Life cycle cost analysis to identify the need for drainage renewal in maintenance of road asset: Case Studies from a New Zealand road network.

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ABSTRACT

This paper presents life cycle cost analysis case studies of drainage improvements in pavement renewal sections. The methodology used was developed by the New Zealand Transport Agency (NZTA) and utilizes Net Present Value (NPV) and Economic Indicator (EI) as the tools for economic justification. Case studies on a number of renewal sites were conducted from a road network managed under a Performance Specified Maintenance Contract (PSMC) in New Zealand (NZ). Due to the contractual nature of a PSMC, that is a lump sum to manage the network for 10 years, the contractors are at risk of expensive maintenance and renewal costs from premature failure. Consequently, they have to be proactive in balancing investment for asset renewal, preventive and reactive maintenance on the road network. The majority of the network comprises of chipseal roads without any comprehensive drainage measures being present. The renewal sites selected for the case study range from flat rolling ground to rugged hilly terrain. There are side hills, natural streams, and bush areas beside the sites, thus making them particularly vulnerable to moisture induced failure. The outcome of the study is encouraging and indicates a positive gain in economic efficiency from the investment in drainage improvement. This study is the first step towards managing drainage on a road network in a more holistic manner, by identifying the costs and benefits of undertaking the appropriate investment.

Keywords: Road asset management, drainage improvement, life cycle cost analysis.
INTRODUCTION

Road network maintenance is increasingly a challenge for road controlling authorities. Roads are deteriorating at a faster rate due to increases in traffic loading and environmental effects. This has increased the demand on maintenance budgets at a time when funds available for maintenance of the road network are either reducing or remaining constant. Consequently, road controlling authorities are seeking ways to reduce the extent of expensive renewal of road pavements and are instead looking at lower cost options that may prolong the service life of the road pavement. The recent conversion from Performance Specified Maintenance Contracts (PSMC) to Network Outcome Contracts (NOC) in New Zealand (NZ) recognizes and accepts the risk of having an over-patched network at the minimum required serviceability level (1). One targeted approach in these NOC contracts is to manage the road network within the reduced maintenance budget through reducing the investment in pavement renewal and instead, spending more on drainage improvements (1, 2). The NOC procurement model differs from the PSMC model by contracting to a certain quantity of pro-active treatments such as resurfacing and rehabilitation, providing a lump sum to undertake routine maintenance, while adhering to a set of performance standards. A contractor is allowed to put forward a scheme for additional proactive treatment, but at the same time sacrifices the claimed savings on routine maintenance from the lump sum. Therefore, spending the routine maintenance lump sum on the right treatment and location is paramount to the successful outcome of the NOC.

Drainage improvement is considered as one of the tools to increase the life of road pavements (3). The transition of road pavements from Tresaguet to McAdam and onwards to modern pavements, resulted in significant increases in strength and serviceability due to the improvement of both surface and subsurface drainage measures. Early improvement of road pavements by Tresaguet introduced sloping interfaces to increase lateral movement of water. Later on, Telford modified the road pavement through inclusion of a thicker base course layer and intermittent surface drain to increase the serviceability. In contrast, McAdam reduced the thickness of the base course and introduced the concept of a raised road pavement along with a self-draining subbase or subgrade materials. All of these efforts were to introduce effective drainage measures to increase the service life of the road pavement (3).

The importance of drainage improvement in road network maintenance has recently been highlighted due to a number of factors. Most rural highways are built with a natural earthen drain with intermittent culverts (23). These roads are low volume roads, especially in countries like NZ. With the increase of commercial activities over the regions, these rural roads have to carry a significant amount of heavy commercial vehicles. The road pavements are usually composed of bound or unbound granular base course with a chip seal layer (4, 6). So the increased loads from heavy commercial vehicles have been causing accelerated deterioration of road pavements. In addition, moisture percolating through either the chip seal surface or the unsealed shoulders is the prime reason of premature failure in road pavements. This has become a growing concern among road controlling authorities. One feasible approach to deal with the issue is to improve the drainage measures to ensure removal of both the surface and sub-surface water out of the road pavement (4, 8). Road controlling authorities proactively include the drainage improvement works along with the renewal of road pavements. However, the investment in drainage improvement needs to be economically justified along with demand for field verification. NZTA has been using a number of tools for economic analysis of any investment in road network management (7). This paper uses a case study based life cycle cost analysis method developed by NZTA to demonstrate the economic assessment of drainage improvement in road network maintenance.
OBJECTIVE AND SCOPE OF THE STUDY

This study aims to identify the need for drainage improvement works along with road pavement renewal. The drainage improvement works are additional investment along with the regular renewal works. The drainage works are targeted to improve the surface and sub-surface drainage capacity of the road pavement. Ideally the road surface should be dry and free of any stagnant water, however, in practice the road surface often remains wet and shows the presence of trapped moisture in the base course layer. All of these indicate that the drainage system (surface and sub-surface) is not adequate or it is not functioning to the desired service level. Case studies were conducted in one of the road networks in NZ. The majority of the road network consists of low volume rural highways. The Average Annual Daily Traffic (AADT) of the road network ranges approximately from 500 to 10000. One tenth of the road network consists of stone mastic asphalt with granular base course. The rest of the road pavements are either bounded (cement or lime stabilized) or unbounded granular base course layer with chip seal surfacing. Details about the materials and construction techniques of these roads are beyond the scope of this paper and readily available elsewhere (5, 6, 7).

BACKGROUND TO THE STUDY

Moisture in road pavements includes water either from precipitation or from the ground water table. Variations in moisture content in the base and the sub-base courses over the years due to changes in season, water table height, and precipitation has a significant impact on the pavement strength and serviceability (12). The pavements consist of a layer (overlay) of good quality crushed stone, placed on an in-situ or improved sub-base and subgrade. Often the aggregates in the granular layer are stabilized with cement, lime or bituminous foam based on their sensitivity and strength requirements for carrying the estimated traffic load. Single or multilayer chip seal is preferred for low to moderate traffic levels, whereas structural asphalt is used for high traffic roads as the surfacing of the road pavement (4). The function of the base course is to distribute the traffic load, thereby reducing the stress on the subgrade, whereas the chip seal layer is designed to prevent the ingress of water into the pavement layers. Properly designed and constructed pavement layers should provide sufficient strength to limit rutting and deformation under traffic (9, 27). However, research has shown that moisture on road pavements percolates through the chip seal layer both in static and accelerated traffic conditions (4, 10). The situation is exacerbated in the wet season due to an increase in sub-surface moisture levels and inundation of road pavements for a prolonged time in the case of flooding. The extent of moisture induced damage includes rutting, differential settlement related cracking, stripping, pumping, raveling, and, finally, subgrade failure.

A well maintained drainage system can increase the life of an ageing pavement by ensuring water will drain from within the pavement layers (8). Both surface and sub-surface drains have discrete functions in the road pavement. The cross fall is the prime component of surface drainage along with the roadside kerb and channel. Often in rural, low volume roads, there are earthen channels that temporarily retain the surface water. Both of these surface drainage systems can be non-functional because of damage or clogging. In addition, water that enters through the chip seal surface has to be drained out of the pavement. In some situations, water enters into the pavement layers through the unsealed shoulder. Consequently, the base course and subgrade layers are designed to effectively drain water out of the pavement layers.

However, there are situations where both pavement layers and shoulders become saturated due to a buildup of an impermeable layer that prevents the moisture draining out (15,16). Often, a granular overlay placed on the existing road pavement shows symptoms of moisture damage like potholes, shoving and heave. The old surface acts as an impermeable layer and hinders water from draining out of the pavement layer placed above. In addition, poor drainage has been clearly identified as a contributor to premature pavement failures, especially rutting and shear
failure in the vicinity of the outer wheel path. Finally, improper drainage can affect the performance of the chip seal surface layer by contributing to the beginning of flushing. All of these can lead to the need for replacement or strengthening of the existing drainage system (surface and sub-surface) of the road section (17, 18).

There is little doubt about the value of an adequate drainage system for a road network. However, the question remains as to the extent of drainage measures required at a particular site. Investment in road network management is limited, so the road controlling authorities have to ensure that the proposed drainage renewal is economically justified and demonstrates lowest whole of life cost (8). In order to identify the minimum whole of life cost, it is necessary to conduct a life cycle cost analysis of the road section.

LIFE CYCLE COST ANALYSIS (LCCA)

Life cycle cost analysis is an economic tool to identify the most cost effective alternatives to procure or implement. While each of the alternatives can be appropriate on technical grounds, LCCA can help to determine the item that will ensure the least whole of life cost. Traditional ‘Cost-benefit’ analysis is an alternative to LCCA, however, it is applicable more in short term projects or investments. In contrast, LCCA is a comprehensive tool and can be adopted for economic assessment of periodic road maintenance works (8). LCCA has proven to be an important tool for economic analysis of road maintenance work. The conceptual life cycle cost model presented in Figure 1, describes the scope of investment in road network management. Here the cash flow or investment in road network management has been plotted over the effective life cycle. The beginning of the life cycle of a road pavement is considered as a major renewal or new build and involves a large initial investment. The road pavement, then requires routine maintenance work and the costs associated with that are plotted over time. Usually the routine maintenance cost increases over time and may involve a number of heavy patches. At this point the road pavement requires refurbishment work that may involve resealing or dig out repairs. This refurbishment work is targeted to extend the life cycle of the road pavement and reduce the routine maintenance costs (Figure 1). However, the road
pavement eventually reaches its end of life cycle when it requires structural treatment which
indicates the effective life span of the road pavement (Figure 1). The effective life span may be
more or less than the design or expected life (generally 25 years) of the road pavement (28).

Road network management in NZ involves a large amount of investment of public funds. In
order to ensure the optimum use of the public funding, any road maintenance work ideally has to
be the least cost option for the road controlling authorities. The LCCA analysis of road renewal
works will take into account the initial construction cost, user costs, future agency and future
maintenance cost as well. The future expenditures need to be predicted based on the historical
trend of the actual maintenance costs. There are a number of indicators used for LCCA analysis,
however, the Net Present Value (NPV) and the Economic Indicator (EI) have been used for this
study. These indicators are used by NZTA for all of its major investment in road network
management (8).

**Net Present Value (NPV)**

Net present value is the difference between the discounted present value of costs or investment
for two different treatment options over the life cycle of a road pavement. If A and B are the
two different investment strategies or treatment options of a road pavement renewal, then the
NPV (choosing B over A) will be the difference between the discounted total present values
over a specific time period.

\[
\text{NPV} = (\text{PV Cost B} - \text{PV Cost A})
\]

Equation 1 (8, 21)

Here PV= Total present value of costs or investment and can be calculated from
Equation 2.

\[
\text{PV} = \sum_{t=1}^{T} \frac{(C_t)}{(1+r)^t}
\]

Equation 2 (8, 21)

Here C= Total cost or investment in time period T
T = Total time period or life cycle (30 year)
r = Discount rate
n= year of expenditure or investment (1 to 30)

A positive NPV indicates that the treatment A is economically advantageous compared to B.
Whereas a negative NPV indicates the rejection of investment strategy A. NZTA use NPV as a
tool for economic analysis to help identify the renewal options with the minimum whole of life
cost (8). Although NPV can provide an indication of the cost saving, NZTA has introduced a
new Economic Indicator (EI) tool. The EI, along with the NPV, can be used to determine the
economically justified treatment in the road network maintenance (8).

**Economic Indicator (EI)**

The Economic Indicator (EI) is an economic tool adopted by NZTA relatively recently to ensure
a degree of confidence is achieved from a desired treatment or renewal work. The EI can be
defined as the ratio of the 30 year whole of life cost savings or comparative advantages achieved
for a treatment or renewal work over the cost difference for a shorter period (usually the contract
period) of selecting the option. The NPV is calculated on predicted future cost based on the
historical maintenance costs for any road section. In reality, the predicted cost may be under or
overestimated in calculating the NPV. So even if an economic analysis produces a positive NPV
for a treatment, there is a chance that it may not be the least whole of life cost option. In order to
minimize the risk of false indication from positive NPV, the NZTA included EI in the economic
evaluation process of pavement renewal. Equation 3 describes the EI of selecting option B
compared to option A for a desired project or program.
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Economic Indicator (EI) = \[
\frac{\text{NPV}_{\text{year 0-39 Option B}} - \text{PV}_{\text{year 0-33 Option A}}}{\text{PV}_{\text{year 0-33 Option B}}}
\]

Equation 3 (8)

Here x= 7 years based on the period of the NoC contract and reasonable life for a reseal holding treatment (8).

Option B is the minimum treatment and option A is the preferred treatment or renewal. The numerator in Equation 3 is the net present value or whole-of-life cost savings of the treatment. The denominator is the cost savings offered over the contract period. It also reflects the cost saving of choosing not to implement or to defer the treatment for the contract period (7 years).

In order to be economically justified, the pavement renewal needs to reflect a positive NPV along with a minimum EI. The NZTA requires an EI value within the range of 0.8 to 2 for any pavement renewal program to be economically justified (8).

METHODOLOGY

The aim of this research is to utilize life cycle cost analysis of road sections to identify the need for drainage renewal. A case study based life cycle cost analysis methodology has been adopted for this study. Data was collected from the West Waikato (South) network in NZ. The sites were selected from the priority list originally developed based on the output or prediction of the deterioration modelling software. In NZ, Deighton’s Total Infrastructure Management System (dTIMS) has been adopted as the pavement deterioration modelling tool. This tool utilizes the World Bank’s deterioration model, however, they have been calibrated to suit the weather, traffic, and materials in NZ (30). Six road sections out of the priority list of rehabilitation sites have been selected for this study. To rationalize the investment in drainage renewal, the economic analyses of those sites have been presented.

The current economic analysis (8) developed by NZTA requires the comparative study of three different treatment strategies. Usually the options for pavement renewal or treatment are specified as ‘Do minimum’, ‘Do something’ and ‘Full renewal’. Here the ‘Do minimum’ indicates maintaining the current regular maintenance without any major treatment. Whereas the ‘Do something’ option includes some major treatment (patching or localized dig out repairs) instead of full renewal. Full renewal of the road pavement includes either overlay or in-situ stabilization based on the forensic investigations from coring and Falling Weight Deflectometer (FWD) tests. These three maintenance strategies are economically assessed based on their life cycle cost analysis using the tools of NPV and EI.

The drainage renewals of those sites are economically evaluated based on the NPV and EI values. ‘Full renewal’ and ‘Do minimum’ were the strategies adopted for the drainage renewal. The ‘Do minimum’ option of the drainage renewal does not involve any major investment in drainage rather it indicates the regular drainage maintenance such as clearing vegetation and, reshaping unlined water channels. The cost model was developed from historical expenditure data obtained from the Road Assessment and Maintenance Management (RAMM) database. The model has been developed based on the pavement, surfacing, and shoulder maintenance costs of the selected sites in the network. The model is generally used for planning and design of road renewal works in the network. Details of the formation of the cost model are beyond the scope of this paper. Once the cost model was developed, the rest of the economic analysis was conducted according to the process flow chart (Figure 2) developed by NZTA for economic evaluation of road renewal works (8).
Figure 2: Framework for Economic Analysis of Drainage Renewal developed by NZTA (8).

For economic evaluation of drainage renewal, all of the steps in Figure 2 were not required. The following tasks were conducted for economic analysis of drainage renewal works in the selected case studies:

- Calculate the NPV’s for both the ‘Full renewal’ and ‘Do minimum’ options of the drainage renewal work. Here the renewal of the pavement is included in both the analyses. However, the maintenance costs have followed a different cost model based on previous experience of road pavements with or without drainage;
- If the drainage renewal work does not yield a positive NPV, a more cost effective investment in drainage was also considered;
- The EI is calculated and analyzed to rationalize the investment and to identify the least cost option from a whole of life cost perspective;
- If the drainage renewal work achieves a negative NPV or positive NPV with an over estimated EI, the whole process needs to be revisited and, finally, discarded if the values remain the same.
RESULTS AND DISCUSSION

The drainage renewal sites selected for the case study range from flat rolling ground to rugged hilly terrain. There are side hills, natural streams, and bush areas beside the sites, thus making them particularly vulnerable to moisture induced failure. These case studies were selected originally based on the deterioration modelling output. The drainage renewal needs were rationalized based on the guidelines adopted by NZTA (8, 29). The current guidelines require intervention with some form of drainage measure in sites with the symptoms presented in Table 1.

Table 1: Guidelines for Selecting Drainage Renewal Works (8, 29)

<table>
<thead>
<tr>
<th>Priority</th>
<th>Symptoms of the Sites Selected for Drainage Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visible surface water near the edge of seal and null or non-functional drainage measures;</td>
</tr>
<tr>
<td>2</td>
<td>Outside wheel track shows premature failures in the form of rutting or shear. Side drains are not adequate (less than 400 mm deep and 2.0 m offset from the edge of the seal);</td>
</tr>
<tr>
<td>3</td>
<td>Programmed for resurfacing due to asset preservation level (Extended flushing or threshold texture);</td>
</tr>
<tr>
<td>4</td>
<td>Any changes in land use causing frequent inundation or saturation of ground on the side road; and,</td>
</tr>
<tr>
<td>5</td>
<td>Inadequate side drains (less than 400 mm deep and 2.0 m offset from the edge of the seal) though not showing any symptoms of premature failure.</td>
</tr>
</tbody>
</table>

Based on the guidelines (Table 1) provided by NZTA, the initial sites were identified and scrutinized for the required treatment or drainage needs. Currently, the following drainage measures (Table 2) have been adopted by NZTA for their network maintenance works. These drainage measures are not exhaustive, however, being rationalized for the major pavement types and highway network in NZ.

Table 2: Drainage Measures adopted by NZTA for Network Maintenance (8, 29)

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Drainage Measure</th>
<th>Scope of the Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Subsoil Drainage</td>
<td>Major drainage renewal works in the form of installation of sub-soil drain along with manholes for temporary storage of water. This measure is targeted to the sites where subgrade water is hampering the structural integrity of the road. Usually selected for those sites with natural constraints on side-slope and storm water channel.</td>
</tr>
<tr>
<td>2</td>
<td>Reform unlined surface water channels</td>
<td>Maintenance of existing surface water channels through the reshaping of unsealed shoulders, side slopes, and longitudinal regard of storm water channel. Usually done on those sites where water does not drain away from the surface or pavement layers.</td>
</tr>
<tr>
<td>3</td>
<td>High Lip Removal</td>
<td>Minor drainage measure to remove the build up material on the unsealed shoulder or side slope over time, which is preventing the water drainage from the surface.</td>
</tr>
<tr>
<td>4</td>
<td>Clearing and Regrading of Side Drains</td>
<td>Another minor drainage work that includes removal of vegetation, debris and slumps obstructing the drainage of surface water. Often this form of obstruction to drainage causes the risk of flooding and aquaplaning.</td>
</tr>
</tbody>
</table>
The major forms of drainage measures adopted for road network maintenance in NZ are presented in Table 2. These forms of drainage measures are selected by NZTA for low to moderate volume rural roads which comprises the major part of the highway network in NZ. The subsoil drainage is the only major form of drainage measure (Table 2) that has been considered for the case studies.

**Drainage Renewal Works**

The drainage renewal programs are aimed at extending the life of the road pavements of the rehabilitation sites by draining water off the surface and from within the pavement layers. For the majority of sites, installation of subsoil drains has been selected to improve the subsurface drainage, and to reduce the risk of premature failure of the road pavement. The main drivers of the drainage renewal programs are:

- To alleviate the presence of stagnant moisture on the surface, near the edge of the seal;
- To reduce the asset whole of life costs;
- To increase the life span of the road pavements through improvement of sub-surface drainage;
- To replace the drainage facilities that are not routine in nature;
- To reduce the risk of premature failure through the shear and permanent deformation due to moisture in the pavement formation;
- To ensure draining of water from the shoulders and the edge of the pavements that usually causes increased rutting, flushing and shear failure in the outside wheel track;
- To prevent the pumping and blistering effects in the surface layer especially at cut or box cut sections by lowering the ground water table; and,
- To improve the efficiency of existing drainage measures through installation and replacement of existing kerb and channel, sub-soil drains and manholes.

A brief outline of the drainage renewal works selected for case studies are presented in Table 3.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Drainage Measures</th>
<th>Reasons for Drainage Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>Replace 400m of kerb and channel, upgrade culverts and install 350m of subsoil drain.</td>
<td>Poor/ineffective existing drainage contributing to shear failure of the pavement. Kerb and channel require lifting to level with the overlay.</td>
</tr>
<tr>
<td>(B)</td>
<td>Replace 350m of kerb and channel and install another 150m, raise 3 catch pits and install the subsoil drain.</td>
<td>Poor/ineffective existing drainage contributing to shear failure of the pavement. Kerb and Channel require lifting to provide for overlay.</td>
</tr>
<tr>
<td>(C)</td>
<td>Install 300m of subsoil drains</td>
<td>Poor/ineffective existing drainage contributing to surface flushing and subgrade softening.</td>
</tr>
<tr>
<td>(D)</td>
<td>Install 500m of subsoil drains</td>
<td>Poor/ineffective existing drainage contributing to subgrade softening and base shear failure.</td>
</tr>
<tr>
<td>(E)</td>
<td>Install 285m of subsoil drains</td>
<td>Poor/ineffective existing drainage contributing to subgrade softening and base shear failure.</td>
</tr>
<tr>
<td>(F)</td>
<td>Install 400m of subsoil drains, 150m of kerb and channel and a new cross culvert</td>
<td>Poor/ineffective existing drainage contributing to surface flushing and subgrade softening.</td>
</tr>
</tbody>
</table>

Note: Sub-soil drains are installed as per NZTA’s design guideline (31)
The drainage measures implemented are limited to either installing kerb and channel or subsoil drain and manholes. These roads are built with natural-earthen side drains, however, the subsoil drain is installed to intercept the water entering into the pavement layers from the shoulder or side hill. The reasons for drainage renewal mentioned in Table 3 reflect that most of the sites were selected based on criteria 1 and 2 from Table 1. So the drainage renewal programs were selected based on the criteria set by NZTA and were expected to have a positive NPV and EI during the economic analysis.

In order to complete the LCCA of the road sections based on the expenditure of drainage renewal, the estimated drainage renewal costs are essential. Figure 3 presents the distribution of pavement rehabilitation and drainage renewal cost. Overall the drainage renewal costs are within the range of 10 to 60 percent of the pavement renewal cost (Figure 3). The percentage of drainage renewal costs are high for sites B and F, because the pavement renewal treatments are either in-situ stabilization or thin overlay and are therefore relatively inexpensive. In addition, the drainage renewal costs are comparatively high due to the expensive nature of kerb and channel installation. The next tasks were to develop the cost model and to implement the LCCA for drainage renewal.

Development of the Cost Model

Maintenance cost models for the road network were developed as a part of the annual planning process. The developed cost models are the prediction tool for LCCA of the road section during NPV analysis. Historical maintenance cost data of a number of treatment sites were collected from the RAMM database. The sites were selected based on the knowledge, experience and similarity in performance of those sites selected for case studies.

Maintenance cost models were developed for pavement failure and surface failure as described in the following sections. The models are based on the actual historical expenditures of road sections before and after pavement or surface treatments. While it would be highly desirable to develop cost models explicitly for the drainage renewal (before and after), this was not possible due to unavailability of suitable data. However, cost data was available where drainage improvements were conducted along with the renewal of road pavement.

Consequently, the case study adopted the economic analysis of drainage renewal programs in conjunction with pavement renewal and resealing. While the aforementioned models include costs for the pavement maintenance, the shoulder maintenance cost models (No. 5 and 6 in Tables 4 and 5) also include the variations in drainage maintenance cost before and after the pavement and drainage renewal.
A. Maintenance Cost Model (Pavement Failure)

The maintenance cost model presented in Table 4 and in Figure 4 represents the sites where pavement failure like shear, rutting, and cracking triggers the pavement and drainage renewal. In order to develop the cost model, three major types (pavement, surface and shoulder) of maintenance costs have been included. The pavement costs include the maintenance- patching, reshaping of pavement, dig out repair and minor stabilization. The maintenance cost related to surface defects such as texture, flushing, and crack sealing are included in surface costs. The shoulder costs include resealing, reshaping of the shoulder, as well as minor environmental and drainage maintenance work.

Table 4: Maintenance Cost Model (Pavement Failure)

| 1. Pavement maintenance cost before renewal | \( y = 2467.9 e^{0.4369x} \) |
| 2. Pavement maintenance cost after renewal  | \( y = 651.49 e^{0.4823x} \) |
| 3. Surface maintenance cost before renewal  | \( y = 142.56x - 291.85 \) |
| 4. Surface maintenance cost after renewal   | \( y = 353.14x - 769.39 \) |
| 5. Shoulder cost before renewal             | \( y = 147.25x - 290.12 \) |
| 6. Shoulder related costs after renewal     | \( y = 223.62x - 541.2 \) |

Note: Renewal include both pavement and drainage Renewal

In Table 4, \( y \) = Predicted maintenance cost at year \( x \) based on the historical expenditures. The cost models shown in Figure 4, are suitable for prediction of pavement maintenance cost before and after pavement and drainage renewal of any road section (No. 1 and 2 of Table 4).

Figure 4: Maintenance Cost Models (Pavement Failure)

The \( R^2 \) (0.9245 and 0.7577) values (cost models in Figure 4) demonstrate a good correlation between the model and the actual historical expenditures in maintenance.

B. Maintenance Cost Model (Surface Failure)

Another common mode of failure in NZ is the loss of skid resistance and texture due to flushing, and bleeding. These are surface failures and significant in NZ. Every year road controlling authorities run the high speed SCRRIM (Sideway-Force Coefficient Routine Investigation Machine) over the network to measure the skid resistance and macro-texture of the road surface. Road sections with the coefficient of friction and macro-texture below the threshold level are selected for visual investigation. Road surfaces below the threshold level are at risk of wet skid crashes, aquaplaning and other moisture damage (32). The cost models presented in Table 5 and Figure 5 are suitable for sites selected for pavement drainage renewal based on the surface defects or failure.
Table 5: Maintenance Cost Model (Surface Failure)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pavement related costs prior to renewal  ( y = 630.78 e^{0.4607x} )</td>
</tr>
<tr>
<td>2.</td>
<td>Pavement maintenance cost after renewal  ( y = 186.02 e^{0.3573x} )</td>
</tr>
<tr>
<td>3.</td>
<td>Surface maintenance cost prior to renewal  ( y = 3461.3x - 5334.6 )</td>
</tr>
<tr>
<td>4.</td>
<td>Surface related costs after renewal  ( y = 142.56x - 291.85 )</td>
</tr>
<tr>
<td>5.</td>
<td>Shoulder maintenance cost prior to renewal  ( y = 223.62x - 541.23 )</td>
</tr>
<tr>
<td>6.</td>
<td>Shoulder maintenance costs after renewal  ( y = 147.25x - 290.12 )</td>
</tr>
</tbody>
</table>

Note: Renewal includes both pavement and drainage.

Figure 5: Maintenance Cost Models (No. 1 and 2 of table 5) (Surface Failure)

The two models presented in Figure 5 are applicable to the prediction of pavement maintenance costs before and after the renewal of the road pavement. The \( R^2 \) values (0.6361 and 0.5486) of the cost models demonstrate a moderate correlation between the model and the actual historical expenditures in maintenance.

Economic Analysis

The economic analysis of the drainage renewal programs has been conducted based on the LCCA method adopted by NZTA (8). NPV and EI are the two indicators used to compare the ‘full renewal’ option with the ‘do minimum’. In both cases, the drainage works have been considered along with the pavement renewal. However, the maintenance cost varies due to the difference in the cost model. The NPVs have been calculated based on a 30 year analysis period \((t = 1 \text{ to } 30)\) and 6% \((r \text{ in Equation } 2)\) discount rate, as recently adopted by the NZTA (8). The EI has been calculated based on Equation 3 using 7 years \((x \text{ in Equation } 3)\) as the remaining contract period for the PSMC network. The NPVs and EIs of the selected projects for drainage renewal have been presented in Table 6.

Table 6: NPVs and EIs of the Selected Sites for Drainage Renewal

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Do Minimum (Discounted Total Cost in NZD) 30 Year</th>
<th>Drainage Renewal (Discounted Total Cost NZD) 30 Year</th>
<th>NPV (NZD)</th>
<th>EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>493,154.00</td>
<td>475,728.00</td>
<td>17,426.00</td>
<td>0.12</td>
</tr>
<tr>
<td>(B)</td>
<td>315,626.00</td>
<td>274,106.00</td>
<td>41,520.00</td>
<td>0.18</td>
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<td>(C)</td>
<td>164,953.00</td>
<td>152,339.00</td>
<td>12614.00</td>
<td>0.22</td>
</tr>
<tr>
<td>(D)</td>
<td>547,102.00</td>
<td>490,573.00</td>
<td>56,529.00</td>
<td>0.26</td>
</tr>
<tr>
<td>(E)</td>
<td>173,766.00</td>
<td>163,649.00</td>
<td>10,117.00</td>
<td>0.11</td>
</tr>
<tr>
<td>(F)</td>
<td>239,443.00</td>
<td>201,650.00</td>
<td>37,793.00</td>
<td>0.85</td>
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</tbody>
</table>
The NPVs of the renewal projects (in Table 6) indicate the acceptance of the full drainage renewal compared to minimum maintenance option in terms of discounted total value. The full drainage renewal is therefore the least cost option for the whole life (analysis period). However, the EI values (Table 6) do not reflect the economic efficiency in terms of the full renewal. NZTA requires the EI values to be within the range of 0.8 to 2. Though all of the sites yielded a positive NPV, only site F produced an EI greater than 0.8. The EI values for other sites do not fulfill the NZTA requirements (8). This may be due to the short contract period remaining (7 years) and relatively large investment of full renewals at the beginning of the analysis period.

CONCLUSION

The outcome of the study is encouraging and indicates a positive gain in economic efficiency from the investment in drainage improvement. This study is the first step towards managing drainage on a road network in a more holistic manner, by identifying the costs and benefits of undertaking the appropriate investment. The comprehensive economic and efficiency analysis introduced by NZTA to prioritize the drainage investment is a new step towards the new maintenance investment strategy. The current investment framework in road asset management has incorporated a shift in risk towards the road controlling authorities. As a consequence of that, increased drainage investment in road asset management has triggered the necessity for a holistic approach to economic analysis. Road pavement renewal works are commonly required to be economically justified. However, this study shows the utilization of economic tools such as the NPV and EI for rationalizing the targeted drainage investment in road asset management.

The NPV and EI values of a number of road sections have been presented based on life cycle cost analysis using the maintenance cost model. Overall the NPVs of the road sections indicated the viability of the investment. The EI values were relatively low compared to the requirement (0.8 to 2.0) of NZTA however, they are greater than zero. In order to improve the EI values, NZTA suggested reviewing the ‘Do minimum’ option, which was not conducted for this study. Because the impact of reviewing the costs of ‘Do minimum’ option would have very little effects on EI values and the NPV values will be abnormally high. Mostly, the EI values are relatively low due to the short contract period (7 years) remaining for the network.

As part of further research, the next step is to monitor the road pavement performance, in order to compare with the outcome of the economic analysis. The long term monitoring of the road sections can help in rationalizing drainage investment in the road network. If the performance of the road network indicates that the service life of the road pavement has increased due to drainage investment, then the economic analysis can be justified. The LCCA of the road sections include the prediction of future maintenance costs based on the historical maintenance of the network. The actual maintenance costs may vary and result in a different NPV and EI. So there is scope for further research to compare the actual performance of the road section and the economic justification presented in this study.

ACKNOWLEDGEMENT

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REFERENCES


