Use of Highway Network Level Data for a Project Level Life Cycle Analysis

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The subject of this paper covers a project that was successfully commenced in 1997 and completed in 1998. This paper discusses the development of a method to use network level PMS data for a project level life cycle costing analysis. The method was successfully applied to a variety of road conditions and structures that make up the primary highway network in Saskatchewan, Canada. This project followed on from a project that implemented probabilistic and deterministic network level PMS within Saskatchewan Highways and Transportation. The project that is the subject of this paper was to determine the whole of life implications on level of service for different funding scenarios on different types of road structures. The paper discusses the details of the method identified and the network level data that was use. The paper specifically focuses on description of the Network Level Probabilistic cost/deterioration models; description of Network Level Deterministic deterioration models; how the models were combined to develop a Deterministic Project Level deterioration versus maintenance cost model; application of the project level models in Life Cycle cause and effect models; the method used to analyze the above to develop Net Present Worth and Equivalent Annualized Cash Flow for different level of service starting case scenario.

BACKGROUND

Statement Of Problem

Saskatchewan Highways and Transportation (SHT) is a major provincial highway agency in Canada. SHT performs a benefit/cost analysis for capital construction projects. One of the inputs in the analysis is the cost of maintenance over the duration of the analysis period. It is recognized the cost of maintaining a roadway increases as its condition deteriorates. SHT wants to take this factor into consideration during their cost benefit calculation.

Issues

To accommodate the above statement of the problem facing SHT, a project was commenced in July 1997 to identify the cost of maintenance by using a life cycle costing analysis, taking into account the following:

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TABLE 1 Probablistic Condition States

CONDITION STATE	IRI	SUB. FAIL	FAT. BLOCK	PERF. INDEX
1	1	1	1	1
2	1	1	1	2
3	1	1	2	1
4	1	1	2	2
5	1	2	1	1
6	1	2	1	2
7	1	2	2	1
8	1	2	2	2
9	2	1	1	1
10	2	1	1	2
11	2	1	2	1
12	2	1	2	2
13	2	2	1	1
14	2	2	1	2
15	2	2	2	1
16	2	2	2	2
17	3	1	1	1
18	3	1	1	2
19	3	1	2	1
20	3	1	2	2
21	3	2	1	1
22	3	2	1	2
23	3	2	2	1
24	3	2	2	2

- A 30 year analysis period;
- Cost reported in per square meter of roadway surface;
- Expressed as a per year cost;
- The analysis must be specific to Region rather than apply to the whole Province; and
- The results must relate to current Network Level PMS condition states (Table 1). Note : 1=good condition and 3=poor.

ANALYSIS METHODOLOGY

Considerations

It was recognized that SHT had a variety of sources of high quality information relevant to the problem. This included:
- Probabilistic prediction models
- Cost vs. condition models
- Deterministic project level prediction models

- Detailed activity cost data
- Time series "actual" condition data

The problem was one of determining the best information to deterministically predict condition and cost using all of the sources available.

Discussion of the Method

The problem outlined was essentially a Life Cycle Cost problem. This was because the condition and the cost of maintaining a roadway fluctuated over time. Predicting deterioration of a roadway is complex because the actual deterioration path is dependent upon which treatments are applied, when they are applied (what is the condition of the roadway at that time) and what is the effect on the roadway performance (how does the condition change). In other words, the deterioration path is related to the preservation strategy applied to the network. A strategy is simply a proposed set of treatments for the expected life of the asset. Life Cycle Costing is applied to the strategy to determine the Net Present Value (NPV) and Equivalent Annual Cash Flow (EACF). The EACF is an equivalent annual cost of a strategy brought to current value.

The option expected to give the "best" result (most representative and repeatable) was to:

- Derive a deterioration path from deterministic performance survival models and relate the deterioration to the probabilistic condition states of the network.
- Apply the condition state costs to a specific strategy. The cost models are also deterministic, specific to a pre-defined set of conditions and have been proven through actual use. (The link to the costs is via the defined condition states in the probabilistic models).

The method of analysis consisted of:

1. Determining the deterioration path for a road pavement class for a geographical area by analyzing the deterministic performance model.
2. Determining the Life Cycle Cost of the normal preservation strategy.
3. Determining Life Cycle Costs based on differing start condition states. The longer the analysis period was, the less sensitive the Life Cycle Cost would be to the starting condition of the roadway.
4. Comparing the normal preservation strategy to a variety of other preservation strategies to determine sensitivity of the solution. A preservation strategy involves application of specific treatments at particular distress levels. If the NPV is approximately the same, the model is not particularly sensitive. If there is a strategy with a significantly lower NPV or EACF, then it is clearly the best strategy.
5. Once the "best strategy" had been derived, we now had a working methodology for a solution. A "reality check" was to review the solution with SHT highway practitioners looking at the sensitivity of strategies and the start condition state. Based on the review, the extent of the analysis for other surfaces was then assessed.

Condition Path

Figure 1 illustrates a condition path for a single distress over time. As the roadway ages, the severity of the distress increases. Periodically, a treatment is applied which results in an improvement in condition or a "Gain in Score" (GIS).

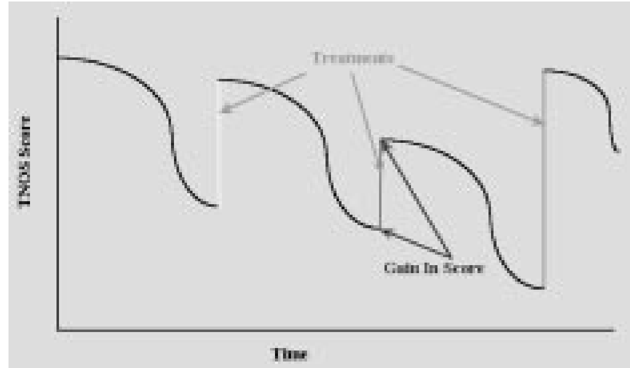

FIGURE 1 Condition path for a single distress.

TABLE 2 Gain In Score and Maximum Gain In Score

Treatments	Gain In Score For Distresses IRI	Sub-Grade Failure	Fatigue Blocking	Rutting
Sandvik Blading	15	10	15	15
Machine Patching	10	10	10	10
Heavy Patching	10	20	15	15
Full Seals	5	8	35	5
Spot Seals	0	5	25	2
Maximum Score	20	30	40	20

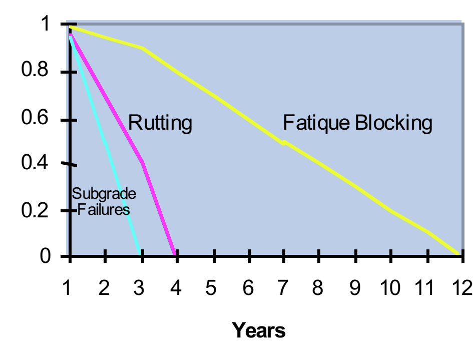

FIGURE 2 Untreated survival curves.

A typical roadway has many distresses that deteriorate at different rates. As illustrated in the diagram, specific treatments improve some distresses more than others. This means that the combination of distresses will determine the specific treatment selected. That treatment may result in improvement to several distresses.

The deterministic model handles different distresses by converting their condition rating to a "score." Relative importance of treat-

TABLE 3 Deterioration Path for the Analysis

	Year								
Start State	0	1	2	3	4	5	6	7	8
1	1	1	1	21	21	21	21	21	23
3	3	3	3	23					
5	5	5	5	21	21	21	21	21	23
7	7	7	7	23					
9	9	17	17	21	21	21	21	21	23
11	11	19	19	23					
13	13	21	21	21	21	21	21	21	23
15	15	23	23	23					
17	17	17	21	21	21	21	21	23	
19	19	19	23						
21	21	21	21	21	21	23			

TABLE 4 Life Cycle Costs for Condition State 1

Strategy	0%	2%	4%	6%	8%	10%
Strategy 1						
NPW	18.81	13.75	10.38	8.05	6.41	5.22
EACF	0.63	0.61	0.60	0.59	0.57	0.55
Strategy 2						
NPW	18.25	19.39	10.06	7.83	6.25	5.12
EACF	0.61	0.60	0.58	0.57	0.56	0.54
Strategy 3						
NPW	17.23	12.61	9.59	7.43	5.95	4.88
EACF	0.57	0.56	0.55	0.54	0.53	0.52
Strategy 4						
NPW	16.56	12.17	9.24	7.24	5.82	4.79
EACF	0.55	0.54	0.53	0.53	0.52	0.51
Strategy 5						
NPW	19.30	14.86	10.58	8.20	6.53	5.32
EACF	0.64	0.63	0.61	0.60	0.58	0.56

ing distresses is achieved by assigning the "maximum" score to each distress. The effect of each treatment on each distress is specified through the "Gain In Score" assigned. to it for each distress. These are illustrated in Table 2.

The method that was developed to be a reasonably realistic modeling of the whole of life decision-making was:

- If the treatment had a GIS for a distress, then that distress took on the new treatment's curve.
- If GIS = 0 then it continued down the current curve.

Deterioration Path

The deterioration path is derived from the survival curves in the deterministic model. The curves are shown in Figure 2. Note that the roads that were the subject of this analysis are low traffic volume, low cost roads and the curves reflect that situation. The method was later successfully applied to structural pavements.

The survival curves are used to determine a score for each distress as the road ages. These scores were mapped against the distress bins shown in Table 5. The combination of distress rating gives the probabilistic model condition state which are shown Table 1.

Analysis began with a road in "like new" condition, that is, all distresses "good." The road was deteriorated using the survival curves and the condition states were derived. For other "start states," the distresses were mapped against the deterministic model score for each start condition and the road deteriorated from there. The resulting deterioration paths for analysis are shown in Table 3.

Maintenance Costs

Maintenance costs were determined through a 30-year Life Cycle Cost Analysis. The analysis was based on the following assumptions:

- Using the deterministic model treatment performance and treatment costs;
- For maintenance costs for each condition state, use the probabilistic routine maintenance cost (including overhead);
- Deterioration was based on the untreazted survival curves;
- Apply treatments the year after the condition that triggers the treatment is reached. This recognizes rating is done in the fall for work the following year;
- Apply Gain In Score (GIS) to the previous year's score. The rationale is the road should improve with treatment and that the road will still be in better shape when the rating is done in the fall;
- Apply maintenance costs to the condition state in the year the rating is done. This is based on the fact the road is in that condition state and that is the state crews will respond to.

TABLE 5 Distress Condition Bins

AC Surface	Condition Bin	Rating
Rutting	1, 0, -1, S1, S2, M1, X1	Good
	S3, M2, M3, X2, X3	Poor
IRI	<2.5	Good
	2.5 to 3.2	Fair
	>3.2	Poor
Cracking	0 , -1, S1	Good
	S2, M1, M2, X1	Fair
	S3, M3, X2, X3	Poor
Shear	1, 2	Good
	3, 4, 5	Poor

Maintenance Strategies

Life Cycle Maintenance strategies were derived from the Agency documented practice. This consisted of typical treatments applied to each distress by condition bin for each distress type. The combination and severity of distresses determine the treatment selected for each maintenance strategy.

For the analysis, the Agency practice was used as the basis for treatment selection. The approach was that as deterioration occurred, treatments were selected with a gain in score that would improve the condition of the distress combination. Treatments were selected from those normally applied to the distress. Since multiple treat-

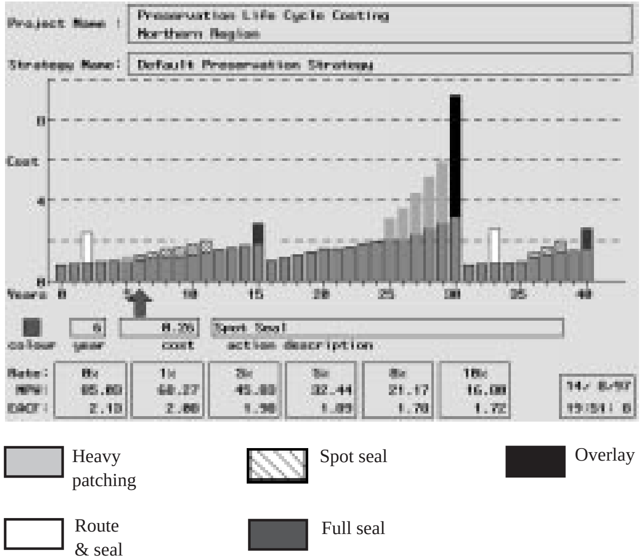

FIGURE 3 Life cycle cost example.

ments can be applied for each distress, various combinations were analyzed to determine the effect on Life Cycle Cost.

Life Cycle Cost Tables

Table 4 shows Net Present Worth (NPW) and Equivalent Annual Cash Flow (EACF) for the five strategies analyzed for Condition State 1 (a new road). The columns represent the result for different discount rates. The table illustrates that the “best” cost strategy is strategy 4.

Strategies 1, 4 and 5 were analyzed for other Start Condition States. Strategy 4 resulted in the “best” cost.

LIFE CYCLE COSTS

Figure 3 illustrates an example of a Life Cycle Cost for one preservation strategy. The example starts with a brand new road and has a complex (real life) treatment program over a 40-year period. The condition related routine maintenance costs fluctuate over time as the overall condition of the roadway changes. The diagram illustrates that condition related costs gradually increase as condition deteriorates and the costs reduce after the application of specific treatments that improve condition. Specific treatments diagrammed include rout and seal, spot seal, full seal, heavy patching and overlay all of which are applied at discreet intervals. Some treatments are shown recurring periodically while some occur several years in succession.

CONCLUSIONS

The overall analysis yielded good results over a variety of pavement types and conditions. When the EACF was compared with the budget predicted to maintain current condition over a long time period the costs per square meter were within 10% of each other. When one considers that the PMS predictions were based on fully probabilistic models and the EACF was not based directly on the probabilistic prediction models this correlation was pleasing and a good reality check on the validity of the analysis.