Optimization of Pavement Preservation Activities

J. Alan Humphries P.Eng, Ph.D.
Director for Transportation Innovation
Alberta Transportation, Edmonton, Alberta

Edwin Ma, P.Eng, MBA
Program Manager
Alberta Transportation, Edmonton, Alberta

Paper prepared for presentation at the

Coordinating Pavement and Maintenance Management with Transportation Asset Management Session

of the 2004 Annual Conference of the Transportation Association of Canada
Quebec City, Quebec

Abstract

Alberta Transportation has initiated a pavement preservation strategy. This strategy calls for the proactive management of the condition of pavements, from time of initial construction, throughout its entire life, to the time of rehabilitation or reconstruction. All types of surface treatments are used as part of a comprehensive, cost-effective and optimized preservation program.

A review of best practices found that Life Cycle Cost Analysis in the planning and programming of projects is becoming the accepted practice in the United States, Western Europe, Australia and New Zealand. Coupled with this has been the development of sophisticated decision support systems to aid transportation agencies in the creation of optimized, integrated multi-year work programs; notably the World Road Association's HDM-4 and, more recently, the U.S. Federal Highway Administration's HERS-ST.

Alberta Transportation conducted a pilot study in the summer of 2003 to determine how such an approach could be applied in Alberta.

The pilot study showed that an economic analysis-based decision support system can be successfully used on Alberta's provincial highway network to optimize the development of a multi-year pavement preservation work program. However, such a system has extensive data requirements and requires a comprehensive asset inventory that includes physical, cost, vehicle, traffic and climatic data. This data must be collected and stored in a manner that is compatible with and readily accessible by the decision support system to minimize data entry and manipulation. The performance of the preservation treatments must be known in order to calibrate the model.

Background

Alberta Transportation is responsible for the management of a provincial highway network that consists of approximately 26,000 kilometers of paved highways, 4,800 kilometers of gravel highway, 3,850 bridge sized structures and 7 ferries. The total replacement value is estimated at over $19.2 billion. Alberta has 2.3 million licensed drivers and over 3.3 million registered vehicles. Traffic is growing at 3.5% per annum and 21% of Alberta's international exports, valued at $7.8 billion per year, is moved by road.

The department is faced with demands for improved highways to support economic growth and increased traffic, as well as the need to preserve the condition of the existing highway network. However, since 1990/91 the department's share of the provincial budget has decreased from 7% to 4.6% for the current fiscal year of 2004/05. Alberta Transportation is spending, on average, less than $120 million per year on structural pavement maintenance and rehabilitation activities for each of the next 3 years. This represents less than 1% of the total asset value whereas private sector norms are in the 1.5-2% range (1).

Highway pavements in Alberta are designed for a 20 year life, with the average pavement actually being rehabilitated after 17-18 years. Second overlays are required after even less than this. This means that, for a network of 26,000 kilometers, the department should be repaving, on average, about of 1,400 kilometers of highway each year to maintain status quo. As shown in Table 1, the average number of kilometers repaved in each of the past 5 years is less than 700 kilometers or approximately half the required long term average. It is clear from this that if Alberta Transportation retains its existing pavement maintenance and rehabilitation practices the highway pavement infrastructure will decay faster than it is renewed, and the province will sink into an unsustainable pavement condition deficit. As substantially increased funding for pavement rehabilitation is unlikely, the department has to find better ways to effectively extend the life of provincial highway pavements.

2000	2001	2002	2003	2004	Average
970 km	892 km	389 km	490 km	590 km	670 km

Table 1. Alberta highways rehabilitated in the past 5 years

In January 2002, the department initiated a pavement preservation strategy. This strategy calls for the proactive management of the condition of pavements, from the time of initial construction and throughout its entire life to the time of rehabilitation and reconstruction. All types of maintenance treatments, including normal, reactive, preventative and rehabilitation are used as part of a comprehensive, cost-effective and optimized preservation program (2). These activities can be defined as:

- Normal maintenance - routine activities that occur on a regular basis such as crack filling and pothole repair.
- Reactive maintenance - activities which are done in response to events beyond the control of the department.

- Preventative maintenance – application of cost-effective treatments to preserve, retard future deterioration, and maintain or improve the functional condition of the highway surface.
- Rehabilitation – activities that restore the original pavement serviceability.

Pavement preservation requires identifying the pavement sections that will most benefit from treatment rather than the sections in the worst condition, the selection of the most beneficial treatment rather than Alberta Transportation's traditional (in the order of 100mm thick) hot-mix overlay, and the timely application of that treatment (3).

Traditionally, the maintenance of Alberta provincial highways, and the associated budget, has been the responsibility of the Operation Manager in each of 10 districts throughout the province. This includes winter and summer operations, non-structural maintenance, normal maintenance and some reactive maintenance. Rehabilitation projects are under the management of the Construction Manager in each of 4 regions throughout the province although priorities and budget are established province-wide through the central Program Management branch. Since 1996, maintenance work has been done by private contractor who are awarded multi-year, geographically based contracts. Rehabilitation work has been competitively tendered on a project basis for more than 40 years.

The adoption of a pavement preservation approach to the management of the highway asset is leading to a blurring of the distinction between operations and construction, and has required a re-alignment of business practices within the department, the not least of which is how the department approaches the development of its 3-year work program.

State of Practice Review

The concept of using economic analysis on highway projects has been around since the mid 1800's but did not gain wide acceptance in North America until the American Association of State Highway Officials (AASHTO) first published "Road User Benefit Analysis for Highway Improvements" in 1952 (4).

The prioritization and selection of candidate highway infrastructure projects into a one-year or multi-year work program – *programming* - has been a topic of interest to transportation professionals for at least 25 years. The U.S. Transportation Research Board held a conference on the Transportation Programming Process in 1975 (5). Critical issues at that time were to disentangle the roles of the different levels of government, establish programming based on goals and objectives, and to provide continuity between planning, programming and project scheduling. Project priority setting was usually done by technical ratings within program categories. Around the same time Carstens wrote that it is essential that the highway planning process be capable of providing assurance that the funds for highway improvements afford an optimum return for the tax dollar invested (6).

In 1982 the U.S. Transportation Research Board published a collection of papers on the transportation programming process (7). It appears that the main focus at that time was the re-organization of agencies to adapt to the shift from highway construction to network management and the introduction of computerized management systems. Any priority setting was generally done based on technical ratings and expert review.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) dramatically changed the decision-making environment for transportation programming in the United States. ISTEA acted as a catalyst for US agencies to move towards integrated, disciplined planning and programming, with a stronger connection between goals, objectives, performance measures, improvement strategies and the funded projects.

In December 1995 the Transportation Research Board in the United States held a national conference on transportation programming methods and issues (8). The conference found that jurisdictions were attempting to move away from category based comparative systems to comparing all projects against each other. There were also increased expectations for altering funds from historic allocations. In other words, changing from historical based programming towards needs based programming. However, it was also noted that needs based programming faced challenges particularly in how to attach a monetary value to many of the perceived benefits for projects. The need for better cost and financial resource estimating was also identified.

The Transportation Association of Canada published A Primer on Transportation Investment and Economic Development (9) in 1994. The Primer emphasizes that the economic objective of transportation policies and objectives should be towards growth in the volume of economic activity. Such growth, whether defined by improved productivity, gross output or living standards, can only happen if more value is put into the economy than is taken out. The Primer states “An appropriate method to assess this value is discounting benefit and cost streams to ascertain the net benefit of a proposed project” – Net Present Value analysis.

The Primer also discusses that many transportation agencies use sufficiency ratings, volume-to-capacity standards, level of service and cost-effectiveness (cost per unit) to evaluate alternative policies, programs and projects. It suggests that these types of measures are narrower than benefit-cost analysis and provide less useful information to decision-makers, and concludes, “net present value leads to different and substantially better investment decisions than sufficiency ratings or cost-effectiveness analysis”.

The U.S. National Highway System (NHS) Designation Act of 1995 required States to conduct life-cycle cost analysis on all NHS projects valued at $25 million or more. This requirement was subsequently removed and replaced by a requirement that the U.S. Secretary for Transportation develop recommended life cycle cost analysis procedures. In 1999 the U.S. Department of Transportation, Federal Highway Administration (FHWA) formed the Office of Asset Management. The Evaluation and Economic Investment Team resides within this office with the mandate to promote and train States in the use of engineering economic analysis procedures (life cycle cost analysis). Currently, the Canadian Federal government requires that the application for any project to be cost shared under the Strategic Highway Infrastructure Program (SHIP) must be supported with a benefit-cost analysis. The Australian department of Transport and Regional Services has a similar requirement.

Starting in 1968 the World Bank began to develop a road project appraisal model. This resulted in Massachusetts Institute of Technology constructing a Highway Cost Model in 1972. This work continued to evolve through the first version of the Highway Design and Maintenance Standards model (HDM) in 1979 and the development of the Road Transportation Investment Model for developing countries in 1977. Over the next few years HDM was improved and updated to HDM-III. In 1995, the International Study of Highway Development and Management Tools (ISOHDM) which is sponsored by the World Bank, the Asian Development Bank, the Department for International Development (UK), the Swedish National Road Administration and others, under the umbrella of The World Road Association (PIARC) fundamentally redeveloped the various models in HDM - III to incorporate a wider range of capabilities and modern computing practices.

The resulting HDM-4 is “a decision support software system for assisting road managers to predict future economic, technical, social and environmental outcomes of possible investment decisions concerning road assets. The HDM-4 system will assist managers in making effective investment choices at all levels. The possibilities may range from policy or strategic planning studies, through programmed allocation of funds to maintenance or improvement works on a network, to the detailed economic and environmental assessments of project options at the project level” (10). The technical secretariat for HDM-4 is based at Birmingham University, U.K. Austroads, the association of Australian and New Zealand transportation authorities, has adopted HDM-4 for the highway asset management practices of their members.

In 1987 the FHWA began the development of the Highway Economic Requirements System (HERS) and it was first used in 1995 to develop estimates of the investments required to maintain or improve the overall U.S. highway system. “The HERS model uses incremental benefit cost analysis to optimize highway investment. When funding is not available to achieve "optimal" spending levels, HERS prioritizes economically worthwhile potential improvement options according to relative merit (that is, benefit-to-cost ratios) and selects the "best" set of projects for system-wide implementation” (11). Starting in 1999 the FHWA began to develop a state version of HERS (HERS-ST). This version predicts the funding required to achieve a specified highway system performance level or estimates the resulting highway system performance under constrained funding. HERS-ST considers improvement projects for correcting pavement and/or capacity deficiencies. The report on the HERS-ST pilot was published in 2002, and Version 2.0 had a general release in November 2003.

The initiatives by primarily the United States, and to a lesser degree, the Canadian federal governments are encouraging North American transportation agencies to adopt Life Cycle Cost Analysis in the planning and programming of projects. This approach is also accepted practice in Western Europe, Australia and New Zealand. Coupled with this has been the development of sophisticated decision support systems to aid transportation agencies in the creation of optimized, integrated multi-year work programs.

Pavement Preservation Optimization Pilot Study

Alberta Transportation currently uses a sufficiency rating approach to prioritizing projects of similar work activities or program. Known as the Comparative Rating System (CRS), the system calculates a total rating for each candidate rehabilitation project using the factors and weights shown in Table 2.

Factor	Weight	Max. Score
Roughness (IRI)	50%	10
Surface Distress Index (SDI)	15%	15
Traffic Volume (AADT)	10%	7
Functional Classification	5%	10
Age	5%	5
Geometrics	5%	5
Overlay Requirements (thickness)	10%	10

Table 2. Typical Factors used in CRS for pavement rehabilitation projects

This approach requires that funding is allocated to each program, and then projects allocated to these funding levels. Typically, program funding is allocated on a historical basis. For a sufficiency rating type process to be credible, the various factors and weightings should be quantifiable and verifiable. There is a trade-off that as the factors become more specific and measurable the applicability of the rating becomes narrower. It is therefore difficult to have a well-defined sufficiency rating that can be applied across the broad range of work activities typically considered when using the pavement preservation philosophy. As shown in Table 2, CRS does not directly consider agency, user or life cycle costs. In addition, CRS bases its ranking on current conditions. A fundamental consideration of the pavement preservation strategy is the effectiveness of a treatment (work activity) and its follow-up treatments over the entire lifecycle. The current physical condition of a highway section is only one of the considerations as a pavement preservation strategy is an early intervention, not a catch-up strategy to fix the worst conditions.

Program Management branch decided, in the spring of 2003, to conduct a pilot study using HDM-4 as a way of prioritizing pavement preservation activities. The study had three parts: firstly to model the candidate pavement preservation projects and pavement rehabilitation projects within HDM-4; secondly to run the economic ranking for the rehabilitation projects and compare the results with those obtained using CRS; and thirdly, providing the results for the rehabilitation projects were acceptable, prioritize the preservation projects using HDM-4.

As a first step Alberta Transportation developed, with the assistance of EBA Engineering Ltd., a toolbox of pavement preservation work activities. This included typical unit costs and expected life of the treatment. In early 2003, a variety of highway segments that were showing signs of premature distress were identified based on roughness, traffic, age and distress. The list of potential projects was submitted to department field staff along with a list of suggested treatments from the toolbox. The field staff used their local knowledge of the highways to eliminate projects from the list, add new projects, and choose what they felt to be the most appropriate treatment. This list of candidate projects and recommended preservation treatment was then submitted to the central office Program Management branch for prioritization.

Pilot Study Objectives

The objectives of the pilot study were:

1. Identify the categories and types of data required for an economic analysis decision support system.
2. Gain an understanding of the models used by an economic analysis decision support system.
3. Explore the linkages required between an asset management system and an economic analysis decision support system.
4. Verify the program level results produced by an economic analysis decision support system for Alberta provincial highway projects.

Pilot Study Findings

The pilot study examined 57 candidate rehabilitation projects and 520 preservation projects. The pilot study was completed in August 2003 (12) and found the following.

Data Requirements

HDM-4 requires vast amount of data. Approximately 270 different data items are required for each segment of highway. Because there may be more than one homogenous highway segment within a candidate project, it may be necessary to assemble more than one set of data for each project.

The data required formed four categories:

1. The highway network – a model of the physical make-up, condition and history of the highway segment. A sample of some of the data requirements are shown in Figure 1.

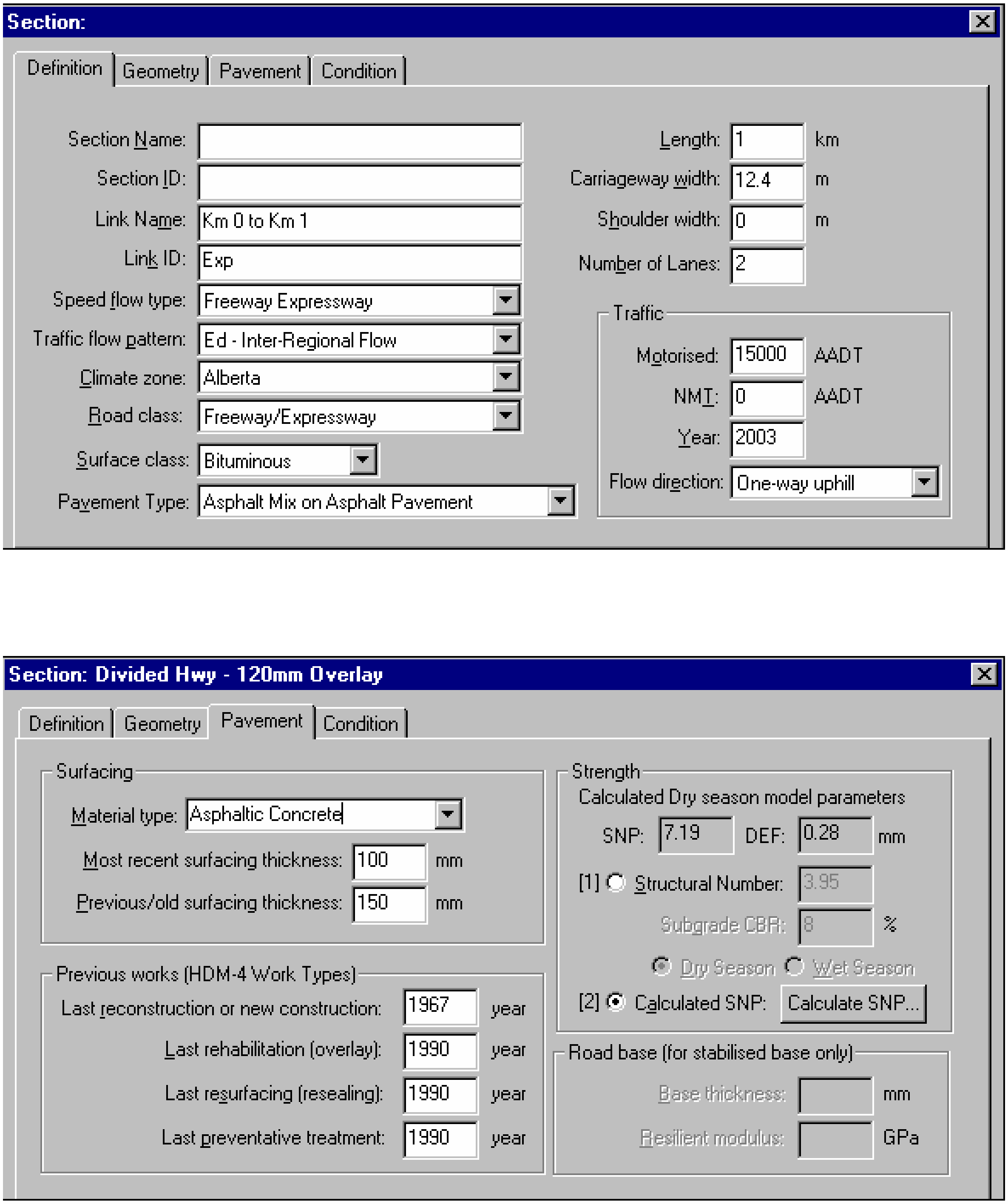

Figure 1. Highway Definition

2. The vehicle fleet – a description of the type of vehicles using the highway and associated user costs. A sample of some of the data requirements are shown in Table 3.

Column	Field Name	Description	Vehicle Type	Default Value	Comments
A	VEH_NAME	User specified name for vehicle type	SU PV RV BU TT	---	
B	CATEGORY	Category of vehicle type (see below) 0 = motorized 1 = non-motorized	SU = PV = RV = BU = TT =	0 for all	
C	BASE_TYPE	HDM-4 base vehicle type upon which this vehicle type was derived	SU = PV = RV = BU = TT =	8 2 11 14 10	0 = motorcycle; 1 = small car 2 = medium car; 3 = large car 4 = light delivery; 5 = light gods 6 = four wheel drive; 7 = light truck 8 = medium truck; 9 = heavy truck 10 = articulated truck; 11 = mini bus 12 = light bus; 13 = medium bus 14 = heavy bus; 15 = coach
D	CLASS	HDM-4 vehicle class to which vehicle belongs	SU = PV = RV = BU = TT =	3 1 4 4 3	0 = motorcycles 1 = passenger cars 2 = utilities 3 = trucks 4 = buses
E	INFO	Long-hand description of vehicle	SU = PV = RV = BU = TT =	single unit truck passenger vehicle recreation vehicle bus tractor-trailer	bus tractor-trailer
F	LIFE_MODEL	Life model used for analysis of road user effects	SU = PV = RV = BU = TT =	1 for all	0 = constant life 1 = optimal life
G	PCSE	Passenger Car Space Equivalent factor	SU = PV = RV = BU = TT =	1.40 1.00 1.20 1.60 1.80	HDM-4 default values for 4 lane/2 lane and consultation with Peter Kilburn
H	NUM_WHEELS	number of wheels per vehicle	SU = PV = RV = BU = TT =	6 4 4 10 18	HDM-4 suggested values
I	NUM_AXLES	number of axles per vehicle	SU = PV = RV = BU = TT =	2 2 2 3 5	HDM-4 suggested values

Table 3. Sample Vehicle Fleet Data Requirements

3. Configuration – traffic flow patterns, speed flow types and climatic conditions. Traffic flow patterns take into account differing levels of traffic congestion at different hours of the day, and on different days of the week and year. Speed flow types models the effect of traffic volumes on speed and the economic consequences of speed changes. Climatic conditions requires information such as mean temperature, temperature range, number of

days below freezing, mean monthly precipitation levels, moisture index and classification.

4. Highway work activities – the applicable treatments, unit costs, service life, surface characteristics after application of the treatment, treatment triggers and criteria.

		Hot In-Place Recycling	Mill and Inlay	Reprofile by Cold Milling
Surface Material		asphaltic concrete	asphaltic concrete	asphaltic concrete
Thickness of New Surfacing (mm)		50	50	N/A
Dry Season Strength Coefficient		0.4	0.4	N/A
Depth of Milling (mm)		50	50	10
Unit Cost Applied in HDM-4		$\$5/m^2$	$\$6/m^2$	$\$2.50/m^2$
PPS Guideline (June 2002)		$\$5/m^2$	$\$6/m^2$	$\$2.50/m^2$
Life of Treatment- PPS Guideline (June 2002)		9 years	11 years	1-2 years
Condition After Work	roughness	derived	derived	derived
	mean rut depth (mm)			
Surface Characteristics	surface texture (mm)	0.7	0.7	0.7
	skid resistance	0.5	0.5	0.5

Table 4. Mill and Replace Operations

Economic values such as the discount rate and analysis period are also required.

Calibration

In order to improve the ability of HDM-4 to model local conditions and deterioration curves, a sample road network was made up of three different road classifications. This sample network was designed to reflect the main types of road in Alberta: divided, major two lane and minor two lane. Each of the possible pavement preservation strategy treatments were then modeled in HDM-4. A life-cycle strategy was then designed to perform each of the treatments on all three types of highway. Based on the analysis reports, calibration factors were adjusted to achieve results that were representative of conditions and performance seen in Alberta. This was used to improve the validity of the results that were obtained for the actual candidate projects. However, the calibration values used are considered rudimentary.

Analysis

The pilot study used the life cycle analysis option in HDM-4. At least two treatment options must be provided for comparison. One option is the "do minimum" or base case. "Do minimum" is applying only normal, routine surface maintenance activities. The incremental benefits derived from implementing other options are calculated over the specified analysis period by comparing the predicted economic cost streams in each year against that of the base case. The discounted difference is the net present value. A summary of the economic indicators for one of the candidate projects is shown in Table 5.

Alternative	Present Value of Total Agency Costs [RAC]	Present Value of Agency Capital Costs [CAP]	Increase in Agency Costs [C]	Decrease in User Costs [B]	Net Exogenous Benefits [E]	Net Present Value [NPV = B+E-C]	NPV/Cost Ratio [NPV/RAC]	NPV/Cost Ratio [NPV/CAP]	Internal Rate of Return [IRR]
base alternative	1.202	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
skin patch (hot mix)	2.576	2.437	1.374	87.776	0.000	86.402	33.538	35.448	52.800

Table 5. Economic Indicators Summary for Hwy 2:46 km 42.9 – 59.3

Road agency costs include capital, recurrent and special work. Road user costs include vehicle operation and travel time costs, and accident costs. The increase in agency costs and decrease in user costs is relative to the base case.

Results

The HDM-4 ranking of the rehabilitation projects using the incremental NPV/cost ratio was compared to the CRS results. Table 6 shows a sample of the 57 rehabilitation projects. The resulting CRS and NPV/RAC ratings were found to be similar. The final provincial rankings were somewhat different due to the modification of the raw scores for subjective factors such as design readiness, winter crushing, tendering schedules and cash-flow.

Project	NPV/RAC	NPV/CAP	CRS Rank	Prov Rank
Hwy 2:15 km 49.661 - 52.891 (R0)	294.786	305.493	840	2004-58
Hwy 2:15 km 49.661 - 52.863 (L0)	262.474	268.733	840	2004-58
Hwy 2:24 km 25.20 - 33.066 (R0)	143.831	148.538	920	2004-12
Hwy 2:18 km 10.780 - 23.130 (L0)	111.295	113.582	915	2004-14
Hwy 22:14 km 0.510 - 19.680 (C1)	53.654	56.553	807	2004-82
Hwy 16A:16 km 0 - 6.790 (R0)	53.040	53.940	890	2004-22
Hwy 35:12 km 4.514 - 14.400 (C1)	52.990	54.988	782	2004-88
Hwy 41:24 km 0 - 0.510 (C1)	48.157	50.519	825	2004-72

Table 6. Sample Comparison Ranking of Candidate Rehabilitation Projects

HDM-4 was then used to rank the 520 pavement preservation activities to assist the Program Management branch in determining the pavement preservation multi-year work program. As shown by the sample results in Table 7, HDM-4 was able to prioritize across different preservation activities that have substantially different application costs and expected performance characteristics.

District	Highway	Preservation Activity	NPC/RAC	NPC/CAP	Cost (2004)
Lethbridge 73	501:01 km 0 - 4.530	thin overlay	40.096	42.309	$189,245
Grande Prairie 59	2:66 km 19.5 - 27.000	thin overlay	39.27	40.997	$326,748
Lethbridge 43	531:02 km 4.9 - 17.1	rout and seal	36.593	37.921	$4,880
Edson 49	22:32 km 0 - 17.067	spray patch (cracks)	35.642	38.071	$27,711
Edson 14	32:08 km 0 - 1.796	thin overlay	35.61	37.249	$59,680
Lethbridge 44	531:02 km 0 - 4.9	skin patch hot mix	35.351	37.103	$424
Vermilion 77	13:14 km 7.498 - 29.338	thin overlay	34.548	36.067	$920,534
Edson 45	658:02 km 26 - 40.710	thin overlay	34.186	36.074	$503,550
Athabasca 42	28:10 km 21 - 29.610	spray patch (cracks)	33.147	35.086	$15,800
Stony Plain 11	43:22 km 14.065 - 23.830	chip seal	31.597	33.838	$278,548

Table 7. Sample Ranking of Pavement Preservation Activities

Conclusions

The pilot study showed that an economic analysis-based decision support system can be successfully used on Alberta's provincial highway network to prioritize the development of a multi-year pavement preservation work program.

Such a system has extensive data requirements, not just in the current and historical physical attributes of the highway but also in the vehicle fleet and associated costs. The use of such a system therefore requires a comprehensive asset inventory that includes physical, cost, vehicle, traffic and climatic data. This data must be collected and stored in a manner that is compatible with and readily accessible by the decision support system to minimize data entry and manipulation.

The life cycle performance of the preservation treatments or activities must be known, and the deterioration models used in the decision support system must reasonably represent this performance. This can only be achieved if the application of the treatments meets specified performance standards.

Recommendations and Future Research

Alberta Transportation is implementing a pavement preservation strategy. Over 40 preservation projects were completed in 2003 at a cost of $2.4 million. A similar number will be completed in

2004. This is expected to increase over time as the department gains experience with the performance of these interventions.

The department is monitoring the performance of the preservation projects to improve its deterioration models.

The department is assessing its data collection requirements with the intent of improving its asset inventory.

The preservation treatment specifications are being reviewed to ensure they incorporate adequate engineering, quality control, workmanship and end product performance so that the applied treatments achieve the expected highway condition improvements.

Alberta Transportation has installed HERS-ST and is conducting an assessment of its capabilities and requirements.

References

1. Alberta Financial Management Commission, *Moving from Good to Great: Enhancing Alberta's Fiscal Framework.* Alberta Government, July 2002.
2. Alberta Transportation, *Guidelines for Assessing Pavement Preservation Strategies.* June 2002.
3. Federation of Canadian Municipalities and National Research Council, *Timely Preventative Maintenance for Municipal Roads – A Primer.* National Guide to Sustainable Municipal Infrastructure. September 2002.
4. Wright, P.H., *Highway Engineering*. John Wiley and Sons Inc, 6th Edition, 1996
5. Transportation Research Board, *Transportation Programming Process.* Special Report 157, 1975.
6. Carstens R.L., *Optimizing Economic Return on Highway Investment.* Transportation Engineering Journal, November 1976
7. Transportation Research Board, *Transportation Programming Process.* Transportation Research Record 867. 1982.
8. Transportation Research Board, *Conference on Transportation Programming Methods and Issues*. TRB Circular 465, December 1996
9. Transportation Association of Canada, *A Primer on Transportation Investment and Economic Development.* 1994
10. PIARC, *HDM-4 Highway Development and Management, Vol. 1 – Overview.* ISOHDM Project Coordinator, The World Road Association, Paris, France. 1999
11. U.S. Department of Transportation, Federal Highway Administration. *HERS-ST Highway Economic Requirements System – State Version*. Pilot Project Report. 2002.
12. Alberta Transportation, Program Management branch, Edwin Ma and Brenda Knopp. *HDM-4 Pilot Project, Pavement Preservation and Rehabilitation, Program Prioritization. Final Report*. August 2003.