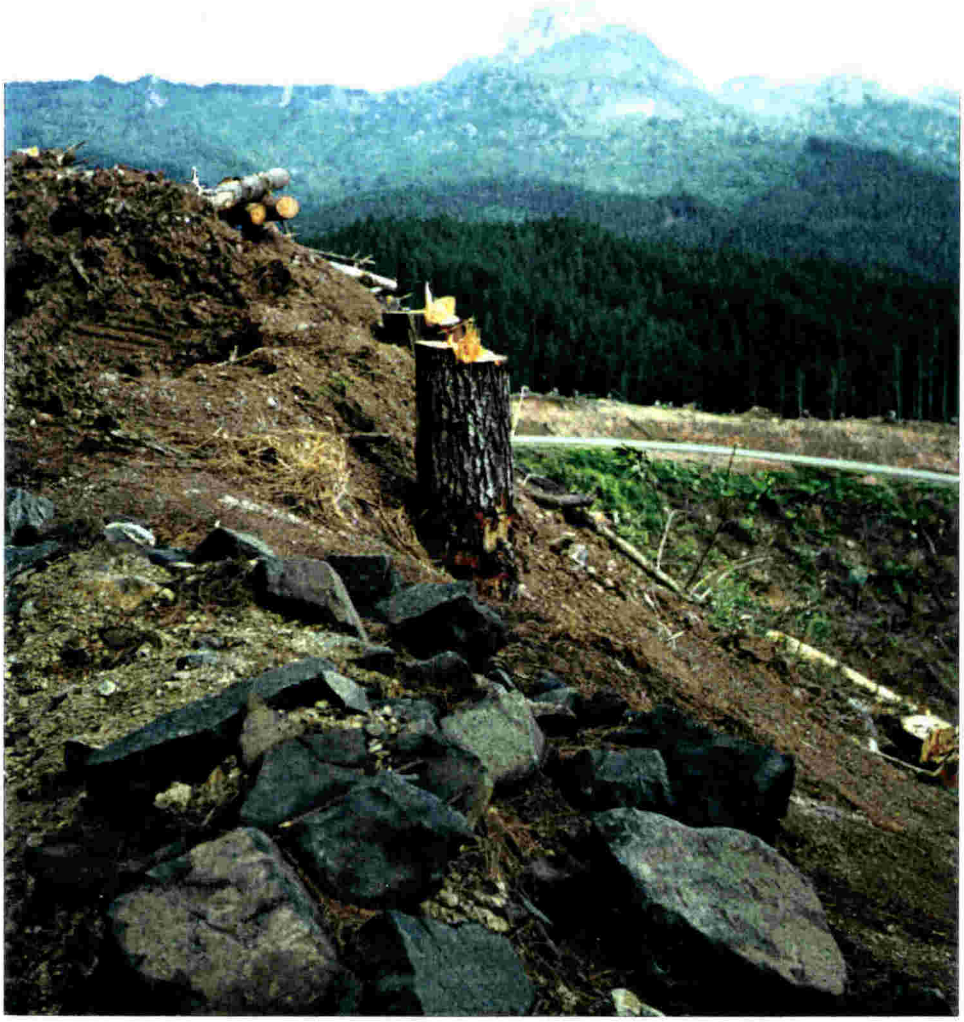

"Where my imaginary line
Bends square in woods, an iron spine
And pile of real rocks have been founded.
And off this corner in the wild,
Where these are driven in and piled,
One tree, by being deeply wounded,
Has been impressed as Witness Tree
And made commit to memory
My proof of being not unbounded."

From *The Moodie Forester*, Robert Frost

LONG-TERM SCHEDULING of HARVESTING with ADJACENCY and TRIGGER CONSTRAINTS

A thesis presented for the Ph D degree
in Engineering Science
at
the University of Auckland

Alastair McNaughton
1998

Abstract

The forest harvesting problem, FHP, is described. A review of the existing literature is presented along with an analysis of the strengths and limitations of various attempted solutions. The diversity of model evident in recent papers is noted. The difference is explained between a strategic model that sets long-term harvesting goals in terms of total area to be cut each year, and a tactical model that produces a short-term schedule of actual blocks. Special attention is devoted to the development of FRI's Forestry-Oriented Linear Programming Interpreter, FOLPI, which is currently used to formulate an LP model of the strategic planning problem. Reasons are presented for the desirability of an integrated model, embracing both strategic and tactical decisions, which is capable of optimisation. Accordingly the project then proceeds to a thoughtful and detailed construction of such a model. Particular care is taken to examine the status and function of FOLPI within this model.

A column generation algorithm is then developed to solve the relaxed linear program formulation. Finally powerful constraint branching techniques are utilised to obtain the desired optimal solution to the integrated model. Throughout the development of the project the Whangapoua forest in Coromandel, New Zealand has been used as a case study. A concluding section presents numerical output from some of the exhaustive computational analysis associated with this application.

Acknowledgments

I must first thank the Forest Research Institute for their generous funding and support of this research project. Bruce Manly's advice, guidance and encouragement have been a major factor in the successful outcome. Much valuable assistance has also come from Simon Papps especially with regard to the technical aspects of FOLPI. His advice on other computer-related matters has always been helpful. The courtesy of being accepted as part of the FRI team and accorded access to their resources, contacts and library has been much appreciated. I trust the result of this project will meet the FRI expectations and that an on-going productive research relationship may continue.

Next I must express my sincere thanks to the Ernslaw One company for allowing their forest at Whangapoua to be used as a case study. Their willingness to trust me with access to confidential forest management data is sincerely appreciated. Throughout the project I have been impressed in many ways with their commitment to manage this forest with the highest regard for the long-term protection and nurturing of the environment. It is my sincere wish that the algorithm I have developed may contribute in some substantial way to this praiseworthy goal. Greg Herrick and Brent Guild on the forest management staff have helped me a great deal. So I would like to thank them both very much for all the hours they have put into looking out various specific numerical data I have needed from time to time. The foresters on site at Whangapoua have always been courteous, patient and helpful. I thank them for allowing me freedom to visit this lovely forest whenever necessary.

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A number of friends have assisted me from time to time with helpful assistance and advice concerning technical aspects of computing. Development of this project has constrained me to acquire skills in a wide range of computer environments, languages, and software. In this regard I must thank Lyndon Drake (C-language), Ed Klotz (CPLEX help with both version 3.0 and 4.0), David Bullivant (PC implementation of CPLEX), Robert Chan (UNIX), Steve Butt (FORTRAN 77), Nick Vautier (windows 95), Terry Hannon (DOS), Kumar Vetharaniam (file maintenance and transfer), and Chris Bradley (UNIX implementation of CPLEX).

Preface

In 1838 Garrett Clearwater, an American whaler hailing from New Jersey, arrived at Otakou, in Dunedin harbour. Shortly afterwards he settled ashore, and established a pit sawmill at Company's Bay. Contemporaries recorded Garrett as a splendid bushman who swore by his "Sharp" American axe. Later the family shifted to Southland and the eldest son, also Garrett, operated a sawmill in the Titipua district. It was here my father's mother, Edith, was born. My mother's family had by then settled in the Henley area in Otago. Her father was a noted rural engineer who devised ingenious techniques for utilising the traction engine to set up power poles across the Taieri plain. Country New Zealand is a treasured part of my heritage, and this was one reason why I took my first degree at the University of Otago in geography. After that my interests led me more towards pure mathematics. As a consequence, it seemed the opportunity to combine serious academic work with a genuine empathy for the countryside was lost. So it was a quite unexpected pleasure in December 1993 to find an opportunity to participate in this forestry research project, for it contains a real mathematical challenge and also is of significant practical importance to the continuing development and protection of our land.

In today's world the use of land for production forestry is often a controversial topic. Some see it as an evil exploitation of nature, others as a sensible way to earn an honest living in a sustainable and responsible industry. I am well aware that the work I have done is going to impact on forestry in both New Zealand and overseas. Any planning tool in the wrong hands is capable of doing great harm. So I do not wish to appear naive. The software that will result from this project will give all participants in the forest planning arena access to a measurable and balanced assessment of likely consequences of various harvesting plans. The concept that the business profit motive should be accepted, but allowed to operate only within certain clearly defined constraints, is to me, as a Christian, very reasonable. The proposal that these constraints should be able to address specific local detail of individual locations within the forest I find very attractive.

This Saturday I again visited the Whangapoua Forest. It was extremely pleasing to see healthy regeneration on blocks that two years ago I photographed as rather desolate areas of recent harvesting. Occasional clay scars testified to three tropical cyclones and other more routine storms, but these are healing well under a splendid mat of native plants of all sorts. The new radiata seedlings are already shoulder high and provide significant protection against further erosion. Underfoot the soil retains a delicious deep friable texture almost everywhere, a tribute to the cable logging technique and the foresters that use it. Unlike the typical rural stream that turns an ugly brown after the slightest shower, the waters of the forest flow clear with clean pebbly riverbeds. Pause a moment and the beauty of wild birdcall is never far away. This is a good land, and this is one of the better ways to utilise and enjoy it.

Contents

page

Abstract 2

Acknowledgments 3

Preface 4

Abbreviations 15

1 Introduction

1.1 The forest harvesting problem 17
1.2 Terminology 17
1.3 Overview of the present study 19

2 Background and Review

2.1 The first forest harvesting model 21
2.2 Use of linear programming 22
2.3 Review of literature 24
2.4 FRI and FHP in New Zealand 30
2.5 Global issues concerning FHP 30
2.6 FOLPI 31

3 Case study: Whangapoua Forest

3.1 The Whangapoua forest 34
3.2 The Coromandel community 36
3.3 The importance of the catchment unit 37
3.4 Integrating catchment constraints in FHP 38
3.5 Other harvesting constraints 40
3.6 Harvesting techniques 40
3.7 Composite blocks 41
3.8 Notation for blocks and road segments 43
3.9 Sustainability 44
3.10 Present procedures for harvest planning at Whangapoua 44

4 Model formulation

4.1 One fully integrated optimisation 46
4.2 The significance of the time intervals in the model 47
4.3 The objective function 48
4.4 General comments on constraints 50
4.5 Strategic constraints 51
4.6 Plan constraints 55
4.7 Road constraints 58

page

4.8 Road sequential constraints 60
4.9 Block constraints 62
4.10 Cable logging adjacency constraints and their aggregation 65
4.11 Green-up adjacency constraints and their aggregation 71
4.12 Initial constraints 77
4.13 Linking constraints 78
4.14 Overlap constraints 81
4.15 Residual linking constraints 81
4.16 The complete objective function 82
4.17 An over-view of the completed model 83

5 Column generation

5.1 The revised simplex method and the reduced cost 86
5.2 The nature and function of column generation methods 87
5.3 An introduction to the theory of column generation 91
5.4 Weintraub's column generation method 94
5.5 The initialisation stage of our column generation method 95
5.6 How a new column is constructed 96
5.7 The reduced cost of a composite column 99
5.8 The selection of an entering column 101
5.9 How the column generation algorithm continues 107
5.10 A defence of the road constraint formulation 109
5.11 Column generation and the adjacency constraints 111
5.12 Alternative methods for avoiding integer-infeasible columns 112
5.13 How the constraints are up-dated during column generation 114
5.14 Wider applicability of this column generation procedure 116
5.15 A theoretic basis for the proposed column generation scheme 116

6 Branch and Bound techniques

6.1 Types of branching available 118
6.2 Formulation of a suitable set of constraint branches 123
6.3 Equivalent and implied constraint branches 128
6.4 The set of block constraints 132
6.5 Other possible branches 134
6.6 Tree search strategy 136
6.7 Node selection policy 140
6.8 The branch decision process 141
6.9 The relationship of branching decisions to forest management 142

7 Implementation

7.1 Computer and language selection 144
7.2 FOLPI 144
7.3 Use of the software package CPLEX 147
7.4 Data files 147

page

7.5 Initialisation 147
7.6 A procedure to address initial feasibility difficulties 148
7.7 Implementation of column generation 150
7.8 Implementation of branch and bound 152
7.9 Fathoming in the branch and bound tree 157
7.10 Implementation of allied constraint branches 161
7.11 The croptype need criteria for branch selection 165
7.12 A technique to safeguard uninterrupted block-availability 168

8 Numerical analysis of results

8.1 Problem characteristics 170
8.2 The first RLP solution and analysis of column generation 171
8.3 Introductory discussion of branch and bound strategies 174
8.4 Effective node selection 177
8.5 Other types of branches investigated 184
8.6 Efficient tree search strategy 185
8.7 Testing the node selection strategy for robustness 188
8.8 Testing the model size for robustness 190
8.9 Testing green-up adjacency constraints 192
8.10 Further analysis of model behaviour: the overlap variables 192
8.11 Aggregating the adjacency constraints 193
8.12 Eligibility of infeasible columns during column generation 195
8.13 Frequency calls to column generation 197
8.14 Over-all quality of model performance 198

9 Interpretation and discussion of results

9.1 Presentation of cutting plan output
and comparison with previous method 199
9.2 Comparing the results of the model
with those of previous manual methods 201
9.3 Presentation of output for the road construction schedule 203

10 Conclusions

10.1 Achievement of goals 205
10.2 Discussion of further development of this project 205
10.3 Suggestions for further research 206

References 208

Appendix A: Model formulation summary

A.1 List of variables 213
A.2 List of constants 215

page

A.3 List of sets 216
A.4 List of equations in model, with page references 217
A5 List of equations in algorithm, with page references 221

Appendix B: Glossary 225

Appendix C: Harvesting plans for Whangapoua Forest

C.1 The strategic plan up to 2003
submitted by Ernslaw One in 1994 234
C.2 The tactical plan for 1995 to 1997
submitted by Ernslaw One 235
C.3 The tactical plan up to 2001
as output from the FHP programme 237

Appendix D: Mathematical proofs

D.1 Theorem 1 243
D.2 Theorem 2 244
D.3 Theorem 3 245
D.4 Theorem 4 247
D.5 Theorem 5 248
D.6 Theorem 6 249

Appendix E: Whangapoua data files and initialisation

E1 : Data files 250
E2 : Initialisation 254

List of Maps

Map 1: Whangapoua Forest location 35

Map 2: The major catchments of the Whangapoua Forest 38

Map 3: A composite block overlapping compartments 42 and 43. 42

Map 4: Quarry Road, an example of road sequential constraints 61

Map 5: Compartment 17 of the Whangapoua Forest 67

List of Photographs

	facing page
Frontispiece: Castle Rock from Quarry Road	1
Plate 1: View towards Whangapoua Harbour	20
Plate 2: A riparian strip along the Waiau river	36
Plate 3: The effects of recent clear felling	38
Plate 4: Action on skid site 33/2	41
Plate 5: Anchorage of cables from the top of the tower	44
Plate 6: Catchment constraints at work in the Waingaroa valley	54
Plate 7: A cutting on a spur road in compartment 33	59
Plate 8: An adjacency constraint in action	65
Plate 9: Detail of rejuvenating forest three years after clear fell	82
Plate 10: Detail of a cable anchorage	117
Plate 11: An adjacency constraint in the Opitonui valley	142
Plate 12: Another anchor point, another adjacency constraint	161
Plate 13: Stability problems at the edge of a skid site	169
Plate 14: Integration of harvest planning and skid site activity	207

List of Figures

page

Figure 1: Constants used to represent time 47

Figure 2: Location of the strategic constraints 52

Figure 3: Typical constraints to conserve strata area 52

Figure 4: Non-declining yield constraints 53

Figure 5: Some examples of catchment constraints 54

Figure 6: Minimum total yield constraints 55

Figure 7: Plan constraints 57

Figure 8: Detail of typical road constraints 59

Figure 9: Examples of road sequential constraints 62

Figure 10: Detail of block constraints 65

Figure 11: Two pairs of cable-logging adjacency constraints 68

Figure 12: Aggregation of cable-logging adjacency constraints 71

Figure 13: Some green-up adjacency constraints 72

Figure 14: Aggregation of green-up adjacency constraints 75

Figure 15: Initial constraints due to cable-logging adjacency 77

Figure 16: Some initial constraints due to green-up adjacency 78

Figure 17: The physical interpretation of the overlap variables 80

Figure 18: Detail of linking constraints 80

Figure 19: Examples of overlap constraints 81

Figure 20: Residual linking constraints 82

Figure 21: A simplified matrix representation of the FHP model 84

Figure 22: A fragment of the FHP model as a study of a simple LP 88

Figure 23: An extra column has been added to Figure 22 89

	page
Figure 24: A second column added to Figure 22	90
Figure 25: An optimal column added to Figure 22	90
Figure 26: The entering column g_{114} added to the RLP matrix from Figure 22	104
Figure 27: Figure 7 has been adjusted to match Equation (4.2′)	109
Figure 28: The complete RLP after the incorporation of all columns from Table 5	112
Figure 29: A binary tree of the start of a typical variable branching strategy for FHP.	119
Figure 30: The start of a binary tree for a constraint branching strategy for FHP	122
Figure 31: The difference in set A between a plan and a block constraint branch	127
Figure 32: Part of the FHP model (a) before and (b) after inserting the extra columns	146
Figure 33: A case of flagrant infeasibility caused by initial constraints	148
Figure 34: A new column added to Figure 33 removes the blatant infeasibility	149
Figure 35: The column generation process	151
Figure 36: The branch and bound process	155
Figure 37: A graph showing typical adjacency relationships between blocks	161

List of Tables

page

Table 1: Numerical data used in Figure 21 83

Table 2: The sensitivity report from the LP solution of the example in Figure 22 99

Table 3: Modified reduced costs and reduced cost corrections from Figure 22 103

Table 4: Modified reduced costs and reduced cost corrections from Figure 22 during iteration 2 105

Table 5: A summary outline of the column generation process applied to the example in Figure 22 107

Table 6: Modified reduced costs and reduced cost corrections from Figure 22 during iteration 3 108

Table 7: Various policies for selection of entering columns in column generation 172

Table 8: A comparison of two simple depth-first methods 175

Table 9: A study of the consequences of giving priority to the earlier years 179

Table 10: Decision functions with few non-zero harvest plan variables given priority 180

Table 11: Branch selection based on croptype analysis 181

Table 12: Branch selection based on RLP croptype need 182

Table 13: A branch selection strategy giving preference to later years 183

Table 14: Branch selection based on the area of the block concerned 183

Table 15: Use of single year block branches 185

Table 16: Various strategies for backtracking with croptype branch selection 186

Table 17: Croptype branch selection with reduced objective tolerance 186

Table 18: The trials in Table 11 are repeated with more efficient backtracking 189

Table 19: Croptype branch selection with various lengths of tactical harvest 190

page

Table 20: Cable logging adjacency trials 191

Table 21: Green-up adjacency trials 192

Table 22: The result of imposing penalties on the overlap variables 193

Table 23: Comparative data on the effects of using aggregated adjacency constraints 194

Table 24: Green-up adjacency trial with 48 clicks each of 3 blocks 195

Table 25: Cable logging adjacency trials with only integer-feasible columns permitted 195

Table 26: A comparison of two types of cable logging adjacency trials 196

Table 27: Frequency of calls to column generation 197

Table 28: Values of variables in the FHP program pertaining to the 1995/6 cutting plan 200

Table 29: The cutting plan for 1995/96 as output from the FHP programme 201

Table 30: The cutting plan for 1995/96 submitted by Ernslaw One 202

Table 31: The road construction output for years 1995 to 2001 204

Table C.1: The strategic plan up to 2003 submitted by Ernslaw One 234

Table C.2: The cutting plan for 1995/96 235

Table C.3: The cutting plan for 1996/97 submitted by Ernslaw One 236

Table C.4: The cutting plan for 1995/96 as output from the FHP programme 237

Table C.5: The cutting plan for 1996/97 as output from the FHP programme 238

Table C.6: The cutting plan for 1997/98 as output from the FHP programme 239

Table C.7: The cutting plan for 1998/99 as output from the FHP programme 240

Table C.8: The cutting plan for 1999/2000 as output from the FHP programme 241

Table C.9: Residue of output for incomplete years of tactical harvest 242

Table E.1: An example of an extract from a data file, dated 1 April, 1995 251

page

Table E.2: An excerpt from the road sequential input file 252

Table E.3: An excerpt from the block file 252

Table E.4: An excerpt from the adjacency data file 253

Abbreviations

CPLEX: This is a software package written to assist researchers who need to solve LPs and other related problems. The letter C has been chosen to indicate that this software is written in the C computer language.

FHP: Forest harvesting problem.

FOLPI: Forestry-Oriented Linear Programming Interpreter. This is a software package produced by FRI that makes a strategic harvest plan for a forest. It requires the assistance of an LP solving device such as CPLEX.

FORPLAN: A software package widely used in North America to analyse the strategic plan. It is purely an LP with no tactical components at all.

FRI: Forest Research Institute, Rotorua, New Zealand.

HIP: A heuristic integer planning model.

IP: A linear programme in which all the variables are binary integers.

IRPM: The integrated resources planning model, (IRPM), developed by Kirby [29], and used as the basis for some later models such as that by Weintraub et al. [62].

K11.1, K7.4, K3.7: Timber in these grades will be milled as rough sawn timber and used for framing and similar purposes. The revenue obtained for this is quite low.

LP: A linear programme.

MCIP: A Monte Carlo integer programming model.

MIP: A linear programme in which some of the variables are binary integers.

P1P2: The premium grade of timber that will fetch the top prices. This comes from correctly pruned trees and hence is largely free of knots.

PC: A personal computer, usually of the IBM-compatable type.

PNW: Present net worth. Future revenues and costs are discounted and summed.

RFHP: A RLP of a MIP, representing a FHP.

RLP: A relaxed LP. That is an MIP in which each binary variable is replaced by a real variable defined on the interval [0,1].

RMA: The Resource Management Act, a piece of New Zealand legislation passed in 1991, which details the necessary process of land users to obtain consent for all manner of activities.

S1, S2: Two grades of fine logs suitable for milling as dressed timber.

SNAP II: Scheduling and Network Analysis Program. This is a widely used software package of tactical planning including roading. It does not include any strategic planning. It was developed by J. Sessions and J.B. Sessions, in Oregon State University. It is heuristic in the Monte-Carlo tradition, providing a very fast feasible tactical plan with a discernible minimisation of optimisation.