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THE RELATIONSHIP BETWEEN TRAFFIC LOADING AND ENVIRONMENTAL FACTORS TO LOW VOLUME ROAD DETERIORATION

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ABSTRACT

Many countries use some form of road user charge model to determine how much to charge road users for using roads. It is expected that trucks would pay for most of the costs as heavy vehicles would be responsible for most of the deterioration of roads. This research documents findings that would ultimately be used for the refinement of the New Zealand road user charge models. The research was undertaken on data from the Long Term Pavement Performance programme with the specific aim of determining the relative damage caused by heavy vehicles loading alone compared to the combined effect of loading and environmental impacts. As part of the over-all research process, a cluster analysis was undertaken. The result from this analysis also emphasised the importance of drainage. The cluster analysis resulted in a recommended stratification of low volume roads on the basis of their urban/rural location, traffic loading and climatic area. This stratification could be used for a more detailed implementation of a user charge model if needed. It was determined that on similar low volume roads, an approximate 0.1mm/year higher rut rate was observed in areas that have a wetter climate in combination with sensitive in-situ soil conditions. It was also illustrated that having adequate drainage is vital for limiting environmental impacts. Roads with inadequate drainage had a rut rate 2.5 times higher than roads with the necessary provision for drainage.

Keywords: Low Volume Roads, LTPP, Road performance, moisture, environmental impacts.

INTRODUCTION

Background

New Zealand (NZ) has a dedicated road fund that is used for the construction, operation and maintenance of road assets at both local and national levels. According to the Road User Charges (RUC) Act of 2012 (1), all motor vehicles contribute towards the transport fund through petrol taxes and licensing of vehicles. All the revenue, collected from road user charges, goes into the National Land Transport Fund and the Regional Land Transport Fund. In principle, the contribution to the RUC is proportionally calculated according to cost incurred as a result of the vehicles travelling on the NZ road network. As expected, most of the costs incurred for maintaining the existing road network are recovered from Heavy Commercial Vehicles (HCV) as most of the damage to roads would originate from these vehicles. The assumptions and calculation of relative damage caused by HCV are being reviewed and updated on a regular basis.

During 2012, the Ministry of Transport initiated a research project with the New Zealand Transport Agency to investigate the relationship between vehicle axle loadings and pavement wear on local roads. The purpose of this research was to provide reliable evidence on the wear characteristics of NZ's local road pavements from accelerated pavement loading studies conducted at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) and validated with field data from the nationwide Long Term Pavement Performance (LTPP) sites. This paper documents the initial findings from the analyses completed on the LTPP data.

Research Objectives

The over-all research objective was to develop a comprehensive understanding of the load – wear relationships for New Zealand local roads. This objective is addressed through a combined analysis of findings from the CAPTIF and LTPP analysis. The specific objectives for the research component that was undertaken on the LTPP data and documented in this paper were:

- To understand the relative influence of factors contributing towards the deterioration of low volume roads. This outcome was used to derive a stratification framework for low volume road networks; and,
- To determine the specific influence of climate on the deterioration rate of roads under comparable traffic loading conditions.

Most of the previous research in NZ, and research in Australia, has been undertaken for loads that were close to the legal load limits or overloaded vehicles (2). However, that research has indicated that there may be a significantly different relationship on local roads, especially for loads below the legal limit. The presented research particularly focused on road damage caused by lightly loaded vehicles travelling on local roads in NZ. These local roads mostly consist of bound and un-bound granular pavements surfaced with thin chip or spray seals. The typical profile of these pavements would vary between 100 to 350mm on relatively weak subgrades, often consisting of soils from a volcanic origin.

Scope of the Paper

This paper covers the initial analyses completed on the basis of data from the LTPP programme on local roads. The main purpose of the analysis was to gain a detailed understanding of the LTPP site performance over the past 10 to 12 years. The analyses also explained the difference in performance for pavements in varying climatic and drainage conditions as a first attempt to isolate deterioration due to the environmental impacts. Later, once the CAPTIF data becomes available, further analysis will be undertaken to refine the relative contribution of vehicle loading versus environmental impacts.

STATUS OF PREVIOUS RESEARCH

The Influence of Moisture on Pavement Material

There has been significant research into the impact of moisture on pavement material. This work can be divided into:

- Laboratory testing of material. The use of the repeated load triaxial (RLT) tests has been extensively used to investigate material performance in wet conditions. (3,4; 5). In their research Hussein et al. (6) investigated the performance of different aggregate grading in relation to its resistance to moisture impacts. The study concluded that an open graded aggregate performs better under laboratory conditions, while a different outcome was achieved under accelerated load testing. The RLT tests suggested superior performance from an open graded material, while this material failed relatively fast under the accelerated condition. It was concluded that the base course material in a natural environment is not subjected to the same constraining forces as simulated in the RLT, thus prone to early shear failure. Other factors that impact the ability of material to perform in wet conditions include the amount of clay and presence of certain geological minerals such as Smectite (7). The most significant finding from this research in the context of this paper is that there is a relative difference in behaviour under wet conditions on the bases of different material types and characteristics. However, all materials tested indicated a significantly poorer performance under saturated conditions when compared to the same material under optimum moisture content; and,
- Accelerated Pavement Testing. Various accelerated pavement test facilities around the world have investigated the impact of water ingress into the pavement (8, 6). A common finding from this research is that the ingress of water often led to rapid and accelerated deterioration.

A common limitation to the literature is the lack of linkage between findings from either the laboratory and/or the accelerated test work with actual field performance.

The Impact of Moisture on in-situ pavement using data from Long-term Pavement Performance Studies (LTPP)

Most LTPP studies recognise the impact of moisture and/or environmental impacts on the long-term performance of pavements. A popular technique of incorporating environmental impacts would be to include climatic regions as a factor into the experimental design of the LTPP study (9, 10, 11). Resulting from this approach, the impact of moisture and/or climate is quantified through using calibration factors to adjust the forecast from pavement deterioration functions.

The World Bank HDM-4 Models went one step further by incorporating a drainage impact factor into the deterioration models. A drainage index was introduced that varies for different material types and freezing and non-freezing environments. The drainage index is then used to alter the environmental impact factors that apply to all deterioration models (12).

In his study, Martin (13) also investigated the impact of moisture on pavement deterioration on the basis of the Australian LTPP programme. In his research, a relative impact was developed on the basis of climate and whether a road surface was cracked or un-cracked. This relative factor in wet conditions varied between 1.22 to 1.14 of a base deterioration rate expected for a dry climate.

THE NEW ZEALAND LTPP PROGRAMME

The NZ LTPP programme originated during year 2000 when 64 LTPP sites were established on the State Highways. Two years later, the same establishment principles were used for the establishment of an additional 84 LTPP sites on local roads, with approximately half of the sections on rural roads and the remaining portion on urban roads.

Sites Established

Henning et al (10) describes the rationale of the site establishment in detail. In summary, the 140 sites were established across the country and covered all the expected factors that would influence the performance of NZ road network including:

- Climatic and soil condition;
- Traffic loading;
- Pavement Types/Strength;
- Pavement Age/Condition; and
- Maintenance regime.

The LTPP sites are 300m in length with each section subdivided into 50m subsections for the assessment purposes. The layout of the sites is depicted in *Figure 1*. Henning et al. (10) adopted a climatic sensitivity rating to classify the combined impact of rainfall and soil moisture sensitivity. According to this classification, NZ was divided into four environmental sensitivity regions. For example, regions with a subtropical climate and significant clayey in-situ subgrades would be classified as a sensitivity region. Typically the far northern regions of the North Island and the West-coast of the South Island were classified as high sensitivity areas. Dryer regions on more stable geological formations, such as the Canterbury region in the South Islands of New Zealand would be classified as low sensitivity region.

Condition Data

A private survey contractor has been undertaking an annual data collection on all the LTPP sites. The contract for this survey specifies the data collection accuracy and repeatability requirements. Due to the fact that only one contractor has been involved since the initiation of the programme, no changes were made to the methodology of data collection. An outstanding outcome from the programme so far was the quality and subsequent usefulness of the data (14). The data collection includes:

- A manual assessment of all defects that involves the recording of the exact extent and dimensions of the defects;
- Manual measurement devices are used for rutting, roughness and texture depth (Refer to *Figure 2*);
- Traffic counts are undertaken using classification loop counters;
- Maintenance is recorded; and,
- Detail site notes and photographs of any changes that occurred during the study period.

In addition to the above, each site is also surveyed annually using the High-Speed Data (HSD) collection survey as part of the NZ Transport Authority (NZTA)-State Highway network survey processes. Four repeated runs are undertaken in both directions for each site using the HSD equipment. These parallel surveys have resulted in significant research opportunities in the data collection area (14).

CLUSTER ANALYSIS RESULTS

A cluster analysis was undertaken in order to gain a better understanding of the main factors contributing towards the deterioration of the pavements. Therefore, the aim with this particular analysis was to investigate potential groupings of LTPP sections that behave similarly, and to determine the factors that could be used to determine these groupings. Often, in executing correlation or regression analysis, complete understanding of behaviour is not always apparent. A second reason for undertaking cluster analysis was for making provision for the event where varying RUC would be applied to different portions of the network. Knowing the most significant and appropriate factors to stratify the network would assist in the varying application of the RUC.

Deterioration Characteristics of the LTPP Sites

Figure 3 depicts the changes in defects of the local council sites since 2002. It shows the number of sites that displayed an increasing, decreasing or no trend during the past ten years. Note that in most cases, a decreasing trend represents sections that have been rehabilitated. The changes were reported for:

- Roughness (in IRI);
- Wheel track rutting (in mm);
- Longitudinal and Transversal cracking (L&T – cracking);
- Alligator cracking;
- Patching – previously potholes or shoves;
- Shoving or shear failure of the roads;
- Edge break; and,
- Potholes.

It was observed from *Figure 3* that approximately half of the sections have displayed deteriorating trends. A more detailed investigation of individual sections suggested that deteriorating did not necessarily show increasing trends for all defect types. For example, if a section shows increasing rutting, it does not necessarily mean the roughness also increases. This observation further confirmed the typical behaviour of low-volume/ low-strength roads that carry relatively light traffic. Another observation was that primary and secondary deterioration mechanisms differed on most sites. For example, for some sites, cracking was observed as a primary defect followed by say rutting after some years. On other sites though rutting was observed a few years before cracking was first observed. It was thus clear that the failure mechanisms differ substantially between sections confirming the findings from Schlotjes et al. (15)

Despite the average age of the inferred pavement for the LTPP sites (over 15 years old), only half of the sites displayed any deterioration. For these sites, little deterioration occurred over time for the predominant period of the pavement's life. These pavements would sometimes even exceed the design life of 20 to 25 years. However, at a certain point in time, the site starts deteriorating rapidly and would require maintenance in a short time-frame. These observations were consistent with pavement model development findings by Henning et al. (16)

A Stratification Framework for Low Volume Road Network

As explained, a stratification framework for low volume roads is required for the application of more refined road user charges. The philosophy is that a) trucks would not cause equal damage on all road types, and b) it is accepted that lighter trucks/or lighter loads would use the low volume road spectrum of local authorities, whereas heavy freight vehicles would normally be travelling on the state highway network. A full set of potential deterioration factors was used for the cluster analysis, although only some physical characteristics were chosen for the stratification framework for networks.

Although the cluster analysis was undertaken for all defect types, it was found that it had the most sensible outcomes for rutting as a predictor. This also fits well with the AUSTRROAD design philosophy that uses rutting as a dominant failure mechanism for granular pavements (17). *Table 1* lists the outcome from the cluster analysis. For each potential value of a factor, the table depicts a probability that a factor and value combination would be used for clustering the rutting behaviour. For the rut analysis, the data was clustered into five groups of different rut progression rates. The percentage depicted in the table gives the percentage contribution of each factor classifying the rut deterioration into one of the five cluster groups. The rural road category for example, has a 57% probability of classifying rut rate into one of the five categories. The top three factors contributing towards a rut behaviour classification were drainage condition, traffic loading and pavement strength, while the climatic region also featured strongly in the clustering results. It was encouraging to note that expected results were obtained from the cluster analysis. However, it was particularly interesting to note that the drainage condition contributed significantly more to deterioration of pavements compared to the climatic region. This finding again

confirmed views from experience of Engineers emphasising the importance of drainage on the long-term behaviour of roads.

FIGURE 4 illustrates the resulting stratification framework for low volume roads. Based on this result, the recommended stratification would be urban/rural networks and then traffic volume and climatic environment. It was decided that the pavement strength classification would not make a significant difference and would also be less practical given that local authorities do not have comprehensive pavement data.

ISOLATING ENVIRONMENTAL EFFECTS

The difficulty in isolating environmental effects from traffic induced deterioration of roads results from the fact that these two impacts do not act in isolation. There is a complex interaction between the pavement, current condition, traffic volume, physical properties and the environment on deterioration of roads. In order to isolate the impact of the environment and drainage, the relationship between the rut rate (mm/year) and the respective factors were investigated. It is acknowledged that the relationship between rut rate, traffic, climate and drainage is most probably not a linear relationship. However, the aim of this part of the research only considers the relative impact, which is better understood by considering the linear trends. For comparative purposes, the current rut deterioration models for NZ are given by (16):

Initial Rut Rate

$$Initial_Rut = 3.5 + e^{(2.44 - 0.55SNP)} \quad (Eq1)$$

Stable Phase Rut Rate

$$RPR = 14.2 - 3.86 \times a_2 SNP \quad (Eq2)$$

Probability of Accelerated Rut Rate

$$p(Rutaccel) = \frac{1}{1 + e^{\left\{-7.568 \cdot 10^{-6} \cdot ESA + 2.434 \cdot snp - [(4.426, 0.4744) \text{ for thickness} = (0,1)]\right\}}} \quad (Eq3)$$

Where:

SNP – Modified structural number

ESA – Equivalent standard axles

Thickness Boundary 150mm

Climatic Region

The climatic regional sensitivity classification has proven to be an effective measure to describe the combined impact of rainfall and soil moisture sensitivity. Many other deterioration studies have confirmed the use of these sensitivity regions to be a valid technique to stratify the country into appropriate climatic regions (15, 18). *FIGURE 5* illustrates the annual change in rutting (mm/year) as a function of traffic loading and the environmental sensitivity. It is observed that there is a significant variation to the trend, which is expected on the basis of findings published in Henning et al. (16). Most significant of these would be the stage of rutting for a particular road that would be vastly different, yet in this section, it is ignored. Also, the other variables that influence rutting, for example those contained in

Eq1 are not considered either. Despite the variation of the incremental rut change, it was also observed that the rate of change of rutting, as a function of traffic loading, was slightly higher for the medium and high climatic sensitivity areas. There was an absolute difference of approximately 0.1mm/year for the traffic ranges tested. The finding suggests that roads in more sensitive climatic zones will have an increased rut rate (by approximately 0.1 mm/year) as compared to the more stable climatic areas, for example at an ESA of 400 axles per day the rut rates are 0.16mm/year and 0.28 mm/year (0.12 mm difference) for the low sensitivity and medium and high sensitivity area respectively. The expected rut rate for roads in New Zealand varies between 0.3 to 0.6 mm/year. It was noted that the linear relationship between the rut rate, traffic loading and climate had a moderate to strong correlation that was significant in both cases. It is also noted that a significant number of data points from the medium and high climatic area falls outside the 95% confidence level. This aspect further investigated by considering the drainage situation for these sites and the outcome is discussed in subsequent paragraphs.

Combined Impact of the environment, Drainage and Traffic Loading

As part of the annual LTPP surveys, all assessments of sites have included a detail rating of the drainage condition and drainage need, where no drainage existed. The previous section has already highlighted that the drainage condition, or absence of drainage where it is needed, had a significant impact on the deterioration of a site. The remaining question was how much the drainage affects the deterioration of low volume roads for different environmental conditions.

The results revealed that for the low sensitivity environment, the drainage condition impact was much less than it was for the medium and high sensitivity environments. *FIGURE 6* shows the rut rates for sites within the medium to high sensitivity climatic area, therefore only taking the medium and high sensitivity data points from *FIGURE 5*. Two trends were observed: one for sites having adequate drainage and the other for sites having inadequate drainage. There was a slight absolute difference between the deterioration rates at the intercept of the two drainage states. However, sites with inadequate drainage having approximately 2.5 times the deterioration rate compared to those sites with adequate drainage. For example, at 400 ESA per day the rut rates are 0.65 and 0.25 for inadequate and adequate drainage respectively. Again, this finding correlated well with engineering experience.

The correlation and significance of the trends are medium to high for the two expressions thus suggesting the relevance of including drainage adequacy in considering rut rate as a function of climate. When comparing the 95% confidence levels between *FIGURE 5* and *FIGURE 6* it is noted that far less data points fall beyond the confidence levels in the latter figure thus supporting the validity of the drainage adequacy as a variable for rut rate progression.

CONCLUSIONS

This paper has documented performance outcomes from the NZ LTPP programme following 10 years of intensive data collection. The main objective of the analysis was to understand how the LTPP pavements have deteriorated under different traffic and environmental conditions. In particular, the study aimed to gain a better understanding of the relative contribution of environmental effects versus the impact of traffic loading alone. The research was part of a larger research project that will ultimately yield a new road user charges model for trucks. Most of this work will be undertaken at the CAPTIF testing facility. However, these tests are undertaken in the absence of access moisture which necessitates the LTPP work on environmental impacts on the deterioration rates.

The findings from this research suggested that the rate at which roads will deteriorate on average be 0.1 mm/year faster in wet climates and areas with sensitive in-situ soil conditions. However, it was established that the condition and presence of drainage, where needed, was much more important than just the environmental conditions alone. Observations from the data revealed that the rut rate of low volume roads was 2.5 times as high on poor drainage sections compared to sections where adequate

drainage was provided. It was also established that sections having poor or inadequate drainage will deteriorate much faster under heavy traffic volumes.

The research has confirmed and quantified some principles that would be emphasised by experienced Engineers, that is, to ensure adequate drainage is provided for roads, especially low volume roads that mostly consist of unbound granular material. The research successfully provided benchmark deterioration rates for low volume roads under varying climatic and moisture conditions. The next stage of the project will involve comparing these results to those from the accelerated testing.

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FIGURE 5 Rut progression as a function of traffic loading and environment.

FIGURE 6 Rut progression as a function of traffic loading, drainage condition and environment.

TABLE 1 Condition Trends of the LTPP Sections on Local Roads

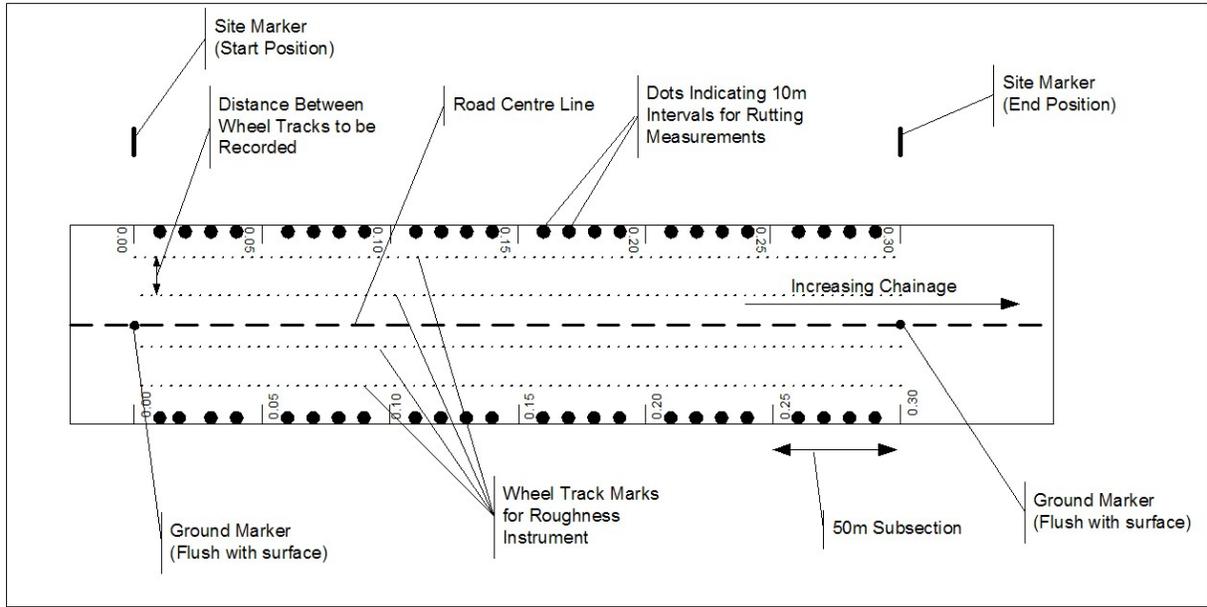


FIGURE 1 NZ LTPP site layout (10).



FIGURE 2 Rutting measurements on the NZ-LTPP Programme.

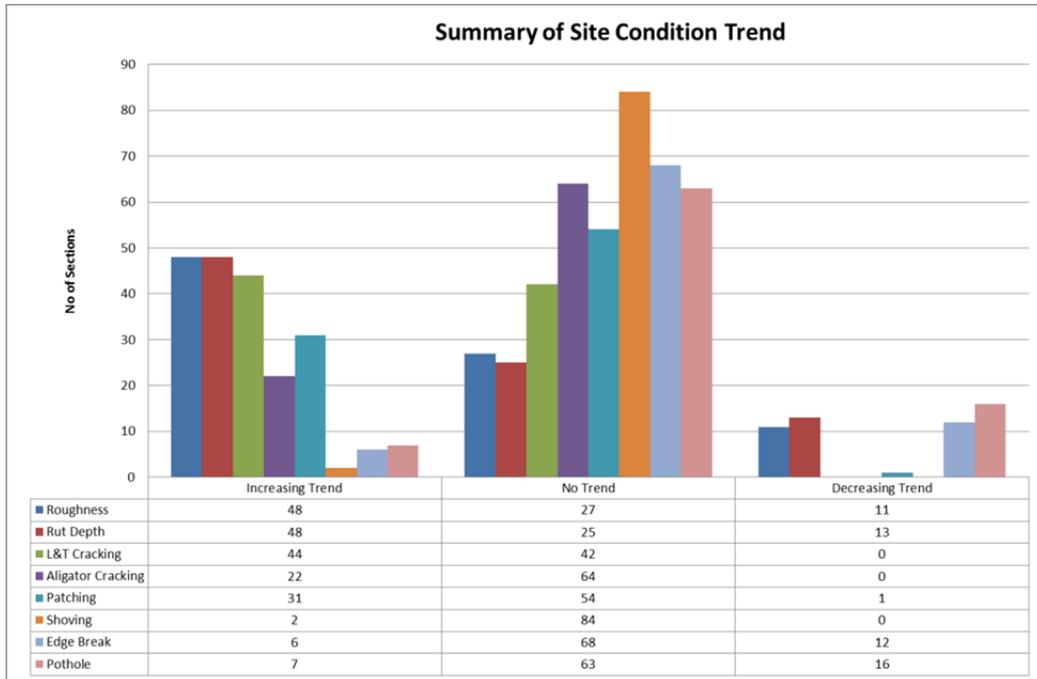


FIGURE 3 Condition trends of the LTPP sections on local roads.

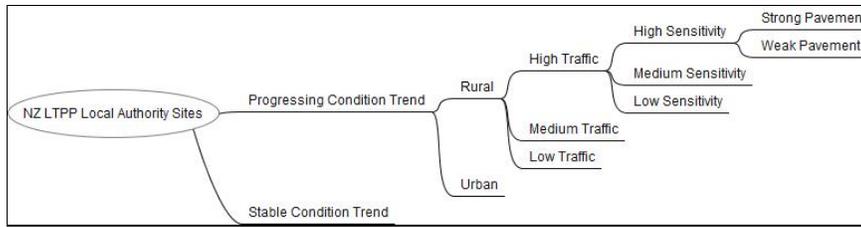


FIGURE 4 Resulting stratification framework for LTPP sections on local roads.

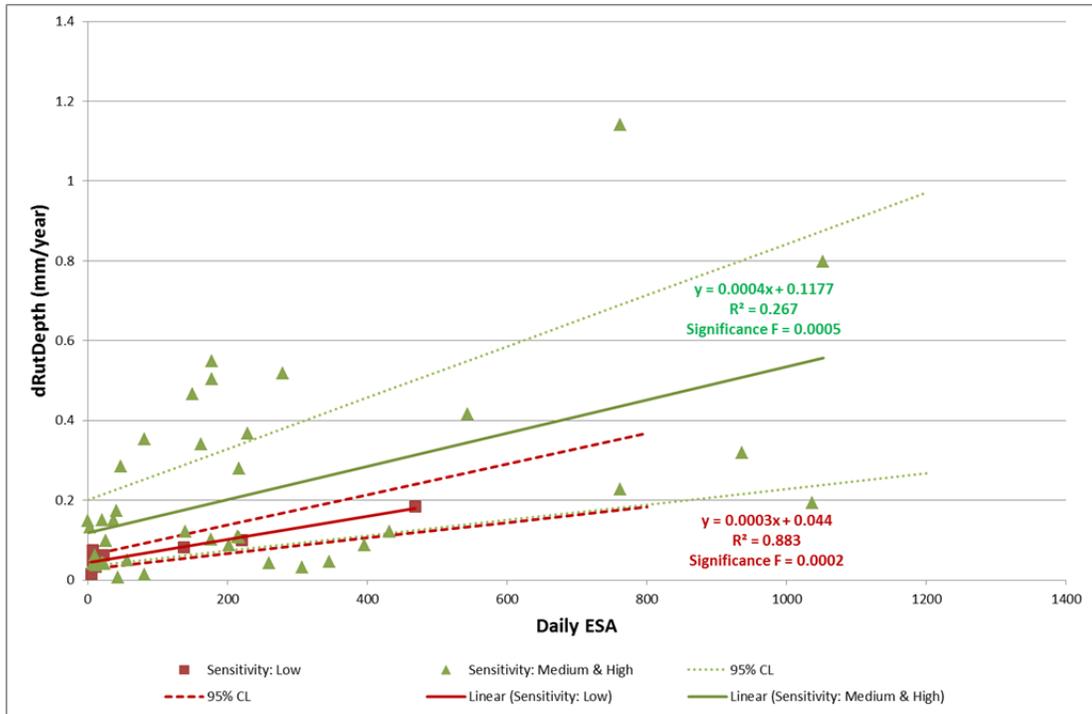


FIGURE 5 Rut progression as a function of traffic loading and environment.

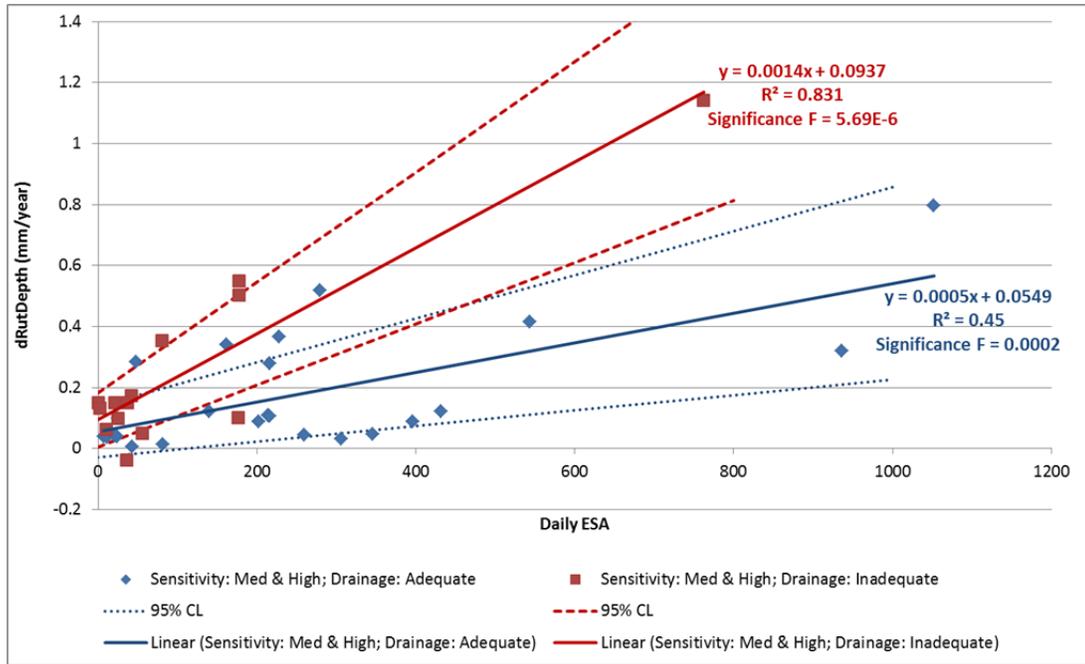


FIGURE 6 Rut progression as a function of traffic loading, drainage condition and environment.

TABLE 1 Condition Trends of the LTPP Sections on Local Roads

Variables	Values	Probability
Drainage Condition Observed from Site Photo	Fair	71 %
Traffic Level _Low_ Daily ESA _100_ Medium_ 100_ Daily ESA_ 200_ High_ Daily ESA_ 200_	Low	62 %
Site Condition Trend Classification	Progressing	59 %
New Pavement Strength classification bases on total pavement depth_ SNP and D0	Strong	57 %
Road Category	Rural	57 %
Road Category	Urban	43 %
Site Condition Trend Classification	Stable	41 %
Sensitivity	Medium	41 %
New Pavement Strength classification bases on total pavement depth_ SNP and D0	Weak	35 %
Sensitivity	High	31 %
Sensitivity	Low	28 %
Avg Annual Rut Chg Rate _mm_	0.1 - 0.2	25 %
Avg Annual Rut Chg Rate _mm_	-0.1 - 0.1	25 %
Avg Annual Rut Chg Rate _mm_	0.2 - 0.7	25 %
Avg Annual Rut Chg Rate _mm_	-0.6 - -0.1	25 %
Traffic Level _Low_ Daily ESA _100_ Medium_ 100_ Daily ESA_ 200_ High_ Daily ESA_ 200_	High	24 %
Drainage Condition Observed from Site Photo	Poor	21 %
Traffic Level _Low_ Daily ESA _100_ Medium_ 100_ Daily ESA_ 200_ High_ Daily ESA_ 200_	Medium	14 %
New Pavement Strength classification bases on total pavement depth_ SNP and D0	NA	8 %
Drainage Condition Observed from Site Photo	Good	8 %