

Network Implementation of an Innovative Structural Remaining Life Model

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ABSTRACT

The structural condition and the long-term replacement needs of the Roads and Traffic Authority (RTA) pavement network have traditionally been determined through indirect methods that did not measure the load carrying capacity of the pavement. The approach included the use of a functional life model and the use of terminal surface condition measures such as roughness, cracking and rutting.

Most of the RTA network comprises of flexible pavement types. The assessment of flexible pavements presented in this paper utilises a new procedure that assesses the load carrying capacity of the pavement through measuring deflections in combination with pavement type, climatic and drainage data. The paper builds on project outcomes from an initial ARRB/RTA partnership which produced a validated procedure for static estimation of pavement remaining structural life using models for estimating structural condition.

The paper explains the strategic view of the network based on the new model which determines the sustainable rate of rebuilding over the life of the pavement asset. The rate of rebuilding is used to set the funding needs that can be reported to both senior management and external stakeholders. The paper will also evaluate the short term structural needs that will ensure accessibility and safety for road users.

INTRODUCTION

The NSW road network (183 134km) represents a significant public asset providing commuters, travellers, business and freight access across the State. The road system is divided into four categories; 17 919km of RTA managed State Roads, 2946km of RTA managed regional and local roads, 18 486km of council managed regional roads with RTA grant funds and 143 783km of council managed local roads. This paper relates to the flexible pavement component of the first two categories (20 865km). The majority of the pavements on the state road network are defined as flexible, 90% of the network. This represents a length of 17 607 carriageway kilometres of flexible pavements. The road network is divided into six regions for administrative and asset management purpose. The regions are called Western, South West, Hunter, Northern, Southern and Sydney. The first two are predominately rural; the later four are coastal and include large urban centres. Sydney is mostly urban.

The RTA traditionally determined the structural condition and long term replacement needs of the pavement network via indirect methods, such as the functional life model. Indirect methods previously applied were based on empirical assessment of the pavement, and terminal surface condition measures such as roughness, cracking and rutting. The RTA did not measure the load carrying capacity of the pavement. The structural condition and the long term replacement needs of the pavement network are best determined through measuring the load carrying capacity of pavements. The evaluation of load carrying capacity of the pavements has progressed from the

initial qualitative measures through to semi-quantitative evaluation by utilising empirical assessment and on to a qualitative procedure of the remaining life assessment.

Structural capacity is a key contributor to retained value, capacity and quality of the pavement network. The sustainability dimension within the RTA's Strategic Vision requires that the rate of pavement rebuilding match the rate of consumption. At a unit rate of between \$0.75 and \$2.00M per carriageway kilometre, a 1% variation in the rate of rebuilding represents approximately \$200M per annum, with significant impacts on the RTA's budgetary capability. Therefore a better understanding of the sustainable structural capacity needs of the network will enable better strategic planning of the future pavement funding needs.

Previous Assessments of Structural Life and Condition of Pavements

The functional life model estimates the actual functional life beyond the design life of the pavements by considering climatic factors and expected usage. The modelling showed a maximum life of 73 years, 4% of the State Roads network has a functional life of less than 30 years, 39% of the network has a functional life between 30 and 39 years, 44% of the network has a functional life between 40 and 49 years and 13% of the network has a functional life of 50 years or greater

Sensitivity analyses of up to 15% indicate the rate of pavement rebuilding needs to be at least 1.75% with a projected optimum that varies in 5-10 year increments between 1.7% and 2.7% over a 30 year period with an annual average of 2.45% per annum. This is close to the previous preliminary models of 3% and 2.75% underpinning the previous RTA Infrastructure Maintenance Plan 2000/05 and Infrastructure Maintenance Plan 2003/04 to 2007/08. A key component of the functional life model's more optimistic forecasts is the projected benefit of the low cost risk mitigation strategies for roadside drainage, road widening and resurfacing (waterproofing).

A condition based approach used terminal levels of roughness, cracking and rutting for assessing the "poor pavement", with a combination of the measures having been used to indicate the pavements that are structurally distressed. These indirect measures of condition have been the best method to approximate structural concerns on the network without directly measuring the load carrying capacity. In 2006, approximately 14.7% of the network was deemed to be in structural distress using the traditional surface condition assessment. This is significantly more than the remaining life results.

The technical process discussed in this paper to evaluate the remaining life was based on RTA funded research conducted by ARRB Group.

METHODOLOGY

The process of determining flexible pavement remaining life involves two separate phases, one for the pavement and the other for the traffic loading. Both of the phases need adequate quality information to ensure the reliability of the predicted remaining life. This process is referred to as the

STEP process (1). Figure 1 outlines the data inputs, analyses and outputs from the process.

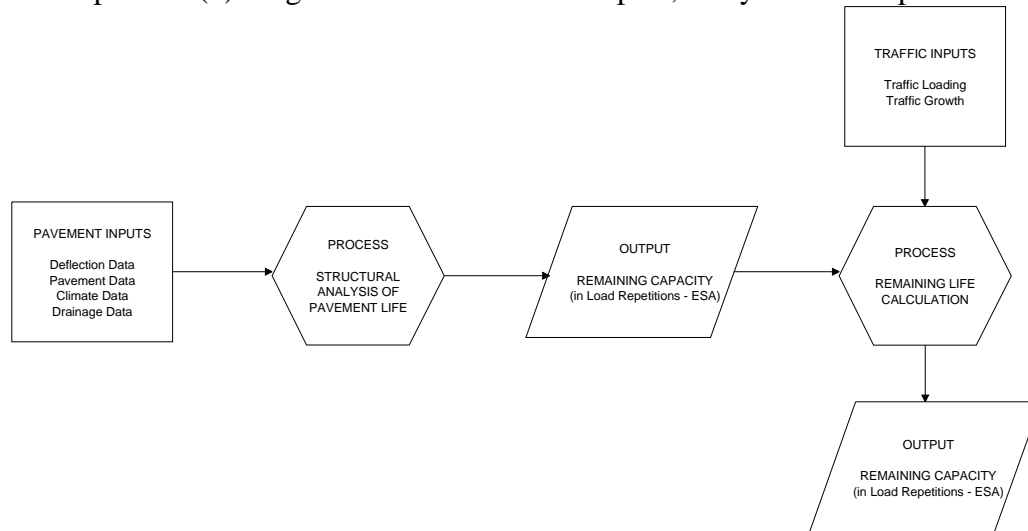


FIGURE 1 Process Flowchart for Determining Remaining Life

The pavement input parameters of the STEP system are the pavement type, load-deflection bowl, climate data and drainage data. The traffic input parameters of traffic loading and growth rate are used to calculate the future usage.

Two climatic condition scenarios were considered to incorporate the possible impacts of global climate change and its impact on pavement condition modelling and remaining life. The two scenarios were the historical climate that was based on a substantial set of long term climate data, and the 2006 climate. The historical climate data was used to predict the remaining life should the long term climate conditions prevail. The 2006 climate was used to model and predict the remaining life if that climate was reflected in the future. The 2006 climate was generally much drier for New South Wales than historical trends. In this paper the 2006 climate is referred to as the Dry Climate.

Analysis

Two types of analysis have been undertaken after the remaining life condition was determined for the network; the sustainable rate of pavement replacement and the short term structural needs for *pavements of structural concern*. The analyses allow comparison with functional life and surface condition methods for calculating these parameters.

The sustainable rate of replacement of the pavement is based on assessing the remaining life predictions in the first 20 years, which are more reliable than longer term predictions. The rate of replacement is best calculated at 10 years or less remaining life. This value was selected due to the uncertainty of traffic volumes and loadings, and heavy vehicle regulations beyond a 10 year period.

The term *pavements of structural concern* has previously been used (2) to define an investigatory condition for the pavement. For the purposes of this work, *pavements of structural concern* refers to the level when the pavement performs in an unpredictable nature due to near or structural failure. In terms of metrics, *pavements of structural concern* include all pavements predicted to have three years or less of remaining life. This level was chosen due to the unpredictable nature of the future performance of the pavement once this level is reached, both structurally and from a serviceability perspective.

Sample Selection

A sample of the flexible pavement network was analysed rather than full network coverage of the deflection data collection in order to deliver the project outcomes within a reasonable timeframe. This was due to the speed at which deflection testing with a falling weight deflectometer (FWD) could be carried out, along with the additional sampling constraints of the deflection measuring device only providing data for a point location.

Previous network deflection testing with a FWD had been completed for assessment of remaining life on a part of RTA network in Sydney Region. In this testing a 100 metre interval between test locations was used. This interval sample provided a reasonable level of confidence for network wide outcomes and thus was used in this project.

The selection of pavement samples was based on identifying representative lengths of pavement. The lengths of the samples ranged between 10 and 45km, with the typical length being about 20km. The approach provided a sound sampling regime and facilitated the incorporation of the local knowledge in the selection of the representative lengths. An analysis of the sample indicated that the sample has an urban bias. As a result there is more confidence in the remaining life predictions for urban type pavements. This is highlighted by 27% of the Sydney network (predominately urban) being sampled and only 5% of the Western network (predominately rural) being sampled.

The methodology used to develop a network wide remaining life distribution included:

- selection of sample lengths based pavement condition, pavement type, traffic loading and climatic conditions
- the assignment of a length of each regional network for each sample length
- the determination of the remaining life predictions and distribution for each sampling length
- the combining of sample length distributions based on the representative length of the network

INPUT PARAMETERS

The input parameters included deflection, traffic loading, climate, pavement type and drainage. The most significant input in the determination of remaining life was deflection data. This data is used to estimate the configuration and the remaining capacity of the pavement. The deflection input for the remaining life methodology was based on the FWD as the data collection device. The FWD was selected due to its proven track record for the collection of repeatable, accurate, precise and meaningful data. The data produced by the FWD is significantly less influenced by the geometry of the mechanical data collection device. It has higher accuracy and precision. This higher data quality has allowed some very useful subtle meaning to be reliably interpreted from the shape of the FWD deflection bowl.

The FWD data used for the remaining life analysis is: D0 – peak deflection under the load, D200 – deflection at 200mm from the load, D900 – deflection at 900mm from the load, Load – actual load for the measured deflections, used to normalise the deflections to 700kPa, Surface temperature – used in the adjustment of the asphalt properties of the pavement, Date – used for the temperature and moisture adjustment of the tested pavement and Time – used in conjunction with the temperature for adjustment of the tested pavement.

The remaining capacity was determined from the pavement aspect of the procedure and compared with the future traffic loading needs. This allowed the period until the pavement reached a structurally terminal condition to be calculated. This was then defined as the remaining life. The

traffic information used for the remaining life assessment was the traffic loading in equivalent standard axles (ESA) for a defined period, the annual growth rate and the year of collection of the data. For this project, the input traffic loading parameter was ESA per day. The traffic loading calculations were based on the use of 12 bin classification data for the sampling location. The classification data was used in combination with representative weigh-in-motion data to determine the traffic loading. It was important that the traffic loading used was only for the lane in which the deflection testing was collected; to give a realistic representation of the remaining life. Thus the classification data must be on a lane-by-lane basis to be suitable for use.

The location of the pavement was deemed important in relating the climate to the performance of the pavement. The climate data was used to adapt the collected deflection data for moisture and temperature effects. The data was adapted for; the time testing is conducted in the day (adjustment of temperature effects for asphalt layers), the month testing is conducted (adjustment of temperature effects for asphalt layers and moisture effects on granular materials), and the recent moisture effects compared to long term effects (adjustment to account for long term climate condition rather than recent weather effects). For each deflection testing location, the closest, representative weather station was used in the remaining life assessment. The weather station information was sourced from the Bureau of Meteorology (3).

The remaining life modelling requires a generic pavement type as an input. This allows the model to understand the differing performance of types of materials within the pavement layers. The pavement type was defined in terms of the combination of asphalt, granular and stabilised materials. The source of the pavement type information was the RTA's Road Asset Management System (RAMS).

Drainage information used included the type and condition of the drainage. The information was combined to determine a drainage effectiveness factor that was utilised in the remaining life modelling. Currently there is not any data readily available that quantifies either the type or condition of the drainage for the RTA network. For the remaining life assessment, a fair condition of drainage effectiveness was applied for all locations.

STRUCTURAL PREDICTIONS

The validation of the remaining life was carried out on all sampling lengths from the RTAs South West region (14 lengths totalling 248km). Two forms of validation were undertaken. The first involved a desk top evaluation of rated condition conducted by the Road Maintenance Planner in the region comparing the remaining life for all the tested locations within the length. The evaluation was undertaken on all the sampling lengths within the region. This process showed that there was a strong correlation between the overall rating, specific additional comments and the remaining life predictions. The second validation included a detailed site inspection on half of the sampling lengths. The inspection method combined a drive through evaluation and walking the pavement to assess the condition at specific locations of interest. This validation process showed there was a significant level of confidence in the remaining life results. The two validation processes also provided confidence that network wide outcomes would be a reasonable representation of the structural condition of the pavement.

The remaining life prediction of estimating the load carrying capacity of the pavement is a different approach from the traditionally used indirect measures for evaluating the short and long term structural needs of the network. Figure 2 compares the cumulative distribution curves for the traditional function life model predictions and the new remaining life method.

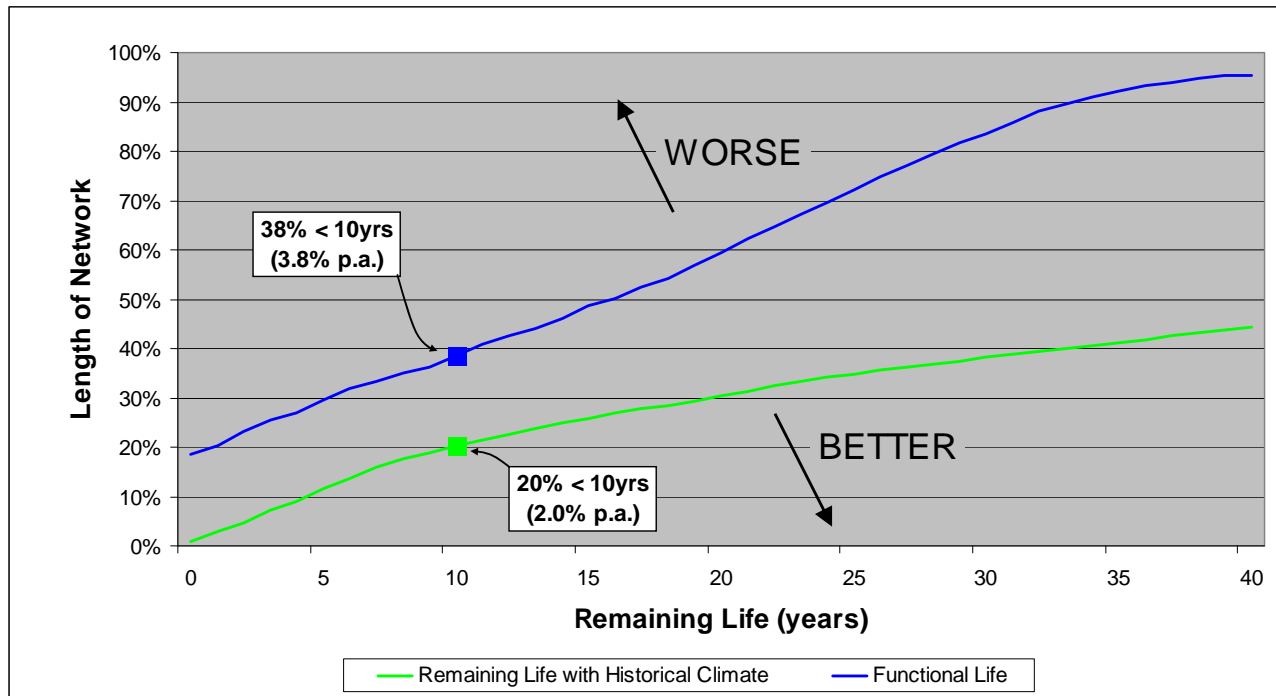


FIGURE 2 Comparison of Remaining Life Methods

There is a significant difference in the curves between the two approaches. The functional life model shows a greater short term need than the remaining life prediction. It also shows almost all the network requiring structural improvement over the next 40 years. The remaining life method shows that a large proportion (approximately 50%) of the network will not need structural improvement for 40 years or more.

The main difference between the approaches is the remaining life method is measuring properties of the pavement whereas the functional life model relies on an empirical assessment basis for determining the pavement life. The functional life model relies on long term average functional lives while not considering the condition of the pavement. Thus the model can not take account of variation in performances along the length of the road, and does not consider the traffic usage or changes in usage over the life of a pavement. The remaining life method is an improved approach as it takes into account the current condition, the future traffic usage and the operating environment of the pavement.

Climate Sensitivity

An important component outcome of the development of the remaining life model was the ability to allow for variations in climate scenarios to be investigated in relation to the remaining life predictions, and to be sensitive to climatic effects. The sensitivity was important to enable the adjustment of the collected deflection data to be transformed to an annualised value through accounting for moisture and temperature effects. The results of the predictions for varying climate scenarios are shown in Figure 3, with the results presented as cumulative distribution graphs for the network. The historical climate scenario shows that there is a reduction in the remaining life across the network compared to the dry climate. The drier climate has the effect of extending the life of the pavement network. The quantification of the effect is demonstrated by looking at the percentage of

the network that has 10 and 20 years remaining life or less, and the variation of the remaining life, as shown in Table 2.

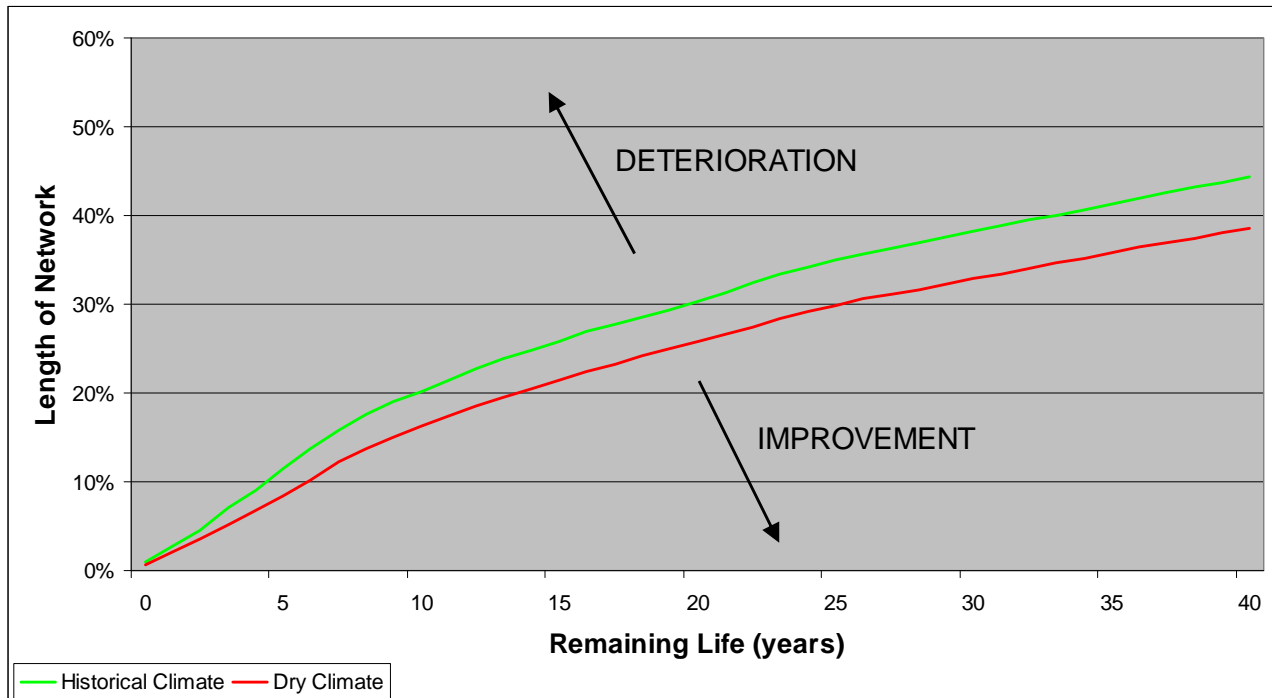


FIGURE 3 Comparison of Varying Climate on Remaining Life Profiles

TABLE 2 Comparison of Climatic Effects on Remaining Life

| Case | Percentage of the Network | | Variation (%) |
|----------------------------|---------------------------|-------------|---------------|
| | Historical Climate | Dry Climate | |
| <= 10 years remaining life | 20.2 | 16.3 | 24 |
| <= 20 years remaining life | 30.4 | 25.8 | 19 |

The analysis shows that the methodology used for remaining life predictions is sensitive to the climatic effects. If a climatic scenario were to investigate a wetter than the historical case, the predictions of life would be reduced, although the magnitude would be governed by the adopted case. Further investigation of the different climatic scenarios was conducted at a regional level to investigate the sensitivity within the remaining life model. Southern, South West and Northern regions were studied. Figure 4 shows the remaining life prediction profiles for each region for both the climate scenarios.

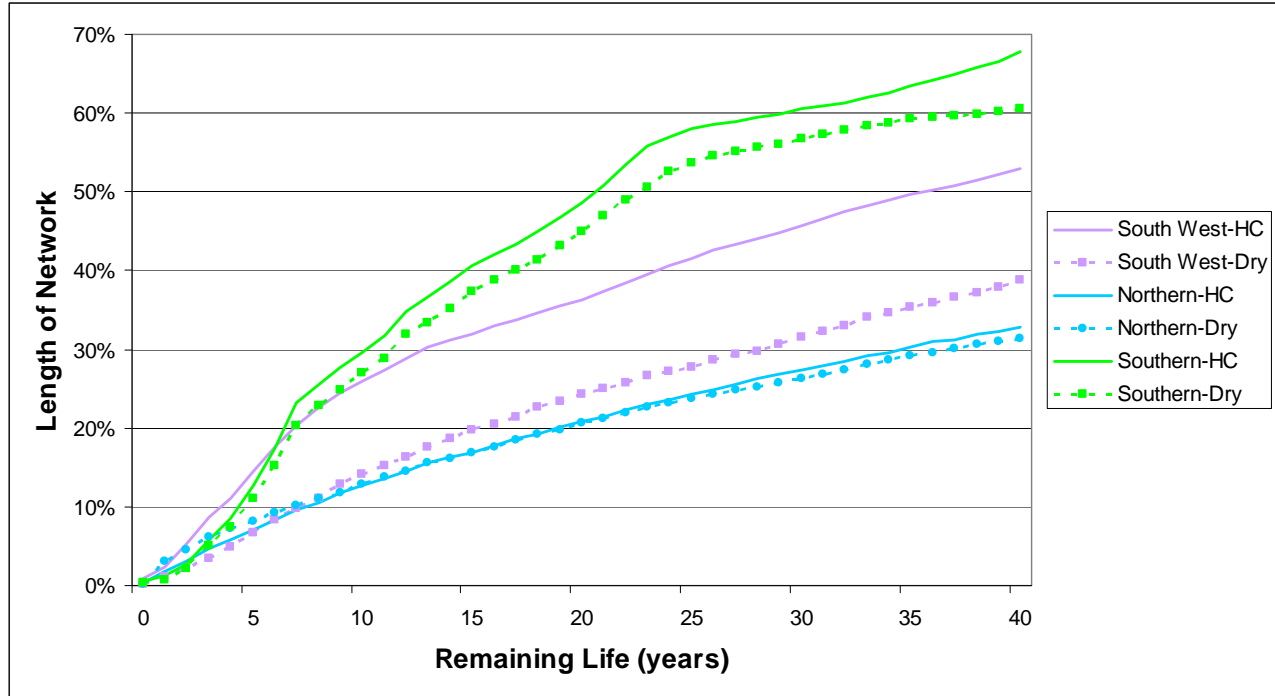


FIGURE 4 Comparison of Varying Climate on Regional Remaining Life Profiles

An analysis was conducted to review the percentage of the network that has 10 and 20 years remaining life or less and undertook a comparison into the network wide outcomes, as shown in Table 3.

TABLE 3 Comparison of Regional Climatic Effects on Remaining Life

| Region | Case | Percentage of the Network | | Variation (%) |
|------------|----------------------------|---------------------------|-------------|---------------|
| | | Historical Climate | Dry Climate | |
| Southern | <= 10 years remaining life | 29.6 | 27.1 | 9 |
| | <= 20 years remaining life | 48.7 | 45.0 | 8 |
| South West | <= 10 years remaining life | 26.0 | 14.2 | 83 |
| | <= 20 years remaining life | 36.3 | 24.4 | 49 |
| Northern | <= 10 years remaining life | 12.7 | 12.9 | -2 |
| | <= 20 years remaining life | 20.8 | 20.6 | 1 |
| State | <= 10 years remaining life | 20.2 | 16.3 | 24 |
| | <= 20 years remaining life | 30.4 | 25.8 | 19 |

The analysis of the regional predictions indicated that there was wide variation in the sensitivity of the remaining life predictions. The sensitivity of the prediction to climate scenarios is shown by the magnitude of the gap between the lines on Figure 4. South West predictions showed the greatest sensitivity between the climate scenarios. This was due to the rainfall levels in South West being significantly lower than mean values (much of the region was drought declared in 2006), along with the pavement types being generally more sensitive to moisture. The predictions for Northern were not overly sensitive as much of the region received close to mean rainfall levels.

The two climate scenarios looked at typical and drier than typical conditions. It is also worthwhile commenting on the likely prediction outcomes if a wetter than typical scenario is modelled. A wetter scenario would reduce the predicted remaining life, with the extent of reduction based on the variance from the typical conditions. The short term implications of the wetter climate is an increase in the quantity of *pavements of structural concern*, while the long term implication in this type of climate change is to increase the sustainable rate of rebuilding. With this greater understanding of the significance of the climate sensitivity on the predictions, care is needed in interpreting the future structural needs based on different climate scenarios.

NETWORK OUTCOMES

Pavements of Structural Concern

The *pavements of structural concern* (those with three years or less of remaining life) describe the immediate or short term structural deficiencies of the network are shown in Figure 5. The remaining life analysis indicates that the *pavements of structural concern* were in the range of 5.2 to 7.1% depending upon the climatic scenario, which represents a network length of between 920 and 1250km.

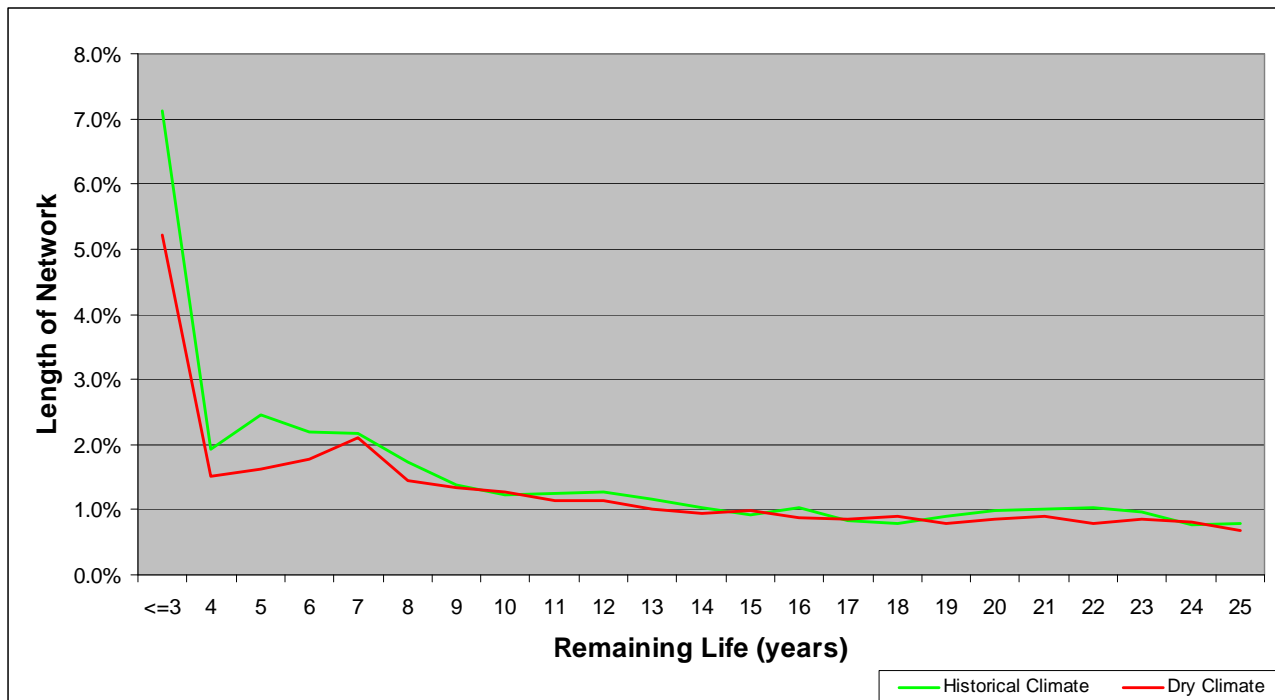


FIGURE 5 Identifying Pavements of Structural Concern

The functional life model indicated that structural deficiency was 18.7%. This process recognised that there are many old pavements on the state network; however investigations as part of this project found that these pavements are not necessarily in a poor structural condition. The surface condition based approach showed that approximately 14.7% of the network was deemed to be in structural distress, primarily due to roughness or cracking conditions. The difference between the remaining life and traditional functional life model (indirect methods) in predicting *pavements of structural concern* is significant. The remaining life predictions provide more realistic evaluation of the short term structural needs as they are based on measuring input parameters directly. The predictions also fit better with the practitioners experience from managing the network. Previous work has also indicated that empirical assessment is not always a good indicator of pavement performance and surface conditions are not always an indication of structural deficiencies of the pavement, but this was the best approach available.

Indicative Rate of Rebuilding

The rebuilding rate of the network predictions over the first 20 years are far more reliable than the later predictions and therefore the value at 10 years was used to determine the rate of rebuilding. This was selected due to the interim nature of the remaining life modelling, the assumptions on the maintenance regime and the difficulty in predicting the long term traffic volumes and loadings, and heavy vehicle regulations. Figure 6 shows the cumulative distribution of remaining life with dotted lines highlighting the predictions at 10 years for each climate scenario.

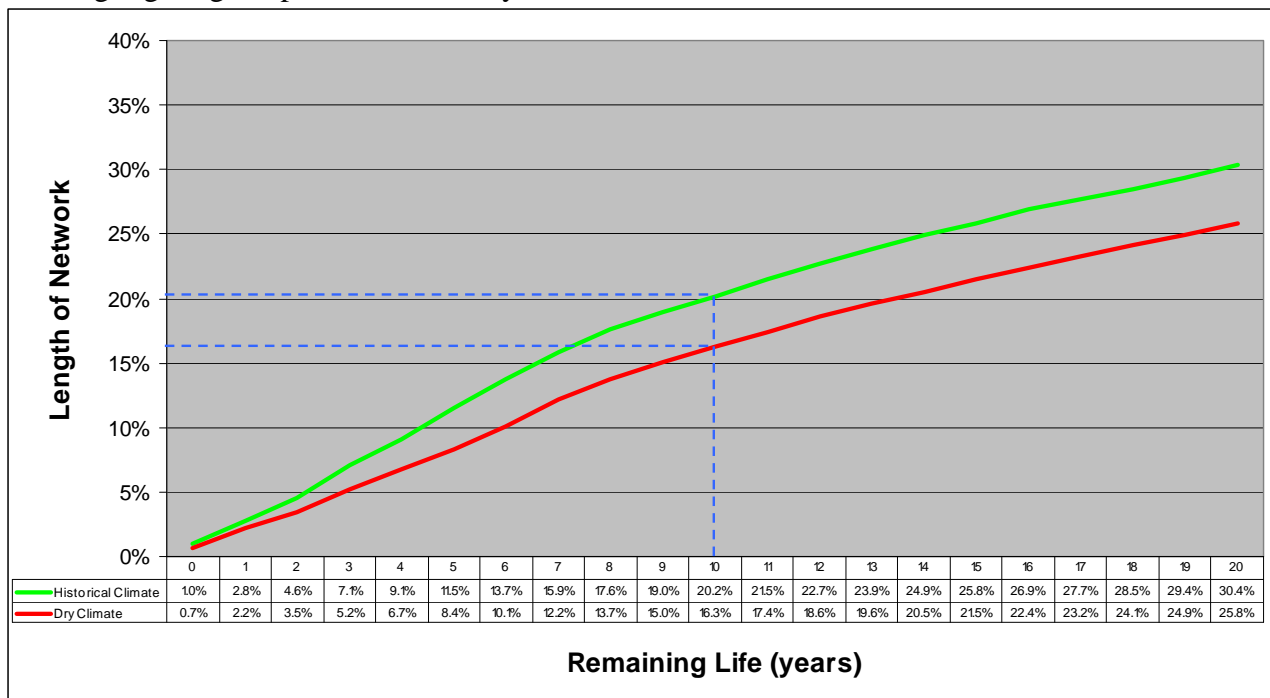


FIGURE 6 Using Remaining Profiles to Determine Rebuilding Rates

Based on the distribution, the rate of rebuilding is 2.02% for the historical climate and 1.63% for the dry climate. The functional life model was also used to predict a rate of rebuilding which was assessed to be 2.45%, although a 50% sensitivity analysis was used in light of the range of uncertain risks associated with the prediction. The predicted value for the 50% sensitivity analysis case was 1.63%. Based on the rebuilding rates that have been calculated, an annualised rebuilding rate needs

to be determined. As the dry climate conditions were extreme, these values should be interpreted as the minimum rate that should be considered with the historical climate being a more realistic guide to the rebuilding needs. It is recommended that the sustainable annual rate of rebuilding for the RTA network be in the range of 2.0%, with a minimum rate of 1.6% over the next 20 years.

CONCLUSION

The paper has demonstrated that the STEP methodology of determining the structural condition of flexible pavement has been utilised to improve the strategic management of the state road network. The move to a methodology that directly measures the capacity of the pavement has been successfully utilised, although the predictions from empirical and surface condition basis have significant differences.

The rebuilding rate recommended that the sustainable annual rate of rebuilding be in the order of 2.0%, with a minimum rate of 1.6% over the next 20 years. In comparison, the functional life model assessed the rebuilding rate to be 2.45%. The reliability of the predictions needs to be viewed in light of the interim nature of the remaining life modelling, the assumptions on the maintenance regime and the difficulty in predicting the long term traffic volumes and loadings, and heavy vehicle regulations.

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