Cautions with Life Cycle Cost Analysis for Optimal Pavement Selection

Arvo Tinni
RFD, BE, FIEAust, AIArbA, CPEng
Tinni Management Consulting
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Abstract

This paper highlights the many shortcomings and likely significant variations in the outcomes of standard Life Cycle Cost (LCC) analysis cost model that is used for comparison of Heavy Duty pavements

It is a technical evaluation of the methodology without referencing any particular pavement type. Attention is drawn to the effect of the likely variations in the input parameters and variations in the final cost models. It suggests the adoption of order of accuracies for the comparison of the results of various analyses of the alternative pavement options.

An overview and illustrations of the non-agreement between various road authorities in Australia are given. These cover issues like:

- difficulty to quantify reliability;
- what the problems are and the likely resultant accuracy; and
- the inconsistency of assessments between States and also some comparisons of the same problems overseas are provided.

This study is based on years of practical experience by the Author, a literature survey and attendance at the Life Cycle Cost Analysis Forum in St Louis, Missouri in April 2009.

Annexures are used to illustrate the differences in estimated timings and quantum of the major maintenance activities in the Maintenance Diaries. A typical Sensitivity Analysis for Discount Rate selection is provided as well as an example of the “Tinni method” of presentation of a model for LCC analysis.

This paper can also be used as a guide for actual project specific LCC analyses.

1. Definition

LCC analysis for road pavements is focused on discrete portion of the Road Asset, rather than the **classical definition:** "LCC is the total cost throughout its life including planning, design, acquisition and support cost and any other costs directly attributable to owning or using the asset".

In the case of roads the discrete costs are construction, maintenance and salvage value. It is assumed that planning, design and acquisition are common to all alternatives and hence are omitted from the calculations.

2. Overview of Life Cycle Costing (LCC) of Pavements

LCC became popular in the 1960s when the concept was taken up by US Government Agencies as an instrument to improve cost effectiveness of equipment procurement. Since then the concept has spread, including into pavement evaluation.

LCC analysis is the methodology for the valuation of estimated deterioration models and the cost of routine and periodic maintenance, repair and rehabilitation.

This paper provides an overview of why we use LCC, how it works and what the current shortcomings are in the methodology adopted by various States.

For any road pavement requirement, be it reconstruction or new, there are always a number of options for a pavement type and for the "money managers" there is the need to know what they are up for up front and in the long term.

To enable these financial comparisons to be made, a methodology called LCC analysis is used. What this involves is the establishment of a benchmark "design life" duration and then comparing the costs of construction, maintenance, salvage values and cost of money for the various pavements, over the "life" period. Some call this process LCC, others - Whole of Life (WoL) analysis.

3. LCC or Whole-of-Life (WoL) Costing?

These time based assessments are purely for comparison of construction and maintenance costs of various pavement types over a nominated time period. It does not mean that the pavements are going to collapse or have to be replaced immediately after the selected time. For example, buying a cheap car will generally require much more maintenance than a better quality car, when compared over the same time period. After this time, however, the maintenance costs of the cheaper car will start to escalate faster, but the car will still be quite usable.

For this reason, the term LCC is preferable, as it infers a cyclic existence, whereas WoL has the connotation that the actual "life" of the pavement has completely expired after a certain time.

4. Understanding Life Cycle Cost Analysis

LCC analysis is an economic analysis technique that allows comparison of design alternatives with different cost streams. It should be noted that this is a secondary analysis, because the primary analysis has already decided that a pavement project must be constructed, and "do nothing" is not a viable alternative.

LCC analysis allows owners, agencies and engineers to evaluate different alternatives for infrastructure projects. It involves calculating the total costs to construct and maintain an asset such as a pavement over a designated time period.

In applying this concept to pavements, the primary factors include:

- Initial (i.e. construction) costs;
- Maintenance costs;
- Rehabilitation costs and
- Salvage or residual value.

  (Some authorities also use Vehicle Operating Costs (VOC) in the cost model).

The different pavement alternatives should always be designed for the same design traffic loading (DTL) and the same subgrade strength.

The accuracy of the LCC analysis results depends on the accuracy of each of the inputs, which typically include:

- Initial construction costs;
- Initial pavement service life;
- Routine maintenance costs;
- Timing, extent and service life of preventative treatments;
- Preventative treatment costs;
- Timing, extent and service life of rehabilitation treatments;

- Rehabilitation costs;
- Discount rate; and
- Salvage or residual value.

The errors in predicting any of the above parameters will result in cumulative errors in the LCC calculations and hence the result. Since all the inputs are estimates and therefore probabilistic in nature (eg as timing of various treatments can occur over a number of years the required extent can be very variable), the resulting LCC value is only an estimate of the actual LCC value and is in itself probabilistic.

It should not be overlooked that LCC analysis involves comparing alternatives with identical levels of service, eg pavement preservation or replacement strategies for an existing road. Where the level of service is different between alternatives being compared, a strict comparison using the normal LCC analysis is inappropriate. In such cases the correct economic tool would be Benefit-Cost analysis.

5. Is it an Art or Science?

As already noted, LCC analysis is not new and has been a valuable comparison tool for highway engineers for a long time. Sophistication has changed, but the principles remain the same. The actual analysis is still an imprecise "art" rather than an exact science even with the sophisticated computer programs that are available. The problem is our general lack of knowledge about the long term pavement performances, the different modes of distress that can occur, the suitable repair or rehabilitation required at the time and the actual maintenance and rehabilitation costs for various strategies. The confidence of the end result is wholly dependent on the quality and accuracy of the generally nonfactual input parameters. In the best of circumstances the actual performance, timings and extent of the various distress mechanisms cannot be predicted. This, of course, is not unique to Australia as the same problems are common elsewhere in the World.

For any analysis, it would be naive to assume that the design assumptions (usually ideal) will always be correct and be reflected in the actual performance of the pavements. Poor construction practices, variabilities in materials and the subsequent preventative maintenance practices and especially timings, influence the performance of the pavements greatly.

Because of the variety of different strategies available for evaluation, ie the assessment period, design lives of treatments, discount rates and timings and the quantum of planned and rehabilitation maintenance, there is no technically correct outcome of the analyses.

6. Assumption

It is assumed that readers have a basic understanding of the LCC analysis and hence details of the routine actions are not presented.

7. How Long is "Life"?

Using Australia as an example, the first hurdle to overcome is that there is no agreement between the States as to what should be a reasonable "life cycle" for comparison of costs. This is illustrated in the following table of design "life" durations:

State	Concrete	DLA	Composite	Gravel
NSW	40	20	20	20
QLD	40	40	?	?
VIC	30	30	30	30
WA	?	?	?	40

From the above, the importance of having uniform criteria for analysis is obvious as by varying the timings for corrective actions it is easy to manipulate or obtain any desired result.

8. Analysis Period

The chosen period of analysis should be not less than the longest design period for any of the alternative pavements. This period will then also apply to each alternative. It is noted that in Canada a 50 year analysis period is adopted for all pavement types and the same is currently under consideration in US.

As in Australia, in the case of US, there is no commonality whatsoever in the design lives of different pavement types. The following illustrates the wide variations in design lives in different States:

- Asphaltic Concrete – 12; 15; 16; 20; 30; 35 years
- Deep Strength Asphalt – 18
- Full Depth Asphalt – 15; 18; 20
- Plain concrete Pavement – 20; 25; 35; 40
- Jointed Reinforced Concrete Pavement – 30; 32; 35
- Continuously Reinforced Concrete Pavement – 30; 32
- Asphalt on PCP (ie Composite Pavement) – 20

By putting the above variations in context, a simple calculation will show that there are 436 permutations available which will give vastly different results, eg there will be a very large difference comparing a PCP with a nominated 20 year life and of 40 year life to any other pavement type.

For such a disparity in what should be regarded as the most realistic prediction, the real value of the analysis becomes questionable right at the start and would not provide meaningful comparisons for Federally funded projects. (In Australia we are only slightly better off).

The US FHWA recommends that the period should be **at least** 35 years. AASHTO on the other hand recommends that for Heavy Duty pavements the period could be up to 50 years.

Some have recommended an analysis period that does not extend beyond the period of reasonable forecasts. No advice is offered as to how this can be tested.

In practical terms, the selection of the analysis period should match the longest design life of the candidate pavements being considered. This then becomes the "cycle length" for all the other alternatives.

The actual pavement **service life** is highly probabilistic and variable. Hence the methodology of comparing cyclic lives which are based on the **design lives**.

9. Service Lives and Defining of Activity Timings

Besides the variations in the estimation of realistic service lives for each initial design alternative, the nominated timings for the planned maintenance and repair also vary significantly. Both are extremely important input parameters for a meaningful LCC analysis.

A further problem is that the estimated service life of the maintenance activities is also highly probabilistic and variable depending on the traffic loadings, weather and quality of the particular maintenance activity. It can be shown that the LCC order can change even with one year delay in rehabilitation timings.

In an endeavour to reduce some of the guess work, Road Authorities have specified the timings and quantum for preventative and planned maintenance activities for different pavement types in the form of "standard" performance models. Unfortunately, these are quite different from State to State.

10. Performance Models

The episodes of routine maintenance, preventative maintenance and rehabilitation treatments (for Heavy Duty pavements) are typically prompted by distress conditions. Codes of Maintenance Standards lay down the intervention levels and allowable reaction times. The extent of these cannot be estimated in advance over the design life of the pavement. Because of this and for the purpose of comparative LCC analyses, Road Authorities issue standard pre-planned cyclic maintenance interventions. Such a listing is termed the **Maintenance Diary.**

11. Maintenance Diaries

The LCC Model abstracts the features of the pavement and its use and translates them into costs. To be of value for other than comparison of alternatives, the inputs must be as realistic as possible. The problem is that the formal prediction of timings, nature, extent and type of maintenance and rehabilitation is subjective and can be varied to suit any pavement type.

To illustrate this, an example of the differences of preventative maintenance and rehabilitation predictions by the Australian States is included in Annexures A and B.

12. Costs Generally

12.1 Cost Factors

A crucial component of the LCC analysis for pavement selection is the cost of construction, maintenance and rehabilitation of the various alternatives being considered. Overheads and profit are generally omitted.

The LCC analysis presentation that I have been using, besides construction costs, is based on consistent routine maintenance, planned maintenance and rehabilitation costs per square metre. This format has a number of advantages as described hereunder.

12.2 Design Costs

Engineering costs can be variable, but as they have to be estimated (for different pavements) their accuracy is questionable. Even though some research shows that they could be as high as 15% of the project cost, because of the unknowns, I prefer to assume that they are part of the construction price. This is certainly the case with Design and Construct (D&C) contracts. Furthermore there is the difficulty of excising pavement design costs from the total design costs and preliminary actios. These inaccuracies will then also reflect in the LCC analysis.

The geometric design is basically similar for all options to be considered. There may be minor differences in the cost of the design of the alternative pavements, eg pavement drainage requirements. I believe that the estimation of these costs is not warranted and hence not included in the LCC analysis.

12.3 Construction Costs

It must be accepted that estimation of actual project costs involves risk and is highly probabilistic. The key considerations should include:

- Only the components of construction that are unique to each design alternative;
- Items that are identical, should be omitted;
- Construction costs and unit rates should be checked against historical records; and
- Identification of project specific aspects that might affect costs, e.g. traffic control.

It is normal for the construction estimate to pick up the variations in:

- Provision for traffic;
- Effect of wet weather;
- Establishment costs (eg plant);
- Supervision and possibly overheads;
- Relocation of services;
- Testing requirements, and
- Fixed costs applicable to duration of the construction.

Generally the construction cost is based either on in-house historical estimates or on Tender pricing. It is assumed that the above considerations and variations are included. If a contractor has to provide a LCC analysis of different pavement options then also detailed estimates, based on previous experience, will be provided by the contractor. In-house estimates have to rely on analysis of historical costs. It should be noted that the total cost is very much project specific as there could be significant variations in the materials and services supply.

For the LCC analysis, it is assumed that the estimates are comparable. However, there are major differences in the inputs values to flexible and rigid pavement calculations, eg the determination of traffic loadings varies markedly – for rigid pavements the annual growth is usually mandated as 4% without accepting that in, say, 40 years there may be no capacity for these heavy vehicles, but regardless, in the design, they all load the original lanes.

In Australia, for rigid pavements a Load safety Factor of 1.1 to 1.3 is then applied to the calculated traffic (**H**eavy **V**ehicle **A**xle **L**oads) to obtain the design traffic loading (DTL) for nominated design reliabilities. The DTL for flexible pavements is based on Standard Axle Repetitions (SARs) which are then increased by nominated load damage exponents, eg for asphalt – 5, cemented materials – 12 and for rutting and shape loss – 7. This illustrates the significant difference in the input DTLs between flexible and rigid pavements which will affect the "wear and tear" if one or the other's traffic figures are substituted. In that case the maintenance requirements over the 40 years could be quite different.

It is assumed that the initial cost reflects correct design and the best workmanship of required quality.

12.4 Maintenance Costs

Maintenance costs are by far the most difficult ones to estimate, because of the need to establish what the planned and required maintenance activities and timings would be. Even routine maintenance costs are quite arbitrary guesses. To lay down these requirements in quantum and extrapolate them over a 40 year period, needs a non-existent crystal ball. Detailed historical maintenance records are virtually non-existent throughout Australia. To provide value in any LCC exercise, it is essential that there be agreement between the major Clients as to what the requirements for the various pavement types are, what quantum and when during the 40 year period these should be carried out. Such information is then listed in the Maintenance Diaries.

The accuracy of this information then becomes irrelevant as the same guideline ("recipe") is applied by all analysts, which then makes the comparison of options more realistic.

Currently there is no such agreement nor are all the pavement types covered by the individual guidelines of the States (including NSW).

All maintenance activities are dependant on the fluctuations of the amount and type of traffic and the variations in distress that will occur.

12.4.1 Routine Maintenance Costs

These will vary between pavement types, climate, traffic and the rate of ageing of the various pavements. At the time of rehabilitation, there will be factual pavement condition data available and it is quite likely that the treatment will differ from the estimate in the Maintenance Diary. In general, there is very little maintenance cost data available from the State Road Authorities (SRAs). Because of this, some overseas authorities actually exclude them. In New South Wales, the Roads and Traffic Authority has actually nominated suitable unit rates, as $/m^2, for different pavement types.

12.4.2 Planned Maintenance Costs

These are preventative treatment costs associated with maintaining the pavement at or above some predetermined performance level.

There is always the problem of nominating planned maintenance methods, timings and quantum for each of the pavement options. To nominate the quantum is purely academic. As also the timings of the planned maintenance can have (large) variations, the whole exercise will thus be completely probabilistic in nature.

12.4.3 Rehabilitation

Rehabilitation costs cover the activities performed in restoring the pavement when problems become severe or extensive. This typically requires overlays or reconstruction.

In some Guides it has been suggested that the engineer should also try to assess the type of rehabilitation activities. This is quite unreal, as the assessment has to be made years before the unknown distress manifests itself. The suggestion is as utopian as the further suggestion that rehabilitation activities and their timings should be based on the predicted distress (and its extent) that will develop in the pavement at a particular time. Both these have no practical value. Hence, to ensure that “apples are compared with apples”, the practical solution is that the Road Authority lays down a standard Maintenance Diary which covers the extent and timings for nominated rehabilitation for different pavement types.

Some, correctly, disagree that standardisation is realistic because:

- A standard rehabilitation rarely addresses the cause of the problem;
- As traffic is always increasing, it is not possible for the same standard rehabilitation to last the same length each time it is applied and
- The underlying structure is also deteriorating and the pavement is losing structural capacity.

There is no doubt that theoretically this is true, but there are no practical ways of determining otherwise. The extent of rehabilitation and its timing will vary and the realistic approach is to adopt an average treatment with an arbitrary timing and quantum for the actions.

This is another reason why on pavements LCCs can only be used for comparison and to illustrate comparative maintenance costs over the analysis period.

Here it is worth noting that diamond grinding is now the most common first rehabilitation treatment in the US.

12.5 Salvage Values

The concept of salvage or residual value is included in the capital costs stream to ensure that pavement alternatives are treated equally where the assessed pavement life extends beyond the assessment cycle. The convention is to deduct or add it to the capital cost after discounting.

At the end of the Life Cycle, ie the analysis period, there is always a residual value of the pavement that can be utilised for rehabilitation into the new pavement. This will vary from one type to the other and also what the method of rehabilitation is going to be.

In the case where the rehabilitation involves the removal of the existing pavement and replacement with a new, the residual value would be negative and amount to the cost of removal. If an overlay is used, the residual value would be positive to reflect the contribution the old pavement would make to the rehabilitated pavement structure. This decision has to be made at the start of the assessment period and hence would be quite subjective.

There is no consensus on the methodology and in most cases it is completely overlooked or an arbitrary credit figure is suggested. Where there is a planned refurbishment during the 40 year cycle, the actual or required methodology has not been stated or documented. For the purpose of theoretical comparisons a suitable standard method should be offered. (In actual situations, proper pavement testing and design will be required).

Salvage value is project specific and should be calculated on a realistic expectation of how the pavement will be salvaged at the end of the analysis period. It may be through recycling, rehabilitation or continued service. Some authorities consider the salvage value to be the difference between the cost of a new pavement and that of rehabilitating the existing.

All the above is easier said than done. AUSTROADS suggests that as the retained economic value of the pavement, at the end of a road's formal life cycle, is difficult to assess, a number of other factors should also be considered:

- The continued use of the existing alignment;
- The feasibility of upgrading or strengthening the pavement by overlay;
- The possibility of recycling of the existing pavement materials or recycling of asphalt in plant or in-situ, and
- The need to remove the pavement before reconstruction.

To provide a realistic assessment of the value, say, 40 years in advance of the event is completely out of the question. It should also be recognised that the salvage values of the same pavement type with identical traffic loading will be completely different depending on whether the road is in urban or rural location. (In some instances a rural road could become an urban road during the 40 year assessment cycle).

To overcome the problem and to provide some uniformity in approach, Road Authorities have provided average values in their standard Maintenance Diaries. This, at least ensures that all evaluators have a consistent approach.

13. User Costs

User Costs are made up from travel time (delays), vehicle operating costs (VOCs), accident costs, discomfort costs and nowadays also possibly pollution by vehicle emissions. If used in the LCC analyses of pavements, these are generally the same regardless of the pavement type, except for those associated with Work Zone operations where different treatments take different times. There are also minor differences due to variations in roughness as the pavements age.

Variations in User Costs or Vehicle Operating Costs (VOC) are due to increased pavement roughness, extra delays and accident costs due to lane closures, maintenance and rehabilitation activities.

There are a number of computer models available for the prediction of VOC. Studies have shown, however that there can be up to 40% differences in costs using the same input data and up to 500% differences in the cost predictions resulting from roughness.

It can be argued that User Costs are not agency costs and should not be taken in account.

Further, User Costs and VOC are not included in Australia, nor in my proposal for LCC analyses, as they will be of the order of 10 times higher than the asset Construction and Maintenance costs and as such will render the latter meaningless. It can also be argued that the difference in user delay costs, regardless of the pavement type, can be considered as insignificant.

14. Reporting Unit

There are wide variations on how the LCC analysis Report is presented, e.g.

- The calculations are based on actual pavement areas on the project.
  - This is a very cumbersome method in that it requires, at least, outline design of the alternative options and calculation of the areas involved;
  - The LCC analysis cannot be done until the geometric designs are available and
  - Any subsequent changes in design may require fresh LCC calculation.
- Some overseas Authorities work on the basis of, say, 1 km length of a particular width pavement.
  - The advantage of this is that the calculations and comparisons can be done without outline geometric design;
  - When it is required to work out the likely annual maintenance allocations, the costs will still need to be converted to square metres and then to cover the total area.
- The method of calculation that I have adopted is that all costs are worked out as $/m^2.
  - This does not require any prior geometric design;
  - Once pavement areas are known or varied, only a simple calculation is required to obtain the actual total LCC;
  - All Unit Rates are calculated for the items listed in the Maintenance Diary, eg if a 80 mm overlay costs $20/m2, but only 50% of the total area is overlaid in Year X, then the unit rate for the overlay becomes $10/m2.
  - Once the preferred pavement has been selected and the actual pavement area is available, it is a simple exercise to calculate the

discounted likely annual maintenance costs, for budgeting purposes for all the years in the assessment cycle.

15. Cost of Money

A typical LCC analysis utilises Net Present Worth (NPW) of future costs to provide a common basis of comparison of pavement types that have different profiles of cost over their lives. A discount rate, which reflects the reduced cost of money which does not need to be spent initially, is used to reduce the value of costs that occur in the future to those of a common base year.

The normal practice is to apply a discount rate of X% to adjust the maintenance costs to the year that the activities are undertaken. The problem, of course, is how to determine the variations or even the average discount rate for the 40 years? In this regard it is normal to provide a sensitivity analysis to allow the Client to choose a rate to suit. Clauses 17 & 18 provide in depth discussion on this aspect.

16. Present Worth Costing

LCC analysis equates all present and future costs and benefits over the life of the project by accounting for the value of money over time. There are two common ways of presenting the results, the Present Worth and Equivalent Uniform Annual Cost. Only the former is commonly used in LCC of pavements.

Present Worth is the sum of all costs over the project analysis period in today’s dollars. It combines initial costs with discounted future maintenance costs, rehabilitation costs and a salvage value. PW analysis is only applicable to comparing of alternatives with equal analysis periods.

Having these input parameter estimates, the process of calculating PW of LCC is a straightforward exercise.

Because the deterministic LCC analysis approach does not account for variations in costs and performance lives, it is important not to accept the outright results of the LCC analysis. Some overseas authorities have established a minimum cost margin of 5 or 10% between the two lowest alternatives, whereby if the minimum margin is not met, other factors like up-front funding and constructability are considered. For example, if the least cost alternative is $1,000,000 and the LCC margin requirement is 10% then the runner up alternative must be no more than $1,100,000 in order for it to remain a viable option. Authorities may wish to vary this percentage.

The small differences in resultant costs must be considered insignificant in view of the variabilities and uncertainties involved.

17. Discount Rate

A simplistic definition of the discount rate is that it is the difference between the Government Bond rate and inflation. These, of course, vary with time and it will not be possible to identify a unique discount rate that would be applicable over the whole evaluation period. For this reason sensitivity analysis will be carried out over a range of discount rates to allow the client to make the selection. AUSTROADS recommends 7%, with the sensitivity analysis from 4% to 10%.

In the US some States have been keeping details of the discount rates for some 30 years and then compute the moving average, which they then adopt, eg Colorado's current rate being used is 3.3%

The annual cost method of calculating LCC costs, which is normally used, is markedly affected by the discount rates, ie low interest rates favour those alternatives that combine large capital investments with low maintenance costs, whereas high interest rates favour reverse combinations. Hence, the LCC can also be manipulated by adopting a suitable rate to favour a particular pavement type.

The American Concrete Pavement Association (ACPA) points out that due to the effects of discounting, the time at which rehabilitation activities are placed into the analysis must be chosen as realistically as possible. If not chosen carefully, a change of one year in rehabilitation timing (in either direction) can have a significant alteration in the LCC result.

18. Sensitivity of Present Worth Discount Rates

An example in Annexure C illustrates the LCC (in $\$/m^2$) for a number of pavement options based on 0%, 4%, 6%, 8% and 10%. These are then graphed to provide a close approximation of the cost of the pavements at any other discount rate that may be appropriate or desirable at the time of the evaluation.

Since all inputs are probabilistic in nature for any specific project, the resulting LCC calculation is only an estimate of the actual LCC value and thus is in itself probabilistic.

19. Accuracy

The accuracy of the LCC analysis depends on the accuracy of each of the inputs, which would include the following:

- Initial construction cost (including the pavement designs undertaken;
- Expected initial pavement life (cycle);
- Routine maintenance costs;
- Timing and expected life of planned maintenance events;
- Cost of planned maintenance;
- Timing and expected life of rehabilitation;
- Type of rehabilitation;
- Rehabilitation costs;
- Discount rate(s); and
- Salvage value.

As an example, if the estimates for the above 10 items are only 90% accurate, then, at equal weightings the probable accuracy of the LCC values is only 35%. The order of this is significant in any future manipulation of the LCC values.

I note that AS/NZ ISO 14040 is silent on the accuracy of the analyses results or tolerances that should be applied for comparison of alternatives.

20. Is there a Need for Risk Assessment?

Both flexible and rigid pavement designs have already inbuilt design reliability factors or load safety factors. Hence a further design Risk assessment is superfluous.

Having demonstrated that the accuracy of the LCC results can be quite low, any further risk analysis becomes an academic exercise only. It should also be noted that the probability of accuracy of the estimated inputs can vary significantly when these are estimated optimistically or pessimistically.

For the purpose of comparison of alternative pavement options, it is pragmatic to assume that the Risk Factors are the same for all alternatives.

21. Presentation

The analyses should:

- Use square metre as the comparison unit, thus allowing easy conversion to the actual pavement areas which will be established during the geometric design;
- Be presented in a tabular form, separating the costs for each year. This allows the Client to determine what its likely annual financial commitments may be or more realistically when peaks in budget allocation occur;
- As the cost of planned maintenance will vary, an outline estimate of the unit rate can also be included in the Remarks column. This will provide background for the LCC analysis evaluators; and
- Have a graphical representation of the discounted costs as a sensitivity presentation.

As an example, an illustrative costed Maintenance Diary output is attached in Annexure D.

From the costed Maintenance Diary the order of annual maintenance costs can be calculated. Again, these costs should only be used for comparisons and as an indication of budget fluctuations. An example is contained in Annexure E.

22. Canadian LCC Policy

I believe that currently one of the most comprehensive and well developed LCC analysis policy hails from Canada.

For the purpose of comparison, I have extracted some relevant information from the Canadian/Ontario Ministry of Transport LCC Policy. These are from an in-depth review of all the uncertainties of the LCC input parameters and their formal guidelines for use now are:

- 50 year analysis period;
- 7% discount rate (now revised to 5%);
- 29 year initial life for rigid pavements;
- 18 year initial life for flexible pavements;
- User Costs not considered;
- Problem still with discount rate; State keeping running averages;
- Sensitivity analysis 4 – 10 %;
- Salvage value should b calculated;
- Traffic on 3-4% annual compound;
- Full Depth Asphalt (FDA) no longer considered as no longer used in Canada;

- Life of other types of pavements:
  - Composite AC/PCC - 21 yrs
  - JRCP – 18 Y as functional and 34 years structural
  - AC overlays:
    - 1st – 11 yeas
    - 2nd – 10 years
    - 3rd – 9 years
    - 4th – 8 years
- Diamond grinding 11 years; and
- Patching and joint sealing – 11 years.

23. Shortcomings of Current Methods

Anybody seeking to make analytical comparisons between different pavement options, or indeed, selection of options for reconstruction, will always generate some form of performance model for each serious option. The decision makers must realise that:

- The input parameters for the model are basically estimates of future occurrences with low probabilities for accuracy;
- The analyses are project specific and cannot necessarily be transferred to other areas or interstate; and
- The accuracy of the LCC value can be quite low.

The problem is that there is no consensus between the States and already Consultants are creating their own Maintenance Diaries within a State. Regardless of the claimed problems, omissions or inaccuracies of the Road Authority methods, a free for all arrangement should not be tolerated. (A similar Guide to the AUSTROADS Guide to the Structural Design of Pavements should be developed and agreed).

A similar problem exists worldwide, with a number of researches having summarised this as:

- Lack of standard methods;
- Lack of data;
- Need for training in LCC methodology;
- Need for software development, training and support, and
- Lack of communication between agencies.

24. Recommendations

1. That results that are within 10 % of each other should be regarded as comparable. If that occurs, a subsequent stage of comparisons must be carried out to cover political, social and environmental issues like:
   - Speed of construction;
   - Urgency of availability;
   - Disruption to traffic;
   - Disruption to commercial activity;
   - Noise during construction and subsequent traffic noise;
   - Vibration, dust and fumes during construction;
   - Sustainability issues; and
   - Design reliability (uncertainty in traffic loading estimates, in-situ and construction materials not meeting design expectations, variations in pavement layer thicknesses and accuracy of design methods for different pavement designs).
2. Because of the accepted inaccuracy of the LCC model, no Risk Analysis is warranted.
3. It is highly desirable that an agreed National Guideline for Life Cycle Cost analysis be developed.
4. In view if the inaccuracies of the LCC analysis, a uniform approach should be negotiated to cover:
   - All heavy Duty Pavements (at least)
   - Maintenance Diary timings for interventions on all pavement types:
   - Agreement on standard rehabilitation methods for various distress types;
   - Definition of quantum for each maintenance intervention;
   - Agreement on discount rates to be used, albeit the Sensitivity analysis should still be provided;
   - Agreement on how to calculate Salvage values; and
   - Agreement that VOC need not be included and that Risk Analyses of the LCC are not warranted.

Annexures

A. Plain Concrete Pavement Maintenance Diary

B. Deep Lift Asphalt Maintenance Diary

C. Sensitivity of Discount Rates

D Example of a Costed Maintenance Diary

E. Annual Maintenance Costs

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ANNEXURE A:
Plain Concrete Pavement Maintenance Diary

LCC Example

Comparison of Maintenance Diary Major Items

PLAIN CONCRETE PAVEMENT (PCP)

Year	RTA NSW	MR Qld	VicRoads
1			
2	Cross stich cracks 20 m/lane km	Cross stich cracks 30 m/lane km	
	Rout 10% and reseal	Rout 10% and reseal	
	0.5% slab replacement		
3			
4			0.3% slab replacement
5	0.5% slab replacement	0.2% slab replacement	
6	Cross stich cracks 20 m/lane km		
	Rout 10% and reseal		
	0.5% slab replacement		
7			
8		Cross stich cracks 30 m/lane km	0.2% slab replacement
		Rout 10% and reseal	
9			
10	0.5% slab replacement	0.5% slab replacement	Replace joint sealant
	Replace joint sealant	Reploace joint sealant	
11			
12	Cross stich cracks 20 m/lane km		
	Rout 10% and reseal		
	0.5% slab replacement		
13			
14		Cross stich cracks 20 m/lane km	
15	0.5% slab replacement	Rout 10% and reseal	
		0.2% slab replacement	
16			0.2% slab replacement
17			
18			
19			
20	Cross stich cracks 20 m/lane km	Cross stich cracks 30 m/lane km	Replace joint sealant
	Rout 10% and reseal	Rout 10% and seal	Retexture 30% of area
	0.5% slab replacement	0.5% slab replacement	
	Replace joint sealant	Replace joint sealant	
	Retexture 30% of area	Retexture 30% of area	
21			
22			
23			
24			0.2% slab replacement

Year	RTA NSW	MR Qld	VicRoads
25	0.5% slab replacement	Cross stich cracks 30 m/lane km	
		Rout 10% and seal	
26			
27			
28	0.5% slab replacement		
	Cross stitch cracks 40 m/lane km		
	Rout 10% and reseal		
29			
30	0.5% slab replacement	0.5% slab replacement	
	Replace joint sealant		
31			
32			0.2% slab replacement
33	0.5% slab replacement		
34			
35	0.5% slab replacement	Cross stich cracks 60 m/lane km	
		Rout 10% and seal	
36	Cross stitch cracks 40 m/lane km		
	Rout 10% and reseal		
37			
38	0.5% slab replacement		
39			
40	Salvage	Salvage	Salvage
	Total slab replacement = 5.5%	Total slab replacement = 1.9%	Total slab replacement = 1.1%

ANNEXURE B:
Deep Lift Asphalt Maintenance Diary

LCC Example

Comparison of Maintenance Diary Major Items

FULL DEPTH or DEEP LIFT ASPHALT (DLA)

Year	RTA NSW	MR Qld	VicRoads
1			
2			
3			
4			
5			
6			
7			
8		!% heavy patching	
9		Mill 10 mm, Place 40 mm SMA	
10			
11			
12			
13			
14			
15	1.5% heavy patching	1% heavy patching	
	Mill 45 mm, place 45 mm AC14		
16			
17			
18		1% heavy patching	
19			
20		Mill 10 mm , Place 40 mm SMA	Replace 5% of pavement
			40 mm AC overlay
21			
22			
23			
24			
25		1% heavy patching	
26			
27			
28			
29		Mill 10 mm, Place 40 mm SMA	
30	1.5% heavy patching		Replace 5% of pavement
	Mill 45 mm, place 45 mm AC14		40 mm AC overlay
31			
32			
33			
34			
35		1% heavy patching	
36			
37			
38		1% heavy patching	
39			
40	Salvage	Salvage	Salvage

	Total heavy patching = 3%	Total heavy patching = 6%	Total heavy patching = 10%

ANNEXURE C:
Sensitivity of Discount Rates

LCC Example

COMPARISON OF RIGID PAVEMENT COSTS ($/m2)

Pavement Type	C & M Non-discounted Costs 0 Years	10 Years	40 Years	Discounted Costs, Discount Rates 0%	4%	6%	8%	10%
PCP	64.80	77.53	87.31	87.31	82.24	79.31	76.91	75.03
PCP+ OGA	82.40	110.29	149.17	149.17	121.19	112.09	105.43	100.55
CRCP	66.20	69.11	45.79	45.79	64.95	67.17	67.97	68.18
CRCP + OGA	83.8	106	128.25	128.25	111.53	105.50	100.77	97.16
CRCP + SMA	76.28	79.19	81.87	81.87	85.43	84.16	82.77	81.56
DSA	80.00	82.86	105.4	105.40	97.36	93.49	90.44	88.13
DSA + OGA	90.40							
DSA + SMA	90.08