness of the message, and relevance, understanding and cognisance from the perspective of the recipient. |
| 9  | 1 | Improve the reporting of the productivity performance data for the construction sector, by providing the data in context, and with greater clarity on how the data is compiled.  
2 | Implement policy directions at governmental level and leadership levels of construction sector client organisations, to reduce the demand volatility and more towards a steady growth of demand upon the construction sector supply chain.  
3 | Develop and implement new strategies to improve the agility of the supply chain to respond to shifts in demand.  
4 | Improve the investment rate in capital inputs, particularly value-adding information and communications technologies applied within the industry sector.  
5 | Develop new partnerships and strategies to work collectively to reduce the volatility of the sector and exit from the boom–bust cycle. |

10.4 Future Research Directions

The topics of information flow and productivity are both broad topics in their own right, and given that the linkages between the two have not been subject to extensive previous research, there is significant scope to continue research in the domain that connects these two fields. Four
broad future research directions have been identified, which we outline with reference to our informational productivity causality model as illustrated in Figure 10-1.

Each of the four future directions of research illustrated are further elaborated, with suggestions for data collection methods in the following subsections.

10.4.1 Development of a Comprehensive Map of Productivity Factors and Interrelationships at Task, Team, Project, Organisational and Industry Levels

In the first instance, it would be useful to have a comprehensive list of contextual factors for each level of consideration at task, team, project, organisation and industry levels. We envisage this would focus on qualitative understanding of the factors, drawing on understanding of issues identified by people with decision-making responsibilities at these levels and across different subsectors of the industry, including clients, designers and constructors. This direction of research should also seek to understand the linkages between context levels of the factors that influence workers. For example, how do factors that influence productivity at the task worker level also influence productivity at the team level, and so on? We hypothesise that it is possible to optimise productivity at one level but to the detriment of productivity at other levels, and hence, a systems thinking approach would be helpful in this respect to help optimise the overall system. It appears that there is a possibility of generating a comprehensive map of factors and interrelationships. Such a systems thinking map would help address possible contradictory
forces and find new ways to improve productivity via interjection of suitable incentives at key points. We suggest that a combination of interviews, direct observations and focus groups could be a good data collection strategy.

10.4.2 Development of a Quantitative or Mathematical Model for the Relationships between Efficiency, Effectiveness and Value

The current productivity data sets focus on the performance of the construction sector at the aggregate level. In NZ we currently have no readily available data measuring productivity at task, team and project levels. The data measuring performance of organisations can potentially be extracted from company reports and annual accounts. SNZ have also started publishing some additional data for the sector in the form of Annual Enterprise Survey (AES) data, which gives an indication of economic performance on the basis of metrics such as return on equity and return on total assets. These start to give some possible means to understand the relationships between company performance and aggregate productivity. However, overall, there is significant scope for further research to devise suitable productivity metrics at different levels of consideration and to prove the quantitative relationships. In our literature review we found evidence that in the USA productivity at the task level is improving while concurrently declining at the aggregate level. Understanding such apparent contradictory trends is important. We hypothesise that a similar trend is occurring in the NZ construction sector and that the reasons for it lie in the waste of resources at the project and organisational levels. We believe we have demonstrated this qualitatively in our current research; the next step would therefore be the development of a quantitative model. Such a model, demonstrating and proving the strength and nature of such relationships, would be very valuable in helping to identify ways of improving productivity. Such research will necessitate the collection of considerable amounts of raw data on actual performance and needs a long-term research plan.

There is also potential to compare the industry performance of the NZ construction sector with other comparable nations using a similar approach to our analyses of volatility of productivity inputs and output. We have already started with such a project, drawing on published data from countries such as Australia, the UK and the USA.

10.4.3 In-depth Investigations into the Linkages between Quality of Decision-Making and Quality of Action-Taking in Engineering and Construction

In the third area for future research directions, we see potential benefits from advancement of knowledge relating to how decisions are turned into actions in engineering and construction. In particular, the areas of how investment decisions taken by clients are translated into designs, and subsequently how design decisions are translated into actions that a contractor implements on site, could yield worthwhile results. There are already considerable bodies of knowledge in lean construction that have contributed much in aspects of the application of lean thinking to the construction sector, which can be drawn upon. Hicks (2007) also has made valuable contributions regarding uses of information, making comparisons to lean thinking. However, a deeper understanding of the quality of decision-making and quality of action-taking via mutual understanding and translation into responsibilities at a fundamental level could help with
advancement of improved models of procurement, risk allocations and delivery mechanisms in engineering and construction. We suggest that a combination of interviews, surveys and direct observations applied in a progressional manner is appropriate to advance this area.

10.4.4 Translating Performance Metrics into Useful Information for Quality Improvements

In the fourth future research direction, there is opportunity to apply an action research approach to seek performance improvements via translating productivity metrics into improved quality of decision-making and action-taking. A series of small incremental improvements could be implemented not only to prove the linkages, but actually generate real and immediate productivity improvements. This will require an experimental approach, with a researcher working collaboratively in conjunction with industry partners who are willing to trial a series of controlled experiments under an action research framework. There is a risk involved as some of the trials may not generate improvements or could potentially have a negative impact. However, the potential value of such a research direction could be very large if findings are published and shared with others across the industry via a knowledge-sharing platform.

10.5 Contributions to Knowledge

Contributions to knowledge from this research are as follows:

- Development of a new information flow productivity causality model linking information flow as an input to productivity outcomes. This model should be useful for organisations seeking to improve productivity outcomes, informing future strategic directions for both the public and private sectors. A general model is offered, applicable for all organisations using information, together with a more specific model applicable to the engineering and construction sector.

- Identification that productivity issues can be decomposed into five layers within the engineering and construction sector, namely, task, team, project, organisation and industry. The means of improving productivity at each level are identified and importantly how productivity issues are linked between the five levels are also identified, with indications of how to translate improvements between levels of task, team, project, organisation and industry. This model should be useful for engineering and construction professionals and practitioners at all levels of industry as a means of delivering productivity improvements.

- Identification of the impact of the digital ICT revolution upon information-seeking patterns by decision-makers, by means of comparisons with research undertaken in the early 1980s. This shows that while search patterns have changed to make more diverse use of modern information sources, such as the internet and database systems, decision-makers still prefer information from colleagues and superiors. People information sources remain the most commonly used while also being rated as the most useful for the understanding process and the solution process. The findings and conclusions are useful for professionals in the engineering and construction sector,
particularly designers, who are seeking to maximise the value of data, information and knowledge. It should also be useful for those seeking to develop new communications tools, such as ICT solutions and applications to enhance information flows.

- A new model for information flow within meetings, incorporating new productivity metrics specifically designed for measuring meeting effectiveness and efficiency, with statistically significant regression analysis results linking informational inputs with productivity outcomes. These findings are useful for anybody who chairs or participates in meetings and will help improve both the effectiveness and efficiency of meetings and subsequent outcomes.

- A new definition of information that enables quantification of the semantic value of an informational signal. This new definition of information provides a theoretical foundation for future directions of research and provides a deeper understanding of the nature of information. The applications of this theory are untested but potentially the theory could provide a significant contribution to knowledge in advancing our understanding of the fundamental nature of information.

- New compelling evidence that the relatively poor productivity growth of the construction sector in NZ compared with other sectors is due in large part to the volatility of the output demand from clients, coupled with the lack of consistency in industry investment in capital inputs by suppliers. This evidence gives insight on where to direct future policy to deliver much better value from the engineering and construction sector, and drive long-term productivity growth.

- A mixed research methodology, with a novel mapping technique, combining contrasting paradigms in a progressional manner to investigate the linkages between the abstract concept of information with the more objective construct of productivity.

In totality, our contribution to knowledge is compelling evidence that information flow matters – that it is a vitally important component to productivity performance in engineering and construction. Our research is in a new field, that of linking information flow as an abstract concept to productivity performance as a quantified metric of performance, which has not been the subject of previous research. Our research therefore also opens up a new field of future research opportunities.

SDG
Appendices
A1  Appendix 1: Productivity Definitions

Definitions of the different methods of measuring productivity are provided and briefly discussed in the following tables:

A1.1  Labour Productivity

Table 11-1: Labour Productivity, based on Gross Output

<table>
<thead>
<tr>
<th>Labour Productivity, based on Gross Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
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<tr>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td><strong>Interpretation</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td><strong>Limitations</strong></td>
</tr>
</tbody>
</table>

Source: Based on (Organisation for Economic Co-operation and Development, 2001), (Davis, 2007), (Huang et al., 2009) & (Page, 2010)
Table 11-2: Labour Productivity, based on Value Added

<table>
<thead>
<tr>
<th><strong>Labour Productivity, based on Value Added</strong></th>
</tr>
</thead>
</table>
| **Definition** | = Quantity Index of Value Added  
 Quantity Index of Labour Input |
| **Purpose** | Analysis of micro-macro links, such as and industry contribution to economy-wide labour productivity. At the aggregate level it forms a link to the widely used measure of living standard; income per capita. It is important as a reference in wage bargaining. |
| **Interpretation** | It is the time profile of how productively labour is used to generate value added. Labour productivity changes reflect the joint influence of changes in capital, as well as technical, organizational and efficiency change (within and between firms), economies of scale, capacity utilization and measurement errors. It only partially reflects the productivity of labour in terms of intensity of labour effort, as the ratio between output and labour input depends to a large degree on the presence of other inputs. In comparison with labour productivity based on gross output, the growth rate of value-added productivity is less dependent on any change in the ratio between intermediate inputs and labour, or the degree of vertical integration. |
| **Advantages** | Easy to measure and read. |
| **Limitations** | It is a partial productivity measure and reflects the influence of a range of factors. It is often misinterpreted as technical change or as the productivity of the individuals in the workforce. |

Source: Based on (Organisation for Economic Co-operation and Development, 2001), (Davis, 2007), (Huang et al., 2009) & (Page, 2010)

A1.2 Capital Productivity

Table 11-3: Capital Productivity, based on Value Added

<table>
<thead>
<tr>
<th><strong>Capital Productivity, based on Value Added</strong></th>
</tr>
</thead>
</table>
| **Definition** | = Quantity Index of Value Added  
 Quantity Index of Capital Input |
| **Purpose** | It is useful in providing an indication of the extent to which output growth can be achieved with lower welfare costs. |
| **Interpretation** | It is the time profile of how productively capital is used to generate value added. Capital productivity changes reflect the joint influence of changes in labour, technical change, organizational and efficiency change (within and between firms), economies of scale, capacity utilization and measurement errors. Like labour productivity capital measures can be based on gross output or value added. Value added based capital productivity measures are less sensitive to processes of substitution between intermediate inputs and capital than gross based output measures. |
| **Advantages** | Easy to read. |
| **Limitations** | It is a partial productivity measure and reflects the influence of a range of factors. Sometimes it is confused with return on capital (return on capital is a measure that relates income to the value of the capital stock). |

Source: Based on (Organisation for Economic Co-operation and Development, 2001), (Davis, 2007), (Huang et al., 2009) & (Page, 2010)
### A1.3 Multi-Factor Productivity

**Table 11-4: Multi-Factor Productivity, based on Value Added**

| Definition | = Quantity Index of Value Added  
|           | Quantity Index of combined Labour and Capital Input  
| Note:     | Quantity Index of combined Labour and Capital Input = quantity index of labour and capital, each weighted with its current price share in total value added. |
| Purpose   | Analysis of micro-macro links, such as the industry contribution to economy-wide MFP growth. Also useful for the analysis of structural change. |
| Interpretation | Labour-Capital MFP indices show the time profile of how productively combined labour and capital inputs are used to generate value added. It reflects the combined effects of disembodied technical change, economies of scale, efficiency change, variations in capacity utilization and measurement errors. |
| Advantages | Ease of aggregation across industries. Data directly available from national accounts. |
| Limitations | Not a good measure of technology shifts at the industry or firm level. |

Source: Based on (Organisation for Economic Co-operation and Development, 2001), (Davis, 2007), (Huang et al., 2009) & (Page, 2010)

**Table 11-5: KLEMS Multi-Factor Productivity**

| Definition | = Quantity Index of Gross Output  
|           | Quantity Index of Combined Input  
| KLEMS relates to Capital, Labour, Energy, Materials and Services  
| Note:     | Quantity Index of Combined Input = Quantity index of labour, capital, energy, materials, services, each weighted with its current price share in total gross output. |
| Purpose   | Analysis of industry level and sectoral technical change. |
| Interpretation | Shows the time profile of how productively combined inputs are used to generate gross output. Conceptually this measure captures disembodied technical change. |
| Advantages | Conceptually KLEMS – MFP is the most appropriate tool to measure technical change by industry as the role of intermediate inputs in production is fully acknowledged. |
| Limitations | There are significant data requirements. |

Source: Based on (Organisation for Economic Co-operation and Development, 2001), (Davis, 2007), (Huang et al., 2009) & (Page, 2010)
Appendix 2: Semi Structured Interviews Qualitative Data

In this Appendix we present a series of data primarily in the form of direct quotes taken from the transcripts of the participant interviews from Chapter 4. These are numbered following the numbering of the questions in the semi-structured interviews.

Note that quotes given in the tables in this Appendix are selected quotes of the key points; they are not the full transcripts. Selected quotes are given as being the more pertinent comments made by the participants and are presented in tabular format for the sake of brevity and making comparisons between comments under each of the semi-structured questions.
A2.1.2 Semi-Structured Interview Questions (Chapter 4)

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
Faculty of Engineering

Project Title
Information Flow Matters: Improving Performance and Productivity in Engineering and Construction
Name of Researcher: Mr Garry Miller
Degree: PhD
Department: Civil & Environmental Engineering
Research Supervisor: Dr Theuns Henning

Definitions
Information: a message used by a sender to represent one or more concepts within a communication process, intended to increase knowledge in recipients.
Data: that which is stated; sensory stimuli that we perceive through our senses; observations and other recordings or collection of evidence.
Knowledge: is embodied in humans as the capacity to understand, explain and negotiate concepts, actions and intentions.

1. Please confirm your Industry Sector?
   - Construction / physical works
   - Consulting / professional service provider
   - Client / purchaser
   - Other (please state) .......................................................... ..........................................................

2. What forms of information does your organisation use? Please summarize the main forms.

3. What information do you receive from people outside your organisation (or in other words what information search methods do you typically use)?

4. What information do you receive from people inside your organisation?
5. What information do you give to others outside your organisation (or in other words what information do you disseminate)?

6. What information do you give to others inside your organisation?

7. How does what you receive match what you need to do your job?

8. Please describe the primary modes of contact you have with people from whom you receive information and to whom you give it (or in other words what are the primary forms of communication)?

9. Please outline the qualities of information that are most important in your view? I’m looking for your views on basic qualities of information such as accuracy.

10. Please describe how you use information for decision making, and how this impacts on subsequent actions and outcomes?

11. Are there information guardians in your organisation? If so please describe their work specialism, their place in the organisation and their contacts with stakeholders in the information they manage?

12. To what extent is technology used to facilitate information flow? Please outline the main ways in which technology is applied in information management in your organisation.
13. Why is information important?

14. In your view is there a link between information flow and performance? If so please describe how this link works? If not please justify?

15. In what ways do you currently use information to optimise productivity?

16. In your view what are the differences between efficiency and effectiveness? How do these relate together for improving overall performance, and where is the greatest opportunity for improvement?

17. There is a close link between data, information and knowledge. In what ways are data, information and knowledge possibly wasted in your organisation?

18. In your view how could your organisation use information and knowledge to improve performance?

19. Are there any important issues relating to information and performance that we have not discussed? If so please elaborate.
A2.2 Semi-Structured Interview Questions Together with a Range of Answers Extracted from Transcripts

A2.2.1 Industry Sector

Q1) Please confirm your industry sector, role and type of organisation

Responses: 24. The split of participants by role and type of organisation is shown in Figure 11-1

![Figure 11-1: Interview participants’ demography by role and type of organisation](image)

A2.2.2 Information Forms

Q2) What forms of information does your organisation use?

<table>
<thead>
<tr>
<th>Quote</th>
<th>Participant</th>
<th>#</th>
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</thead>
<tbody>
<tr>
<td>“All sorts, increasingly electronic of course. We still use a lot of written information; in the nature of construction contracts there is still a reliance on the written and signed document. Specifications and drawings, and drawings are the crux of engineering I guess, there’s a heavy reliance on them! But increasingly those documents that we regard as printed are electronic – I’m not sure there is a lot of difference - it’s the means of transmitting them I suppose. We still print them out and use the hard copy a lot. It's amazing how email has become such an integral part of business these days, and a very important part of maintaining contact with people and sharing information.”</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I guess we use consultants as a form of information in terms of design, and costing of projects and that sort of thing. Whilst we have an ability to have a database of information, the market changes all the time, so we are reasonably reliant on our consultants to keep us in an up-to-date mode, and keep our costing up to date, what are the new products and materials, that sort of thing.</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>There are all the standard pieces of code that we are referring to regularly, as is in building code and all of those sorts of compliance documentation that would be one aspect that we call on a lot, depending on the project. There is quite a lot of trade and product literature that we keep and maintain active library in, and that is constantly updated and referred to.</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>The main sources of information that we use would be drawings, specifications, we would use.. we do a lot of standardisation so a lot of our information is kept in house.</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>It ends up being a whole range…whether it be New Zealand standards, other design codes, contracts. Other information is all about records or previous work; we have quite an</td>
<td>14</td>
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</tr>
</tbody>
</table>
extensive library of [that].
We are continually drawing on detailed reports about infrastructure right across the whole sector. So, the sort of information sources will be local council long term plans, central government department long terms plans for capital investment etc….We’re also drawing a lot on international research in infrastructure, so there is a lot of information downloaded from all sorts of parallel organisations, institutions globally.

At a project level, typically the main reliance for information comes from the design team. Whether that’s based within the contractual responsibility that we have, whether it sits with a professional consultant hired by the client to provide that information or whether it’s the client team. The key information flow is the production of that design information. Otherwise, the key challenge at a project level is sharing the various information and the project plans. Other things that will have a bearing on that will be consenting information, utility information, all the other stakeholders that will come into play.

A2.2.3 Information from people outside the organisation

Questions 3) to 7) inclusive relate to an information input–processing-output model as illustrated in Figure 11-2

**Figure 11-2: Information input-processing-output model for Questions 3-7**

Q3) What information do you receive from people outside your organisation?

<table>
<thead>
<tr>
<th>Quote</th>
<th>Participant</th>
<th>#</th>
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</thead>
<tbody>
<tr>
<td>Oh well all sorts of things. You will get an old client who sends his old drawings from the 1950’s and we have to always redraw things, but that's inevitable…and we get quite a bit of information from our GIS team from the Auckland Council types. It gives all the land information and the as-built. We tend to get lame information from service providers, which cause a lot of headaches.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>We receive information from both our consultants and our contractors in whatever form we require. Typically if it is a capital project we will have a series of requirements established for our consultants. A project is essentially divided into 3 phases from that perspective, the information is more the nature of the two way information of the project so we have to get information from the users of the building, for instance if we were doing a capital work somewhere or a refurbishment, which is a part of a capital work, we take a brief from the users and then analyse the requirements inherent in that brief. We try to assimilate the requirements and also try to separate the wishes from the needs, we make value judgements all the way through but we do get a huge amount of information from those user-briefs and we go back sometimes several times back to refine that information</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>For information from outside the office, more and more we just use the internet, we have a license for Australian and New Zealand standards. The licensing arrangement is pointed towards use online rather than storing electronic copies or paper copies. Of course there is no control document if you print it out. If you get it online you get the latest version.</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>One of the really big voids of information in New Zealand in our view is the lack of a</td>
<td>16</td>
<td></td>
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</table>
concise one-stop shop database for projects across the country. So as a result there is no clear project pipeline, there is no easy way of disseminating information.

In terms of a contracting organisation in general, sort of going back in time now, the prime people that we are dealing with outside the organisation are either the clients or the suppliers and then to some extent the statutory authorities within the environment that you work. Backwards and forwards between clients and their engineers. A lot of that information sits within traditional engineering documents, that is: reports, specifications, drawings, that sort of thing. The client defining what he wants in terms of the project that we are going to deliver for him. To some extent you have the same thing going backwards and forwards with the suppliers. Defining what we want, sending it across to the supplier and getting his quotation, making sure he actually mentions what you want and then booking the delivery documents as they come through.

It is apparent from the comments that engineering and construction are reliant upon a wide range of information sources, and that it is a very information rich environment.

A2.2.4 Information from people outside the organisation

Q4) What information do you receive from people inside your organisation?

<table>
<thead>
<tr>
<th>Quote</th>
<th>Participant #</th>
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<tbody>
<tr>
<td>Well I guess the way in which I thought about this, was I divided it into three categories. One is corporate information, the other relates to our business functions (on how we operate in what is business development) and the other one is project delivery. So there’s information that is received from people in our organisation relating to those three areas of activities, both top down and bottom up. So there’s a contribution towards corporate information but it’s also received top down from corporate. Up and down the structure is probably the easy bit. As I suggested earlier, we a regional empowerment model, and within a region it is pretty straightforward to communicate from top to bottom and vice versa. You are still sitting in the same room and you all have your weekly meetings within your team and monthly meetings in the wider organisation. The difficult thing for us is the coordination of those individual regional teams with what is essentially the national objectives. Too much (laughs). A lot of the information that I receive is financial, so I will get lots of financial reporting. There is an accounting system, there’s a time sheet system, there’s a job workflow planning tool, there’s a forward cash flow prediction tool Mainly just spoken really; orally. Internally, we don’t really email each other, so it’s just oral. We just talk about things, especially in the yard, the production side of things; we don’t send emails to one another. Well you do if you want to keep a trail of it, to say that “I’ve sent you an email.” It happens a lot between drafters and the production team, that there are emails with drawings attached, so they can keep a record of what’s been sent, so they can lessen mistakes, or prove who made a mistake.</td>
<td>1 3 14 19 24</td>
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The answers to Question 4 are somewhat different to Question 3, with information received from inside the information being more focussed on commercial and financial information.

A2.2.5 Information issued to people outside the organisation

Q5) What information do you give to others outside your organisation?

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<thead>
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<th>Quote</th>
<th>Participant #</th>
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<tbody>
<tr>
<td>Stakeholders, the neighbours. We tend to give a lot of information to stakeholders, who are the neighbours essentially, people who are going to be impacted. People tend to get more annoyed when they don’t know in advance about something when something actually happens. If we are working, say 9 or 10 o’clock at night, people are very annoyed if we work until 10 pm if they don’t know about it, if they know about it they are much more</td>
<td>9</td>
</tr>
</tbody>
</table>
accepting.

We swap ideas as well as that we have a virtual chat showing going on all the time… We will swap notes on what’s happening and we will put together a common approach to governmental or to the regulatory authority. If we go to conferences we share that information to the people here.

At one end of the scale it might be verbal advice, a conversation, and that might lead to other work and might extend right the way out to all of our construction documentation and along the way there would be sketches, 3D information that we would exchange with other consultants.

We’re issuing reports, designs, and tender documents, that’s the information on the whole that we are giving out. Within those reports, some of that reporting is done online; so a vast majority of our monitoring sites are online so that a client can see what is happening. We’re giving our clients our modelling outputs online so they can actually see.

A2.2.6 Information issued to people inside the organisation

Q6) What information do you give to others inside your organisation?

<table>
<thead>
<tr>
<th>Quote</th>
<th>Participant</th>
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<tbody>
<tr>
<td>There is a whole range of them there, from the simplest things; I give our finance team and project manager information as to how I spend my time in a week. So you’ve got that, there is an attempt to do some mentoring, an attempt to share your technical knowledge.</td>
<td>14</td>
<td></td>
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</table>

A2.2.7 Information match to suits needs of role

Q7) How does what you receive match what you need to do your job?

<table>
<thead>
<tr>
<th>Quote</th>
<th>Participant</th>
<th>#</th>
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<tbody>
<tr>
<td>For me, it’s difficult to answer, because when I say information received, really my role doesn’t rely upon a lot of information being received, it’s about me obtaining it in the market through communication and through understanding where the market is, what our clients are trying to achieve, determining strategies as to how we can assist them achieve what they want. So… that’s not readily available.</td>
<td>1</td>
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<tr>
<td>It varies a lot is the answer to that one. What I found is ideally you’ve got to spend a lot of time to develop – you got to know what you want first which sounds pretty basic but in a lot of cases the rush is to get a response quickly, where you haven’t got the details confirmed and that’s always where the problems starts. Where people have used a template when really you’ve got to spend the time, you got to think down the line: what you got to receive back from them. Because if you’ve gone for three or four tenders for example from different organisations at the end it all becomes a nightmare to read through the different things. The key is, I suppose, investing upfront some time and effort to get it clear</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>It’s less of a problem I believe than it used to be because the queries about what you are requesting and whether or not it meets what you need are so much faster now than they used to be. Because packaging up information and exchanging it used to be a much more onerous task, if someone fires you a set of drawings, minutes later you are able to say, “okay, I haven’t reviewed this in full, but I can see that say, these are two areas of things that we want to understand more,” and you print something out your extract of your 3D model, and you draw a circle around it and you show where you want it cut and reviewed, and you fire it back, and usually the response comes back fairly quickly as well. So I suppose that is only treating the symptoms if the information doesn’t match what you need, but the corollary is that it is very easy now to help make it match what you need, because we all communicate much more quickly now.</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>It’s something that I’m constantly working on is trying to stream that information to get exactly what I want. We’ve got a financial system that allows you to write your own queries so I’m constantly developing new queries to get just what I want. So I have some influence in that area. I still get much more information than I can cope with.</td>
<td>14</td>
<td></td>
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</tbody>
</table>
A2.2.8 Channels (Modes) of information flow / communication

Q8) Please describe the primary modes of contact?

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<td>Generally face-to-face In a role of business development manager, or client relationship manager, it’s about engaging with the client and understanding where their business is going. So the different modes are regular meetings with our key clients. The obvious one is meetings with people, face-to-face, that works best most of the time. The next one we have would be phone calls, which we have to make lots of. We can’t be in meetings all the time because otherwise we don’t get anything done. A phone call will last considerably shorter than a face-to-face meeting. The next one down would be email, instant, bang, but that’s information that straight away there, so you’ve got to be very careful what you say in the emails so that you’re not dropping people in it. Basically more and more it’s gone electronic. It just means if you receive a pdf for example it is easy to copy and save in your file locations and find and track that and pass it on to site people as well. The primary mode is face-to-face or email, closely followed by this (interviewee pointing to his iPhone). I get various papers to read, and I cant actually read and certainly not assimilate all the information that comes across my desk on a daily basis. But the main form is email. And in terms of our construction projects for instance, there are various data sharing, something like Aconex. I personally prefer face to face, but I would suspect that email is the majority of information. Whether it’s relevant information is a different matter, and whether I read it or not, is a different matter. I’ll get 75 emails a day; I doubt that I would have 75 conversations a day. I do talk a lot, but I personally seek to make talking the most important bit but I think that email is taking over. It can be by one to one interviews, meetings, that usually at the beginning of a project, that’s the best way to establish an understanding as to how you’re going to work together. The next stage is usually done by emails, if it’s simple its usually done by emails. If you’ve got to try and ask for something or develop a discussion around something its around telephone, and once you’ve established the way of gathering data, what you’re going to gather; then you can send out forms, or spreadsheets in which they could fill that data in, or you described how they can send the data to us in its raw form, its existing form and we will convert it into the form that we need it.</td>
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<td>Coding of the transcripts was undertaken to identify all the different uses of information, with a node identified for each within NVIVO 10.</td>
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A2.2.9 Qualities of information

Q9) Please outline the qualities of information that are most important?

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<td>For me, reliability and sensitivity trends. Again looking at the client from the perspective of understanding their business, it’s understanding their drivers, to understand the value chain of the supply chain. The drawings have to be clear. They have to have ownership of a single person. We’re trying to sell a lot of pride on the quality of information. Accuracy, of course! My personality profile says; be brief, be bright, be gone. I’m looking for accurate information, I’m looking for it not surrounded by waffle. There is accuracy and the order of information and this goes for what you’ve asked for as well, cause you got to convey not just what is important but in which order you want people to do it. It just makes it easy to make comparisons and make decisions. Accuracy, but that has to be tempered with how accurate do you expect it to be? Internally</td>
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<td>Coding of the transcripts was undertaken to identify all the different uses of information, with a node identified for each within NVIVO 10.</td>
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it is more about risk and externally it is more about reputation.
The timeliness and accuracy in a form that is easily understood, and accessibility, 10
Accuracy is of course important, and fundamentally as you get closer and closer to people building things from what you are documenting. Sometimes the speed in which something is delivered is a very important quality, I think that is a fair quality to attach to information, sometimes it is required very urgently.
Brevity helps, but I must admit that if a person sends me a page long email it doesn’t get read. Things really need to be quick and snappy.
Timeliness. It needs to be concise, clear, unambiguous and for that reason we use people who are adept at communicating, as opposed to people who are good at engineering for instance, to get the message out.
I think visual, for me. But most managers will suffer from a bit of ADHD [Attention Deficit Hyperactivity Disorder]; we don’t focus for long because there is a pile of reading to do.
The key thing with drawings is that there is enough information on them. The second thing in a good drawing is that it has been checked and approved by someone.
I think probably two things, one is how the information is organised, and also how well it is adapted to its intended user.

A2.2.10 How information is used for decision-making

Q10) Please describe how you use information for decision-making?

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<td>We use it for business planning input so that helps shape our business towards our clients from that market. We use information for opportunity pursuit, so getting down to the next level of; what projects are coming up and where our entry point is and what services we’re going to sell. So we rely upon that information to corral our resources and to improve activity in a certain direction. That means that were all incurring money so we use that information to commit to expenditure that doesn’t necessarily provide a return, so we want reliability in that.</td>
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<td>When you break down our business or the construction industry, it’s all about risk management; we’re trying to mitigate risks around health and safety, environmental management, commercial upside and downside. The people who do well in our business have a fine tuned sense of risk, when it’s tipping, gone way or the other. You either; if it’s tipping one way then you’ve got to mitigate that; if it’s tipping the other then you’ve got to maximise the opportunity. So how do I use information? I guess in the number of years that I’ve been in the business it’s almost intuitive, you identify an opportunity, or a downside and what to do.</td>
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<td>I’m using information the whole time in regards to making decisions from looking at our finances to say how much forward work have we got, are we hiring or are we firing? Looking at project performance against budget, and saying why is it where it is? What’s happened to change it? Everything is based on information so it’s hard to give you an example of how I use it, other than that I do.</td>
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<td>I guess in an engineering context most of the stuff that we do is problem solving in one form or another. It’s a three-step process, step one is defining what the problem is in the first place, that quite often actually involves having a pretty good look at the information because quite often people will come to you with a problem that is half defined or sometimes it’s a solution looking for a problem to justify it. In that respect one of the first things you have got to do is get back to what the core problem is that you are trying to solve and get it properly defined. Out of that you will then start to look at possible options for solving that problem. Then the things that will help you decide between those options are more information about them, the quality that the outcome is going to produce and what it is going to cost to get you there. I guess if you look at a construction process you start with a very low level of information and the volume of information actually progresses as the job goes on and you know more and more about it. Initially, when you are trying to do a tender for a design-build job you have got to do enough design work to give you the amount of information you need to make the first major decision, which is: what is it going</td>
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to cost? Once you have got the job you work from that point to get more and more information developed until you actually have enough to start building it.

A2.2.11 Information guardians

Q11) Are there information guardians in your organisation?

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<td>There are people who are document managers and coordinators but I think it is an area which could be strengthened,</td>
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<td>I guess at one end of the scale the person who helps the product library would be an information guardian, so that might be a person who is responsible for when new suppliers get in touch. Another person would be the people who manage things like our IT and CAD standards, for example in a large office it is pretty important that you have a consistent standard.</td>
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<td>We have a high number of specialists; just by the specialist nature of who they are they become informal guardians of information.</td>
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<td>Things that we will keep to ourselves will be discussions that are going on, will be, do we do this or do we do that? And what is the rationale? Because, if we go to the public too soon, we create a false expectation. If we tell somebody: 'we are thinking about doing this', they interpret it as: you are going to do that. So we have got to be careful about that.</td>
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<td>Well yes, I guess, it’s quite a small business but the information guardians are people mainly around accounting. But its only because you trust that person because you can access that information, because it’s an accounting system and because you probably don’t understand it if you were just looking at the raw data or even the analysed data you probably have to have someone to explain it to you, or answer your questions.</td>
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A2.2.12 Use of technology to facilitate information flow

Q12) To what extent is technology used to facilitate information flow?

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<td>It’s already used a lot, I think it’s hard to know whether we could use it more because we don’t see what our competitors are doing, but we certainly have extranet, or we certainly use intranet on project sites for the sharing of information with the project team, and increasingly that is with the client and consultant as well. I think as we talked about earlier, there is a lot of potential of better information sharing within the organisation. I don’t think we should be sharing information in the market place though. Interestingly though, in recent times, certainly the big contractors are very happy to share their safety incidents, because safety is first; &quot;look we’ve had this incident, we learned this from it!&quot;</td>
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<td>I think the GPS is the biggest one, I think the asset management stuff is making a big difference, having the tablets in the car and having all the stuff there. They would be even more useful if they’d done the as-builds properly in the first place and the infrastructure under the road was where it was supposed to be.</td>
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<td>Yeah it is used. The issue you got around technology is, particularly if you use a number of systems; you have different levels of competence and knowledge about the various systems. Particularly when it is something outside the norm, when I say norm it is a Microsoft type of platform. When it is a web-based system used it could be a challenge and people who have been in the industry a long time and used to one thing and it just gets too hard for them, it is something that could be managed better.</td>
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<td>For our request for information, design instructions we use InfoPath which is another Microsoft system, which uses excel and word and bits and pieces and channels them together so you have forms, basically an electronic form system. So you can do it and send it to the next person and they get a link, open the link up and they can do their section of the document so you have access rights and all of that. It basically means you don’t have to open a document, print the document, give it to someone else, they think about it, reply,</td>
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sign it, photocopy it, send it back, file it in the cupboard. That is all held within InfoPath.
I would say hugely, if you look at email, look at the internet, the fact that our financial system is completely online, timesheets are submitted electronically, you can go in and interrogate jobs, the whole thing is all online.
What we do need, and do use is GIS, and linking the GIS to property information, project information, and services information. We are trying to bring in other network utility operators into a combined system
We do use a bit of Skype, we do use conference calling and would like to use video conferencing because quite a lot of us are out, and I think that to tell the truth for a small business we could save quite a bit of money by getting into video conferencing, if there was a standard type of video conferencing that you could use, like Skype but more reliable.
It’s a very old school industry; people are very stuck in their ways. Everything is 2D drawings, because the shop drawings are there with the information that a person needs.

A2.2.13 Information importance

Q13) Why is information important?

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<td>It enables knowledge transfer, and upwards, downwards, sideways. And it enables generation of ideas, so, one doesn’t have a mortgage on knowledge, but information flow allows you to quickly test your own thoughts with others, receive inputs from others and have a higher level of confidence in what your end advice or product is. So there’s a world body of knowledge that you can tap into through communicating with your own internal networks or external networks or whatever the case may be. You’ve got access to the greater pool of ideas, so information is vital for that. It’s also for collaboration, both intellectual and for sharing physical data or product or whatever it is, so no one person or organisation has a mortgage on knowledge. So information enables you to achieve more and have more effective outcomes or higher confidence in whatever you want to achieve. Basically if you haven’t got information the job won’t get done, particularly in a large complex situation, where you’ve got a lot of interactions. You’ve got lots of requirements, labour requirements, health and safety, there are various activities, if you haven’t got the information well managed and controlled there are huge risks of failure. It’s all about past future and present. Without information you can’t get an accurate view of where you are and you can’t predict where you want to be, and you can’t make judgement calls or predict or advise. What would you have if you didn’t have information I ask? Not much.</td>
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A2.2.14 Linkage between information flow and performance

Q14) In your view is there a link between information flow and performance?

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<td>It leads to better solutions being derived, so you get a better outcome, you can get a speedier outcome. Because the process can flow more rapidly it helps you avoid going down blind alleys or reinventing the wheel. So I think you can test ideas, you can be challenged. Information can be transferred to locations that are well outside your geography, right around the world, and to different organisations more rapidly. It breaks down some of the barriers, telephone is important and face meetings even more important and effectiveness of communication to me is directly related to how well you know somebody and the level of confidence you have with them so getting on a plane and meeting them is vital. But once you set up those relationships, you can transfer work rather than people, and you can do that effectively so that’s a good model and information flow allows you to do that and become more productive because you can send work to low cost centres. So we need to get all the information to the team. The flow of information needs to be</td>
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consistent, it’s not just up front; it needs to continue all the way through the job. That’s why we set these weekly meetings up. If at any time that goes off on a tangent or stops their performance takes a hit, they’re hanging round waiting for more information, they’re going off in the wrong direction so they have to come back again so their performance drops.

Of course, but what is the link? Perhaps it’s easier to explain than the link between information and efficiency, which probably leads to performance, but certainly nothing frustrates people more than inaccurate information that causes time lost. The classic is in a contractual situation where you get issued construction drawings and there is not enough information to build it. And you’ve got to go back to the consultant and ask for more information, and they don’t want to give you more information because their fees get pegged and they’re not getting paid any more and issuing more information is... so you get into this ridiculous situation where you are all standing around looking at each other. And it’s difficult to know what the answer is and certainly as a contractor we have always advocated to our clients, don’t put your consultants on a lump sum, that’s very inefficient.

Yes it is similar if you don’t communicate what is needed to be done and coordinate it, it isn’t going to happen, you know. If you look at the program as one of the key documents of any project; if people don’t know that a certain element has to be finished by a certain date and there is not the pressure to do that it can have a huge effect on the success or failure of the project.

There is definitely a link between information flow and productivity. The two aspects of that, one is timeliness as always, and the other one is the quality of the information. Certainly from my experience and something that concerns me greatly, even on the projects we are currently doing, quality issues have been very substantial and the rework has been very substantial. It is highly expensive and quite unnecessary, expensive to both to the contractor and also to the client, because the contractor must somehow be pricing into it. So information, getting the right information, it’s not just from source the information flow through the system is critical.

If there wasn’t a flow there wouldn’t actually be a project, there wouldn’t actually be any performance, so I think they are completely linked with one another. One flip side of the increasing speed of information that we’ve got now, is that it does become easier to nibble away at the problem, than to actually parcel it up and consolidate all of the issues and exchange them as we used to. There is more of a tendency to exchange requests; it is easier to just exchange requests as they occur to you. It is so easy now to just go, “oh while I remember, can you move that thing to there?” And off it goes. I think that can potentially slow you down, I think that as it becomes easier to communicate you are encouraged to communicate more, not trivially but to break the task up into a hundred small bits, rather than do it in two big consolidated bits and I see that happening. I’ve done a lot of teaching and definitely seen the difference that has happened in people, across that time and the way in which they manage their time and deal with tasks and deal with communication, I think there has definitely been a change there. It’s easy to say, “well yeah, we can address the problems quickly now because we can ask for responses now and get them.” But it naturally tends towards more frequent communication, but perhaps less frequent communication is more effective?

Availability of accurate information of course will impact on your efficiency with which you do the job. If you rely on inaccurate information, you get out onsite, you have a major problem because you haven’t picked up something critical. So clearly there is a link. That is why we put in so much effort to our asset management systems.

Yes, the first thing is you have to acknowledge is that it’s not linear: information flow and the construction process is an iterative process, both in decision-making and design and delivery. So information flow is a circle as well, it’s not all one way, and there has ... Okay, first its iterative, it goes round and round and round and each evolution should give you a better outcome to a point where you decide where you don’t want to do any more iterations because you have a good enough outcome for the money. So there’s a rotation thing about information. Secondly there has to be two-way flow, because you have to confirm that the information you receive is right, so there is a link between information flow and performance but its circular and two way. And it’s not just about speed, although speed is important, it’s the availability and it’s not just about availability because as you get more and more information you may not be able to see the thing that you want to see, it’s about clarity in the information.
A2.2.15  Ways information is used to optimise productivity

Q15) In what ways do you currently use information to optimise productivity?

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<td>It helps us identify gaps and areas of improvement and we can look ahead to optimise productivity and utilisation. So information is important for looking at our own business efficiency…Also if there’s a dip in utilisation somewhere in the business round the globe, because the next major project hasn’t come in, but you want to retain your resources, you can wash work across as best you can. So information is vital for optimising resource utilisation and productivity in our business.</td>
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<td>Well the way that we use it is to bring together what is recognised as best practise and then publish and communicate that via the methods I spoke about before. We as an organisation play a bit of a broker role I suppose in bringing that information together into a common place and then communicating it.</td>
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<td>I think it’s more about using the right sort of information to optimise productivity. When running a business, you’re always looking to find simple information to put together. You don’t want to over technicalise the timesheets or the accounting system or the requirement for people to fill in job start-up forms. You’ve got to keep it simple, but it’s getting more out of a simple system to collect data, to analyse your clients, and analyse who you should be marketing to. So from all of that I think there is lot of stuff we can do around just turning the handle on either the production or business.</td>
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<td>Within our own organisation there are two main streams, one is the quality of the design, the better your design is, the more efficient it is and that quite directly impacts on the productivity. If you can build something with less then you are more productive. The other parallel stream is your production methodologies: how well you build them, how efficiently you build them. Again, probably the single most important factor there is planning your work well, what you are going to need in terms of resources, equipment and having them available when you need them so that you are not under-resourced and taking longer than required but you are not over-resourced and have guys standing round under-utilised.</td>
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<td>The way we do is everything in writing improves productivity, we are hot on it, verification to contractors, orders to suppliers, paperwork to clients, that definitely improves productivity because you remove the ambiguity of “oh I didn’t say that.”</td>
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A2.2.16  Differentiation between efficiency and effectiveness

Q16) In your view what are the differences between efficiency and effectiveness?

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<td>I think efficiency is about minimising the effort to achieve the outcome, whereas effectiveness is around maximising the fit for purpose outcome.</td>
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<td>I’ve got people in my team who are very inefficient but they get the job done effectively, but you’ve got other people who are highly efficient but because of their low skill set in that subject they won’t be as effective as somebody else.</td>
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<td>Effectiveness is the more important one, which is doing the right thing, and efficiency is doing that thing well. So you have to, the first question is, are you doing the right thing?</td>
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<td>Efficiency is sort of a factor of how much you do in the time it takes you to do it. I’m struggling to define it, but I know it’s not the same as effectiveness. Effectiveness is more like what I was alluding to before, where if those tasks have greater punch or almost like a distillation of concentration. Efficiency is a lot of activity, you are doing a lot of things in a certain time, effectiveness is maybe you can boil off everything that is superfluous in those tasks down to something that is absolutely necessary for them.</td>
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<td>One of the Stephen Covey’s comments is that you can’t be efficient with people; you can only be effective with people. That’s something that he talks about. I think that describes a difference, perhaps efficient is doing it in the least time possible, but effective is train</td>
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someone else to do it next time. It’s efficient for me to go and get that fish and feed you, its
effective to teach you to feed yourself in the future. I think that might be the subtle
difference for me, but in business it’s the balance of those two things. We want to be
efficient, we want to have the appropriate systems in place to streamline what we do, that is
efficiency. Ensuring that our staff are motivated and happy is effective rather than efficient.

Oh yeah! You can deliver the wrong result very efficiently!

You can be very efficient about what you do but actually achieve nothing. To be effective in
what you do is delivering what is being asked of you or expected of you. You might be quite
inefficient in doing that process, but at the end of the day if you deliver that outcome, you
know! I’ve seen some of the most disorganised filing systems but someone has the
capability to be able to deliver exactly the right piece of paper at the right time. Now in
terms of process, its inefficient is hell, but terms of effectiveness it seems to work. So, I
think effectiveness is what you should be targeting, not efficiency.

A2.2.17 Ways in which data, information and knowledge are wasted

Q17) In what ways are data, information and knowledge possibly wasted in your organisation?

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| When we’re looking at waste in our organisation, it’s about the effectiveness of communication of people and getting people on the same page and not going down blind alleys, before you launch into the production of high volume output that’s quite expensive and possibly misdirected. It’s to engage with your client sufficiently early based on mug drawings or preliminary information to be absolutely sure that there’s good understanding as to the ideas that are being generated and the direction that they want to go down. Sometimes there’s a temptation to just launch into detail design and CAD drawings because there’s a ledger in there waiting anxiously to get involved, and I think that’s waste. We’ve got a lot of projects historically where we rely upon the knowledge of all the people, the information just doesn’t exist and the data has been lost. The clients come back and ask you question, and because the knowledge has left, they’ve moved on, they’ve retired, they’ve left, the data never was recorded properly and everything is gone. So knowledge is a really good thing but if we haven’t got it recorded somewhere it’s gone. I’m going to go back to our procurement process. If you take simple projects, with defined risk profiles, clearly defined scope, (here to here, cut fill), clearly established: we don’t want to waste with excess management layers. So we try and tailor the appropriate delivery model for the risk profile of a project, and as the risk profile of the project increases so does the reporting. Waste in terms of management is one of the unfortunate things. If we look at our P&G, (our preliminary and general costs), they vary, and again it varies depending on the procurement model. I think knowledge if often wasted. Knowledge is accumulated by individuals, and often when it is needed by someone, they don’t know who has that knowledge or where it is, but it’s clearly not possible to link together a whole lot of human brains like you can computers and network them and search for who has that knowledge. The real challenge is finding out who has that knowledge and tapping into it. Information is different; the net makes information accessible to everyone and anyone, just about. I think I’ve talked about the procurement, in my view there is waste in procurement. The project, the sub-projects of this that we are looking at, at the moment; the cost of tendering, we are anticipating if we extrapolate it out, we haven’t got the numbers yet, but to put a stake in the ground we are looking at between $80 and $100 million dollars a year wasted just in tender conditions that are mucked around with or improper allocation of risk. Yes, I think there is because there is a lot of data out there, not all of which we need, sometimes the data that we need it takes us a long time to get hold of, we can make some informed decisions and turn that into information that we tell to somebody. But when we actually tell them, we don’t actually tell them all that we could tell them: there is a lot more that we could tell them that we don’t. And the other thing is that we don’t make enough out of the data that we could have
A2.2.18  Ways in which information can be used to improve performance

Q18) In your view how could your organisation use information and knowledge to improve performance?

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<td>I think it’s about getting information to the right people quicker and getting specialist knowledge, adding value into the project, so communication is about understanding who’s got what tick of confidence.</td>
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<td>We certainly need to work smarter; we tend to go off on tangents with options that the client doesn’t want to hear about. Task briefing up front of all our meetings is a bit lame. We tend to put a lot of effort into bids, huge amount of effort. Big clap, big celebration and then we’re off. Without stopping for a week or so just to get the task brief, the scope the client communication, all the information collected for the project. Things could exist already that we didn’t know about, we will go off and repeat things that we didn’t need to do because we didn’t know it was there.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Can I answer that in a long-winded way by talking about my view of productivity? And the fact that while, for example, the Productivity Partnership at the moment is talking about a 20% improvement by 2020. I would say that 19.5% of that improvement comes from the front end of projects, not from the delivery end.</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I suppose it is the old thing, which goes back to people, processes and systems. You got to focus on the people first, have the right people in, I suppose train and encourage… It becomes particularly challenging when you have a project based organisation, as in the staff can fluctuate in the number of internal and external people so you still got to have the people who can disseminate the information and track it and realise where the knowledge comes from and put it in a useful way. Processes probably become more important, people are the most important but processes become more critical when you’ve got a moving workforce in terms of people working on different projects, different environments, different key stakeholders and all that type of thing.</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>In terms of productivity on our commercial side I think the guys on site, particularly the site engineers need to know and the foremen need to know how much it is costing to build while they are building it. It’s like a kind of balance book or clock system in a factory, they know what they are producing and if they are making money and every time the light stops they are not making money.</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>I think we definitely could from a cost point of view. Everybody gets regular bulletins from the likes of Reuters or some of the QS businesses that put out tracking industry trends or costs and that sort of thing, but that is at a very high level. If there was more information at a detailed level, like a cost database then you would try and tap into that a bit more. But then saying that our QSs are that database for us, and once again it depends what your role is and what your resources will allow you to do.</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>I think the only way you can improve performance is through knowledge and information. It is that monitor, review, evaluate, whatever, loop (Plan Do Check Act). I have been pretty much decamped into monitoring at the moment because we have got to sort this part of our business out. Part of the problem is that we haven’t been tracking our information and data sufficiently to actually understand what is going right and what is not going quite so right so that we can actually change things.</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>I think about that all the time! One of the areas, and I’ve raised it with a number of consultants, is we feel convinced that when it is a design build project, the consultants push their design harder because they are on the other side in terms of getting it from the contractor in terms of what is actually built. There is a percentage that comes back to them or doesn’t as the case may be. Whereas if they are doing it for us they are more conservative, I’m convinced of it.</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>
A2.3 Word Frequency

A word frequency analysis reveals the key words most often used by interviewees, as indicated in Figure 11-3. The word cloud has been generated by NVIVO10 software and excludes common language words. The size of the word is indicative of how frequently the word was used during interviews; unsurprisingly information is the most commonly used word.

Figure 11-3: Word cloud illustrating commonly used words by the interviewees
A2.4 Coding Matrix Query Results

Figure 11-4: Coding Matrix Query for Information Channels against Industry Sector

Figure 11-5: Coding Matrix Query for Information Types against Industry Sector
Figure 11-6: Coding Matrix Query for Information Repositories against Industry Sector

Figure 11-7: Coding Matrix Query for Information Attributes against Industry Sector
Figure 11-8: Coding Matrix Query for Ways Information is Used against Industry Sector

Figure 11-9: Coding Matrix Query for Information Technology against Industry Sector
Figure 11-10: Coding Matrix Query for Information Issues against Industry Sector

Figure 11-11: Coding Matrix Query for Information Human Agency against Industry Sector
Figure 11-12: Coding Matrix Query for Information Context against Industry Sector

Figure 11-13: Coding Matrix Query for Information Underlying Issues against Industry Sector
Figure 11-14: Coding Matrix Query for Information Channels against Role

Figure 11-15: Coding Matrix Query for Information Types against Role
Figure 11-16: Coding Matrix Query for Information Repositories against Role

Figure 11-17: Coding Matrix Query for Information Attributes against Role
Figure 11-18: Coding Matrix Query for Ways Information is Used against Role

Figure 11-19: Coding Matrix Query for Information Technology against Role
Figure 11-20: Coding Matrix Query for Information Issues against Role

Figure 11-21: Coding Matrix Query for Information Human Agency against Role
Figure 11-22: Coding Matrix Query for Information Context against Role

Figure 11-23: Coding Matrix Query for Information Underlying Issues against Role
A3 Industry Questionnaire (Chapter 5)

A3.1 Research Ethics Documents

UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE

09-Mar-2012

MEMORANDUM TO:

Dr Theunis Henning
Civil & Environmental Engineer

Re: Application for Ethics Approval (Our Ref. 7950)

The Committee considered your application for ethics approval for your project titled *Information flow matters: Improving performance and productivity in engineering and construction* on 09-Mar-2012.

Ethics approval was given for a period of three years.

The expiry date for this approval is 09-Mar-2015.

If the project changes significantly you are required to resubmit a new application to the Committee for further consideration.

In order that an up-to-date record can be maintained, you are requested to notify the Committee once your project is completed.

The Chair and the members of the Committee would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made through the UAHPEC secretary at humanethics@auckland.ac.nz in the first instance.

All communication with the UAHPEC regarding this application should include this reference number: 7950.

(This is a computer generated letter. No signature required.)

Secretary
University of Auckland Human Participants Ethics Committee

c.c. Head of Department / School, Civil & Environmental Engineer

Additional information:
1. Should you need to make any changes to the project, write to the Committee giving full details including revised documentation.
2. Should you require an extension, write to the Committee before the expiry date giving full details along with revised documentation. An extension can be granted for up to three years, after which time you must make a new application.
3. At the end of three years, or if the project is completed before the expiry, you are requested to advise the Committee of its completion.
4. Do not forget to fill in the ‘approval wording’ on the Participant Information Sheets and Consent Forms, giving the dates of approval and the reference number, before you send them out to your participants.
5. Send a copy of this approval letter to the Manager - Funding Processes, Research Office if you have obtained funding other than from UniServices. For UniServices contract, send a copy of the approval letter to: Contract Manager, UniServices.
6. Please note that the Committee may from time to time conduct audits of approved projects to ensure that the research has been carried out according to the approval that was given.
A3.2  Industry Performance Questionnaire

The questionnaire was administered using SurveyMonkey

<table>
<thead>
<tr>
<th>Information Flow Matters: Performance Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consent</td>
</tr>
</tbody>
</table>

Thank you in advance for taking the time to complete this survey by the University of Auckland.

Your views are important to us to help us with research on methods of improving productivity performance of the engineering construction sector. This survey should only take about 10-15 minutes of your time. This research project is sponsored by Building Research Association New Zealand (BRANZ). If you have any questions, please contact us at g.miller@auckland.ac.nz or call +64 (0)9 373 7599 ext 88558

1. I have read and understood the information in the Participant Information Sheet describing the aims and content of the following questionnaire (link provided below). I am aged 16 year or older. I understand that by submitting this questionnaire I agree to take part in this research under the terms indicated in the information provided

- [ ] Yes
- [ ] No

A copy of the Participant Information Sheet is available on the following link:

This questionnaire asks some simple multiple-choice questions followed by some open-ended questions.

In order to progress through this survey, please use the following navigation links:
- Click the Next >> button to continue to the next page.
- Click the Previous >> button to return to the previous page.
- Click the Exit the Survey Early >> button if you need to exit the survey.
- Questions with a * (star) are mandatory: you will need to provide an answer to such questions before progressing
## Information Flow Matters: Performance Factors

### Information Sources Importance

* 2. How important are the following objectives for your organisation:

<table>
<thead>
<tr>
<th></th>
<th>Very Important</th>
<th>Important</th>
<th>Moderately Important</th>
<th>Of Little Importance</th>
<th>Unimportant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Social performance</td>
<td></td>
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<tr>
<td>Environmental performance</td>
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<tr>
<td>Cultural performance</td>
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</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Other (please specify)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
### 3. How important are the following sources of information for your organisation:

<table>
<thead>
<tr>
<th>Source of Information</th>
<th>Very Important</th>
<th>Important</th>
<th>Moderately Important</th>
<th>Of Little Importance</th>
<th>Unimportant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer records</td>
<td></td>
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<tr>
<td>Supplier records</td>
<td></td>
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</tr>
<tr>
<td>The information products of the organisation which are outputs to the outside world</td>
<td></td>
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<tr>
<td>The information products of the organisation for the internal audience of employees</td>
<td></td>
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</tr>
<tr>
<td>Information from suppliers which are inputs for the organisation’s products and services</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Operating / project plans and budgets</td>
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<tr>
<td>Financial performance reporting</td>
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</tr>
<tr>
<td>Feedback reporting from monitoring of production processes / project progress</td>
<td></td>
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<tr>
<td>Research and development information</td>
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<tr>
<td>Competitor information</td>
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<tr>
<td>Industry sector information (e.g. market trends, legislation etc.)</td>
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<tr>
<td>Information relating to the broad environment (e.g. the economy, social trends, demographics etc.)</td>
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<tr>
<td>Lessons learned from previous projects</td>
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<tr>
<td>Knowledge sharing between organisations (e.g. sharing of know-how, tools, techniques, methods etc.)</td>
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<tr>
<td>Knowledge sharing within the organisation (i.e. between staff)</td>
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<tr>
<td>Other</td>
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</tbody>
</table>

Original text: *Other (please specify)*
## Information Flow Matters: Performance Factors

### Information Sources Performance Rating

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Average</th>
<th>Poor</th>
<th>Very Poor</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic performance</td>
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<tr>
<td>Social performance</td>
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<tr>
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<tr>
<td>Cultural performance</td>
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<tr>
<td>Other</td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Other (please specify)

* 4. Please rate the performance of your organisation against the following:
5. Please rate the performance of your organisation in the management of the following information:

<table>
<thead>
<tr>
<th>Category</th>
<th>Excellent</th>
<th>Good</th>
<th>Average</th>
<th>Poor</th>
<th>Very Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer records</td>
<td></td>
<td></td>
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<tr>
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<tr>
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<tr>
<td>Knowledge sharing within the organisation (i.e. between staff)</td>
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</tbody>
</table>
Information Flow Matters: Performance Factors

Productivity Performance Factors

In the questions on this page we are interested in factors that have an impact upon productivity performance at different levels of: task; team; project; organisation; and industry sector.

Please describe some issues at each level using either key words or descriptive sentences.

If unsure feel free to skip this page and proceed to the next page.

6. Please describe some factors that have an impact on your daily task-level productivity performance as an individual worker (i.e. task-level issues):


7. Please describe some factors that have an impact on the productivity performance of your immediate team (i.e. team level issues):


8. Please describe some factors that have an impact on the productivity performance of projects you are involved with (i.e. project level issues):


9. Please describe some factors that have an impact on the productivity performance of the organisation you work for (i.e. organisational level issues):


10. Please describe some factors that have an impact on the productivity performance of the industry sector you work in (i.e. industry level issues):


## Information Flow Matters: Performance Factors

### Information Flow and Project Performance

11. To what extent do you agree with the following performance statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery of projects within budget is fundamentally dependent upon information flow</td>
<td></td>
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<tr>
<td>Delivery of projects on time is fundamentally dependent upon information flow</td>
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<td></td>
</tr>
<tr>
<td>Delivery of projects to quality requirements is fundamentally dependent upon information flow</td>
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<td></td>
</tr>
<tr>
<td>Delivery of projects ensuring customer satisfaction is fundamentally dependent upon information flow</td>
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<td></td>
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<tr>
<td>Project risk management is fundamentally dependent upon information flow</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Continuous performance improvement is dependent upon information flow</td>
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<td></td>
</tr>
<tr>
<td>Programme and portfolio management of multiple projects is dependent upon information flow</td>
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<td></td>
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</tr>
</tbody>
</table>

12. To what extent do you agree with the following statement:

"Most firms do not know how to describe or define their information flow, much less how to manage it"

- [ ] Strongly agree
- [ ] Agree
- [ ] Neither agree nor disagree
- [ ] Disagree
- [ ] Strongly disagree
A few simple questions on demographics follow. These are optional, however it is helpful and valuable for the research if you could complete as many of these as possible.

13. Please confirm your industry sector (select one only):
   - Constructor / physical works contractor (Main Contractor)
   - Constructor / physical works contractor (Sub-contractor)
   - Supplier / manufacturer
   - Consultant / professional service provider (Engineer)
   - Consultant / professional service provider (Architect)
   - Consultant / professional service provider (Quantity Surveyor)
   - Consultant / professional service provider (Project Manager)
   - Consultant / professional service provider (Legal advisor)
   - Consultant / professional service provider (other)
   - Client / purchaser / funder
   - Academia
   - Student
   - Other (please specify)
14. Please describe your role (select one only):
   - Executive
   - Senior management grade
   - Senior technical grade
   - Middle management grade
   - Middle technical grade
   - Junior management grade
   - Junior technical grade
   - Administrative
   - Support
   - Trainee / apprentice / student
   Other (please specify)

15. Please confirm your age band (select one only):
   - 16-19
   - 20-24
   - 25-29
   - 30-34
   - 35-39
   - 40-44
   - 45-49
   - 50-54
   - 55-59
   - 60-64
   - 65-69
   - 70 or over

16. Please confirm the size (number of employees) of your organisation:
   - 1-5
   - 6-25
   - 26-250
   - >250
09-Mar-2012

MEMORANDUM TO:

Dr Theunis Henning
Civil & Environmental Engineer

Re: Application for Ethics Approval (Our Ref. 7950)

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(This is a computer generated letter. No signature required.)

Secretary
University of Auckland Human Participants Ethics Committee

c.c. Head of Department / School, Civil & Environmental Engineer

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2. Should you require an extension, write to the Committee before the expiry date giving full details along with revised documentation. An extension can be granted for up to three years, after which time you must make a new application.
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6. Please note that the Committee may from time to time conduct audits of approved projects to ensure that the research has been carried out according to the approval that was given.
A4.2 Decision Questionnaire

The questionnaire was administered using SurveyMonkey. Note that the two surveys were conducted separately, with different participants, but under the one Ethics Approval
2. Identify a recent decision you have made. This should be from the work-place, which involved a degree of complexity and some information gathering, ideally on some aspect of engineering, construction management, design or project execution. Please describe briefly:


3. Please classify the decision identified in the previous question using one or more of the following descriptors (select all that apply):

- Design
- Co-ordination
- Layout / spacial issue
- Choice of materials or system
- Implementation methodology
- Physical works / construction
- Use of human resources (labour)
- Use of capital resources (plant and equipment)
- Investment decision
- Project management related
- Contractual related
- Procurement decision (e.g. supplier selection, contract award, etc)
- Risk mitigation / risk management decision
- General management
- Other

Other (please specify)
<table>
<thead>
<tr>
<th>Decision Origin and Constraints</th>
</tr>
</thead>
</table>

4. Please identify the original issue(s) creating the need to make the decision (select all that apply):

- [ ] Alternative required
- [ ] Contractual query
- [ ] Request for information
- [ ] Design step
- [ ] End-user requirement
- [ ] Lack of Information
- [ ] Previous decision
- [ ] Technical query
- [ ] Cost reduction
- [ ] Quality improvement
- [ ] Other

Other (please specify) 


5. Please identify the significance of the decision constraint(s):

<table>
<thead>
<tr>
<th></th>
<th>Extremely significant</th>
<th>Very significant</th>
<th>Moderately significant</th>
<th>Slightly significant</th>
<th>Not at all significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance standards</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Codes / regulations</td>
<td></td>
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<tr>
<td>Contractual</td>
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<td>Financial</td>
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<td>Functional</td>
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<tr>
<td>Layout / spatial</td>
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<tr>
<td>Methodology / sequencing</td>
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<tr>
<td>Physical</td>
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<tr>
<td>Time</td>
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<tr>
<td>Other</td>
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</tbody>
</table>

Other (please specify)
## Information Sources

6. Reflecting upon the contribution you made to the decision from your personal knowledge and experience please rate the following:

<table>
<thead>
<tr>
<th></th>
<th>Very High</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
<th>Very low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own knowledge</td>
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<tr>
<td>Formal education</td>
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<tr>
<td>Formal work training</td>
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<tr>
<td>Previous similar experience</td>
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</tbody>
</table>

7. Reflecting upon the contribution made by other people please rate the following:

<table>
<thead>
<tr>
<th></th>
<th>Not applicable</th>
<th>Very High</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
<th>Very low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others' general knowledge</td>
<td></td>
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<tr>
<td>Others' expertise</td>
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<tr>
<td>Others' general work experience</td>
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<tr>
<td>Others' previous similar experience relating to decision</td>
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<tr>
<td>Others' networks (able to refer to other people)</td>
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</tbody>
</table>
Copy of Information Flow Matters: Decision Survey

Information Sources and Means of Communication

* 8. Please select the people and form(s) of communication used with each person consulted in making the decision (select all that apply):

<table>
<thead>
<tr>
<th>Informal face-to-face</th>
<th>Formal meeting</th>
<th>Workshop</th>
<th>Telephone</th>
<th>Text</th>
<th>email</th>
<th>Video conferencing</th>
<th>On-line / web-based forum</th>
<th>Not used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior</td>
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<tr>
<td>Colleague</td>
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<td>Subordinate</td>
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<tr>
<td>Consultant - Architect</td>
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<td>Consultant - Engineer</td>
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<tr>
<td>Consultant - Quantity Surveyor</td>
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<td>Regulatory Authority</td>
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<td>Main Contractor</td>
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<tr>
<td>Manufacturer or Supplier</td>
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<tr>
<td>Other person</td>
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</tr>
</tbody>
</table>

Other Person (please specify)
9. Please list the documentary information sources you used in making the decision (select all that apply):

<table>
<thead>
<tr>
<th>Source</th>
<th>Hard Copy (paper based)</th>
<th>Internet (e.g. Google search)</th>
<th>Own Soft Copy</th>
<th>Company Extranet</th>
<th>Online Database (e.g. OECD Stats)</th>
<th>Virtual Model (e.g. BIM)</th>
<th>Collaborative Document Management System</th>
<th>Not used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codes and Regulations</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Standards (New Zealand)</td>
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<tr>
<td>Standards (Other)</td>
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<td>Technical Publications</td>
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<td>Product Data</td>
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<td>Research Information</td>
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<td>Previous Work</td>
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<tr>
<td>Contract Documents</td>
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<tr>
<td>Other documentary information source</td>
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</tbody>
</table>

Other documentary information source (please specify):
10. Reflecting on all information sources (people and documentary sources) what were the two best sources used for making the decision:

<table>
<thead>
<tr>
<th>Source</th>
<th>Best</th>
<th>2nd best</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colleague</td>
<td></td>
<td></td>
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<tr>
<td>Subordinate</td>
<td></td>
<td></td>
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<tr>
<td>Consultant - Architect</td>
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<tr>
<td>Consultant - Engineer</td>
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<tr>
<td>Consultant - Quantity Surveyor</td>
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<tr>
<td>Consultant - Other Specialist</td>
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<tr>
<td>Client</td>
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<tr>
<td>External Agency</td>
<td></td>
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<tr>
<td>Regulatory Authority</td>
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<tr>
<td>Main Contractor</td>
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<tr>
<td>Subcontractor</td>
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<tr>
<td>Manufacturer or Supplier</td>
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<tr>
<td>Codes and Regulations</td>
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<tr>
<td>Standards (New Zealand)</td>
<td></td>
<td></td>
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<tr>
<td>Standards (Other)</td>
<td></td>
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<tr>
<td>Technical Publications</td>
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<tr>
<td>Technical Drawing</td>
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<tr>
<td>Product Data</td>
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<td>Cost Information</td>
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<tr>
<td>Research Information</td>
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<tr>
<td>Internal Reports</td>
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<tr>
<td>Previous Work</td>
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<tr>
<td>Contract Documents</td>
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<tr>
<td>Other source</td>
<td></td>
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<tr>
<td>Other source (please specify)</td>
<td></td>
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</tr>
</tbody>
</table>
11. Reflecting on the best sources of information selected in the previous question please rate their contribution towards:

<table>
<thead>
<tr>
<th></th>
<th>Best Source</th>
<th>2nd Best Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>The understanding process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The solving process</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. Why was the best source of information useful?
### Duration and Decision Iterations

13. From start to finish, what was the overall time span of the decision making process? (Note this is not a measure of work effort, rather the overall duration):
- Minutes
- Hours
- Days
- Weeks
- Months

14. How many iterations (revisions) were necessary before finalizing the decision?
- Not iterative (i.e., decision made first time and not subsequently changed)
- 2 - 3 iterations
- 4 - 5 iterations
- 6 - 10 iterations
- More than 10 iterations

15. If it was iterative, why was it so? Name the factors that caused the information search and decision to be iterative (e.g., consenting issues, client revisions, missing information, design development etc.):
16. If the decision relates to a project what is the current status of the project (if the decision is not project related select "Not applicable"):

- Not applicable
- Initial business case
- Feasibility
- Briefing / appointment of designers
- Scheme design
- Detailed design
- Consent / permits / approvals
- Working drawings and documentation
- Tender
- Construction
- Occupancy
- Maintenance
- Other

Other (please specify): ________
17. What is the approximate $value of the decision:
- Less than $10,000
- $10,001 - $50,000
- $50,001 - $100,000
- $100,001 - $250,000
- $250,001 - $500,000
- $500,001 - $1m
- $1m - $5m
- Greater than $5m
- Don't know
- Confidential

18. If the decision relates to a project what is the total cost of the project:
- Not applicable
- Less than $1 million
- $1 - $5 million
- $5 - $25 million
- $25 - $50 million
- Over $50 million
- Don't know
- Confidential
Copy of Information Flow Matters: Decision Survey

Demographics

A few simple questions on demographics follow. These are optional, however it is helpful and valuable for the research if you could complete as many of these as possible.

19. Please confirm your industry sector (select one only):
   - Constructor / physical works contractor (Main Contractor)
   - Constructor / physical works contractor (Sub-contractor)
   - Supplier / manufacturer
   - Consultant / professional service provider (Engineer)
   - Consultant / professional service provider (Architect)
   - Consultant / professional service provider (Quantity Surveyor)
   - Consultant / professional service provider (Project Manager)
   - Consultant / professional service provider (Legal advisor)
   - Consultant / professional service provider (other)
   - Client / purchaser / funder
   - Academia
   - Student

   Other (please specify)
20. Please describe your role (select one only):
- Executive
- Senior management grade
- Senior technical grade
- Middle management grade
- Middle technical grade
- Junior management grade
- Junior technical grade
- Administrative
- Support
- Trainee / apprentice / student

Other (please specify)

21. Please confirm your age band (select one only):
- 16-19
- 20-24
- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- 60-64
- 65-69
- 70 or over
22. Please confirm the size (number of employees) of your organisation:

- [ ] 1-5
- [ ] 6-25
- [ ] 26-250
- [ ] >250
23. In making the decision approximately how long did you spend using the following forms of communication (with all sources):

<table>
<thead>
<tr>
<th>Means of Communication</th>
<th>Less than 5 minutes</th>
<th>5-15 minutes</th>
<th>15-30 minutes</th>
<th>30-60 minutes</th>
<th>1-2 hours</th>
<th>2-8 hours</th>
<th>More than 1 day</th>
<th>Not used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informal face-to-face</td>
<td></td>
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<td>Formal meeting</td>
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<td>Video conferencing</td>
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<td>On-line / web-based</td>
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</tbody>
</table>


24. For the information sources you used in making the decision how long did it take to find the information you required:

<table>
<thead>
<tr>
<th>Information Source</th>
<th>Less than 5 minutes</th>
<th>5-15 minutes</th>
<th>15-30 minutes</th>
<th>30-60 minutes</th>
<th>1-2 hours</th>
<th>2-8 hours</th>
<th>More than 1 day</th>
<th>Not used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codes and Regulations</td>
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<tr>
<td>Standards (New Zealand)</td>
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<td>Standards (Other)</td>
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<tr>
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</table>

Other documentary information source (please specify source)
### Information Sources Quality Factors

25. For people sources of information, please rate the importance of the following attributes:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Very Important</th>
<th>Important</th>
<th>Moderately Important</th>
<th>Of Little Importance</th>
<th>Unimportant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timely Availability</td>
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<td>Reliable</td>
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<td>Accessible</td>
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<td>Trustworthiness</td>
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<tr>
<td>Understandable / Comprehensible</td>
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<tr>
<td>Relevant / Constructive towards purpose</td>
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<tr>
<td>Other</td>
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</tbody>
</table>

Other (please specify) ____________________

26. For documentary sources of information, please rate the importance of the following:

<table>
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Other (please specify) ____________________
A5 Industry Observations (Chapter 7)

A5.1.1 Research Ethics Documents

Office of the Vice-Chancellor
Research Integrity Unit

UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE

09-Mar-2012

MEMORANDUM TO:
Dr Theunis Henning
Civil & Environmental Engineer

Re: Application for Ethics Approval (Our Ref. 7950)

The Committee considered your application for ethics approval for your project titled Information flow matters: Improving performance and productivity in engineering and construction on 09-Mar-2012.

Ethics approval was given for a period of three years.

The expiry date for this approval is 09-Mar-2015.

If the project changes significantly you are required to resubmit a new application to the Committee for further consideration.

In order that an up-to-date record can be maintained, you are requested to notify the Committee once your project is completed.

The Chair and the members of the Committee would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made through the UAHPEC secretary at humanethics@auckland.ac.nz in the first instance.

All communication with the UAHPEC regarding this application should include this reference number: 7950.

(This is a computer generated letter. No signature required.)

Secretary
University of Auckland Human Participants Ethics Committee

c.c. Head of Department / School, Civil & Environmental Engineer

Additional information:
1. Should you need to make any changes to the project, write to the Committee giving full details including revised documentation.
2. Should you require an extension, write to the Committee before the expiry date giving full details along with revised documentation. An extension can be granted for up to three years, after which time you must make a new application.
3. At the end of three years, or if the project is completed before the expiry, you are requested to advise the Committee of its completion.
4. Do not forget to fill in the ‘approval wording’ on the Participant Information Sheets and Consent Forms, giving the dates of approval and the reference number, before you send them out to your participants.
5. Send a copy of this approval letter to the Manager - Funding Processes, Research Office if you have obtained funding other than from UniServices. For UniServices contract, send a copy of the approval letter to: Contract Manager, UniServices.
6. Please note that the Committee may from time to time conduct audits of approved projects to ensure that the research has been carried out according to the approval that was given.
A5.1.2 Industry Observations Data Collection Forms (Chapter 7)

The following series of screen shots show the data collected via FileMaker Pro, with data entered directly into database system with the aid of an Apple IPad. The screen shots serve to give the data fields collected for each agenda item. There are 6 screens for each agenda item.
References


