Dedicated Pavement Type Networks Based On a Probabilistic Life-Cycle Cost Analysis

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Abstract

In 2001, the Québec Ministry of Transportation (MTQ), in Canada, adopted a policy subdividing the existing pavement network into dedicated concrete and asphalt networks. This paper summarizes the methodology used for determining these respective networks using probabilistic Life Cycle Cost Analysis (LCCA) and provides an assessment of the situation four years after implementation. Sixteen (16) different combinations of Average Annual Daily Traffic (AADT), number of lanes, truck percentage, and truck factor yielded 32 pavement designs in asphalt and concrete that were compared in pairs over an analysis period of 50 years using a probabilistic LCCA software. Regression equations were used to generalize the results of these standard cases. The network allocation criteria were determined by applying dominance tests to these probabilistic results; in the areas without clear dominance further analyses would be necessary using project-specific data. After minor adjustments to ensure continuity, the respective networks ("white" for concrete, "black" for asphalt and "gray" for further analysis) were established officially. Since 2001, the clarity and convenience of this policy were seemingly appreciated both by the industry and MTQ officials

Introduction

Until year 2001, the MTQ (Québec Ministry of Transportation) policy for pavement type selection on existing roads was that concrete pavements remained in concrete and asphalt pavements remained in asphalt, unless a technical and economic analysis concluded otherwise. The nature and methodology of these analyses were not specified, so for most rehabilitation projects objections were raised either from the asphalt or concrete industry about the choice made by the MTQ: results of the analyses were disputed, hypotheses were challenged, costs and performance of future treatments were questioned, etc.

In 2001, a new policy on pavement type selection (Transports Québec 2001) was adopted which defined dedicated asphalt and concrete pavement networks after an extensive study, using a probabilistic Life Cycle Cost Analysis (LCCA) method,

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determined which conditions were best for each pavement type. The main benefits of a dedicated networks approach compared to the previous policy are:

- There are no disparities in the decision process between different territories in the Province.
- The cost-effectiveness and economic viability of both pavement types were demonstrated on a comparable basis in the study, according to the hypotheses that were used.
- A minimum market is granted to both industries, giving them more stability and encouraging the preservation and development of their expertise.
- The controversy over specific projects is ended.

This paper should be of great interest for practitioners of Administrations wishing to implement such an approach for selecting pavement types within their road network.

Probabilistic Life Cycle Cost Analysis.

The purpose of the LCCA method is to determine, among several possible alternatives, the one for which the Net Present Value (NPV) – that is, the sum of all the discounted costs anticipated over the analysis period – is lowest. Since the estimation of LCCA parameters always entail some degree of uncertainty, a probabilistic method was employed to account for this uncertainty and measure its influence on the results.

The Visual/LCCA™ software, a module which is part of the MTQ's pavement management system developed by Texas Research and Development Inc. (TRDI – now AgileAssets Inc.), was used to perform the analyses. This software calculates the NPV of several alternatives, including work zone user costs if desired. It takes into account the probabilistic uncertainty for the following four parameters: reconstruction and rehabilitation treatment costs, duration of treatment life, traffic growth rate and discount rate. A function can also be used to carry out sensitivity analyses of the main variables. The uncertainty about the basic parameters was taken into account by means of a triangular probability distribution, based on the minimum, maximum and most likely values estimated. This type of distribution is more concrete and easier to use than a Gaussian distribution. The Monte Carlo sampling simulation technique is used by the software to compute the NPV distribution resulting from the variability of the parameters. Typically, 10,000 simulation runs were performed for each analysis.

Since the LCCA method is normally used at the project level, 16 standard cases most representative of the conditions encountered on the MTQ road network were defined and then analyzed by comparing a concrete pavement reconstruction alternative to an asphalt pavement reconstruction alternative for each. The factors defining these standard cases are the Annual Average Daily Traffic (AADT), the percentage of trucks, the number of lanes in each direction and the load spectrum type (local or transit) with the associated truck factor. Local traffic mainly consists of single-unit trucks with a lower truck factor than transit traffic, which mainly consists of semi-trailers (see Table 1).

Table 1. Standard cases numbering and description.

Type of Load Spectrum		Local	Local	Transit	Transit
	% Trucks	5	10	10	25
	Truck Factor*	1	1	2	3.2
Lanes per direction	AADT				
2	20 000	1	2	3	4
2	40 000	5	6	7	8
3	50 000	9	10	11	12
3	90 000	13	14	15	16

*: Equivalent Single Axle Load per truck

Thickness Design of Standard Cases. The pavement structures of the concrete and asphalt alternatives were designed for each standard case to estimate the cost of initial reconstruction, given that this study concerned an existing network. Various other rehabilitation methods for existing pavements could have been considered, but for a study on a network scale this would have necessitated the analysis of too many cases. The thickness design method and parameters employed are those commonly used at the MTQ. For instance, the design periods used were 30 years for concrete pavements and 20 years for asphalt pavements.

In the MTQ pavement thickness design method, two criteria must be met: structural capacity based on the AASHTO pavement design guide (AASHTO 1993), and partial protection from frost. The greatest total thickness resulting from the calculations for both these criteria is selected. Some examples of the pavement structures designed are presented in Tables 2 and 3.

The common design parameters for all standard cases were based on the average or most representative conditions encountered in southern Québec. For example, the subgrade was a very fine sand and the freezing index was 1000°C-days. The annual traffic growth rate was set at 1.5 ± 0.5%.

Table 2. Examples of concrete pavement layer thicknesses [mm] for 4 standard cases.

Case Layer	1	6	11	16
Concrete	180	226	253	337
Base	150	150	150	150
Subbase	749	703	676	592

Table 3. Examples of asphalt pavement layer thicknesses [mm] for 4 standard cases.

Case / Layer	1	6	11	16
Asphalt	153	204	231	313
Base	199	194	196	184
Subbase	727	681	652	593

Sequence of Treatments. A sequence of future treatments was established for each alternative to cover the 50 year analysis period. The treatments chosen are well-mastered techniques commonly used in Québec. Several other techniques exist but were not selected to limit the number of cases to be analyzed.

For the concrete pavement alternative, the sequence involves three rehabilitation treatments during the analysis period. The initial treatment is the complete reconstruction of the pavement to a thickness corresponding to the partial frost protection. The second treatment is the restoration of 8% of the slab area, followed by diamond grinding of the surface and joint resealing. The last treatment is partial reconstruction, that is, removal and replacement of the concrete slab without removing the base layer. The routine maintenance activity taken into account for the concrete alternative is periodic joint resealing.

The asphalt pavement alternative involves seven rehabilitation treatments. The first treatment is a reconstruction similar to that of the concrete pavement alternative, except for the nature and thickness of the surface layer. Two asphalt overlays follow. Partial-depth reconstruction of the pavement is then planned and consists of an in-place recycling and stabilization of the pavement overlaid with a new asphalt surface course. Two other asphalt overlays are carried out, and finally a last partial-depth asphalt reconstruction, similar to the 4th treatment, is planned. The routine maintenance activity associated with each treatment of the asphalt alternative is crack sealing.

Treatment Life. After the sequences of treatments were established for the two alternatives, the life of each treatment was determined. Treatment life is defined as the number of years before the next treatment. These were established based on the MTQ's LCCA Guide (Transports Québec 1999).

The treatment lives for the concrete alternative are presented in Table 4. For this alternative, the same treatment lives were retained for all standard cases, given that concrete pavements are structurally designed to withstand heavy traffic and are not much prone to surface characteristics degradation by traffic.

Table 4. Treatment lives for the concrete pavement alternative for all standard cases.

Treatment	Treatment Sequence	Treatment life [years]
Complete Reconstruction	1	29 ± 5
Slab Restoration	2	10 ± 2
Slab Reconstruction	3	29 ± 5

For the asphalt pavement alternative, the treatment life varied from case to case, diminishing as a function of both the AADT and proportion of trucks, because even though the structural design period is identical for all standard cases, some defects like ruts, wear and cracks, as well as the roughness, deteriorate more quickly on roads with high traffic volumes. Some examples are presented in Table 5.

Table 5. Treatment lives for the asphalt pavement alternative for 4 standard cases.

Treatment	Treatment Sequence	Treatment life [years]			
		Case 1	Case 6	Case 11	Case 16
Complete Reconstruction	1	14 ± 2	13 ± 2	11 ± 2	9 ± 2
Asphalt Overlay	2-3	12 ± 2	11 ± 2	9 ± 2	7 ± 2
Partial-Depth Reconstruction	4	14 ± 2	13 ± 2	11 ± 2	9 ± 2
Asphalt Overlay	5-6	12 ± 2	11 ± 2	9 ± 2	7 ± 2
Partial–Depth Reconstruction	7	14 ± 2	13 ± 2	11 ± 2	9 ± 2

Regarding the routine maintenance activities, joint resealing is scheduled on a 7-year frequency after each reconstruction treatment for the concrete pavement alternative, while crack sealing is scheduled 2 years after each treatment for the asphalt alternative.

Agency Costs. The reconstruction, maintenance, rehabilitation and administration costs, as well as the remaining service life value, are the Agency costs considered in this analysis.

The unit construction costs (materials and work) are based on the average historical costs for similar work. Table 6 indicates the main unit costs used.

Table 6. Construction unit costs.

Materials	Minimum Cost ($CAN/m^3)	Average Cost ($CAN/m^3)	Maximum Cost ($CAN/m^3)
Concrete Slab	144	155	170
Asphalt Layers	122	139	156
Base	17	21	24
Subbase	13	16	20

For the initial reconstruction, only the costs that differ from one alternative to the other have been taken into account. The unit costs of subsequent treatments are based on current costs, since there is no indication they will trend differently in the future.

Administration costs, taken as the cost of work zone traffic control, were associated with each treatment. It is difficult to differentiate alternatives in this regard at the network level, so a fixed percentage of the construction cost, established at 17%, was used for this type of costs.

The remaining service life value is based on the cost of the last rehabilitation treatment and the percentage of design life of that treatment remaining at the end of the analysis period. It is calculated automatically by the software.

The unit costs were applied to a 5 km pavement section in order to represent the overall cost of an average project.

Discount Rate. The discount rate recommended at the MTQ for LCCA is 5%. This rate represents the opportunity cost of money for the public at large, computed from the historical interest rate of bonds issued by the government minus inflation. The uncertainty for this parameter is estimated at ± 1 %.

Work Zone User Costs. The Visual/LCCA™ software calculates work zone user costs according to the United States Federal Highway Administration "Life Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin" (FHWA 1998) which makes use of the 1972 NCHRP Report 133 (National Research Council, Highway Research Board, 1972) based on a study by Winfrey from 1969. The costs obtained by this method are in 1970 U.S. dollars and must be converted into today's Canadian dollars by means of an escalation factor. At the MTQ, this factor is established annually by the Economics and Transportation Master Plan Service. For this study, the escalation factor was 4.199.

Work zone user costs were computed in an initial analysis, but upon examination of the results anomalies raised enough doubts for this type of costs not to be considered in further analyses. The main problem encountered when including user costs in the probabilistic LCCA is that NPV distribution is often bimodal instead of the unimodal distribution obtained when only Agency costs are considered. When the distribution is bimodal, the mean value and the standard deviation are still calculated by the software as if a normal distribution were involved.

In Figure 1, for example, the NPV of alternative B could either be significantly lower or significantly higher than that of alternative A even though both mean values may be quite similar.

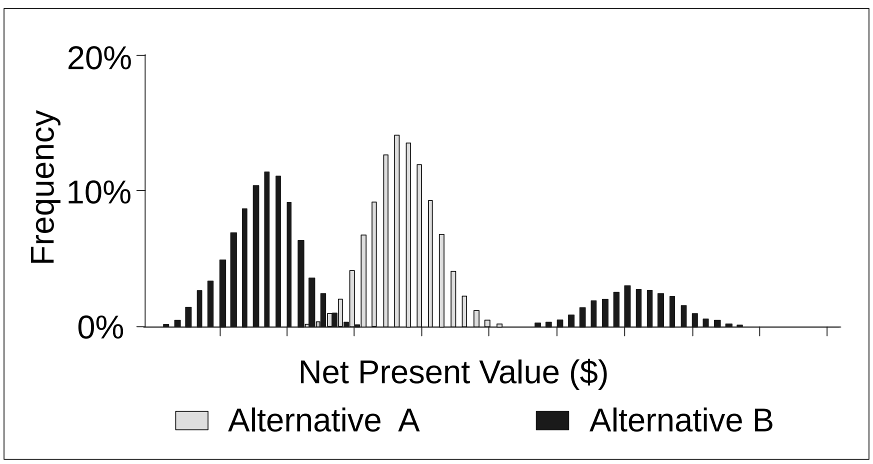

Figure 1. Example of bimodal NPV distribution.

The most obvious explanation for this phenomenon is that no remaining service life values were considered for work zone user costs by the software we used. When a treatment occurs near the end of the analysis period, the construction cost is practically negligible due to discounting and the remaining service life value applied to it. By opposition, the user costs generated by this treatment are much greater, in part due to the exponential increase in traffic over time, which makes up to a certain extent for the discount rate, but even more so because no remaining service life value is considered to reduce these costs.

So in Figure 1, the NPV of alternative B would be higher for the simulation runs where the treatment lives are shorter, so that the last treatment and the user costs it generates arrive just before the end of the analysis period, and it would be much lower for the simulation runs where the treatment lives are longer, when this major treatment would occur only after the end of the analysis period.

This phenomenon creates at least three problems: first, it is very difficult to identify the best alternative in a case like the one in Figure 1; second, the NPV of both alternatives are affected but it is not possible to know to what extent; and third, it impossible to perform regression analyses to generalize the results because the mean and standard deviation are not representative of the distribution.

Even when NPV distribution is unimodal the lack of a remaining service life for user costs distorts the results: the alternatives are not compared on a fair basis because the last treatment incurring user costs within the analysis period will not happen at the same time for different alternatives and will generally not have the same life expectancy. If only in principle, the same logic that assigns a value to the remaining service life of a pavement treatment at the end of the analysis period should allow amortization of the work zone user costs over the life of the treatment by which they are caused. At the end of the analysis period, the portion of the user costs that will not have to be incurred before the next treatment represent a benefit in comparison to an alternative that would require a treatment sooner, and on this basis should be considered in the analysis so that alternatives are compared fairly.

The literature we consulted at the time showed no mention of a remaining service life value being considered for work zone user costs and TRDI programmers did not want to depart from FHWA recommendations then. Meanwhile, a new primer about Life-Cycle Cost Analysis was published (United States Department of Transportation, Federal Highway Administration 2002) as well as the software "RealCost" (United States Department of Transportation, Federal Highway Administration 2004), in which it is not only possible but also recommended to include the remaining service life value of work zone user costs in life-cycle cost analyses. In the light of our experience with this project, we can only emphasize even more the importance and appropriateness of always doing so.

Calculations. After all the parameters were determined, the 16 standard cases were analyzed with the Visual/LCCA™ software.

The results of the Monte Carlo simulation runs are best illustrated as NPV frequency distributions for the concrete and asphalt alternatives. Figure 2 shows the NPV distribution for a case where the results of both alternatives overlap considerably (Case 8) and a case where the overlap is not significant (Case 16).

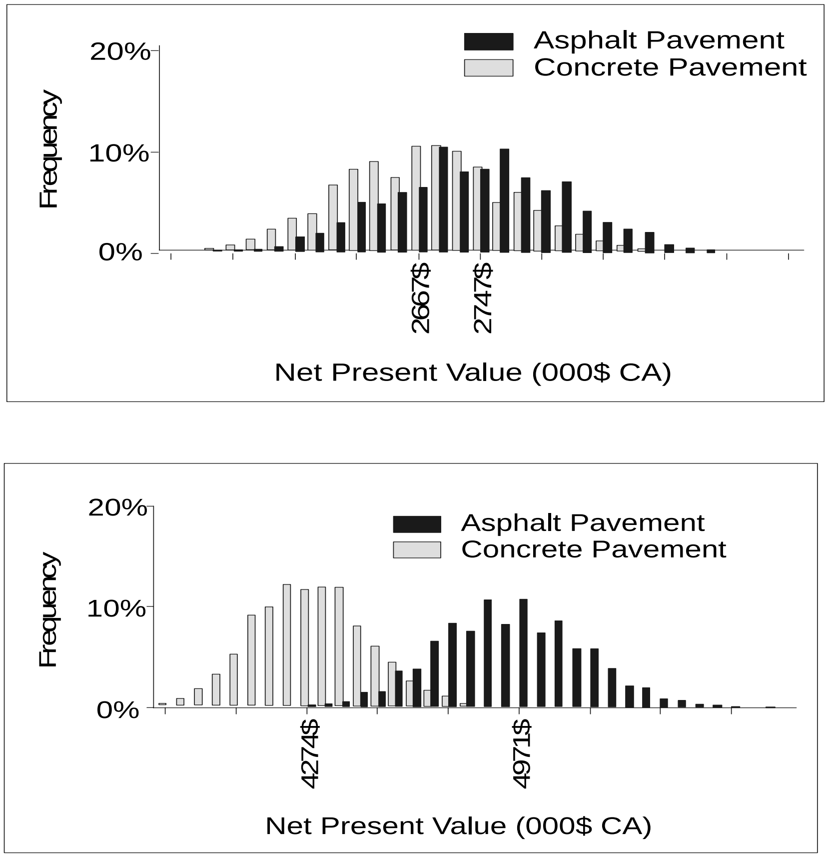

Figure 2. NPV distribution for Cases 8 and 16, without user costs.

Generalization of the Results

Regression Analyses. For every standard case, the mean value and the standard deviation of the NPV distribution for each alternative were calculated by the software.

Several empirical tests were necessary to determine the parameter to which the NPV could be correlated to generalize the results of the standard cases analysis, so that they could be extrapolated to other conditions. This parameter turned out to be the number of trucks, that is, the percentage of trucks multiplied by the AADT. However, it was not possible to obtain a unique regression equation fitting the 16 standard cases so they had to be subdivided into 4 regression categories based on the number of lanes in each direction and the load spectrum type (see Table 7).

Table 7. Regression Categories.

Category	Case Number
Local 2 lanes	1-2-5-6
Local 3 lanes	9-10-13-14
Transit 2 lanes	3-4-7-8
Transit 3 lanes	11-12-15-16

For each category, the mean NPV values of each alternative were plotted on a graph according to the number of trucks specific to each standard case. A polynomial regression equation was then determined and a break-even point could be identified (see Figure 3).

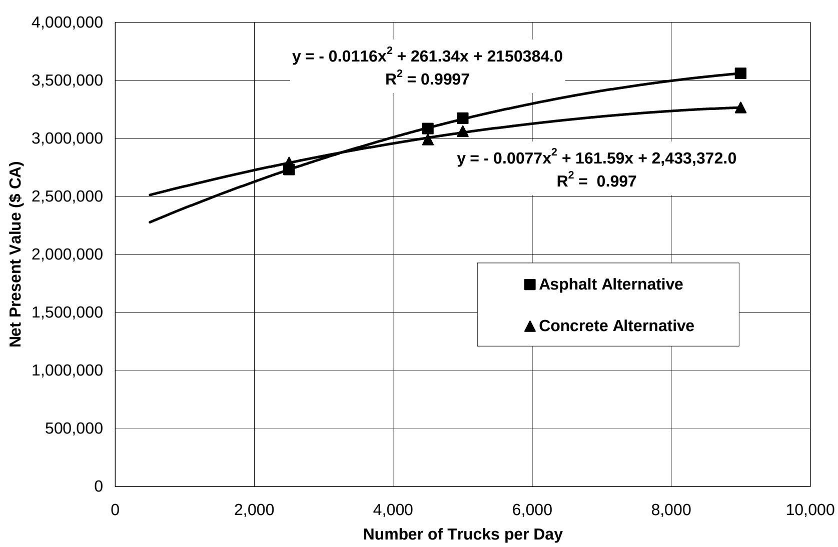

Figure 3. Example of NPV regression for the “Local 3 lanes” category.

Regression curves were also established for the standard deviations. When these are added to the previous curves, the break-even point becomes a zone where both alternatives show at least some probability of having the lowest NPV. Figure 4 shows the large scope of the overlap zone when a variability of ± 2σ is considered.

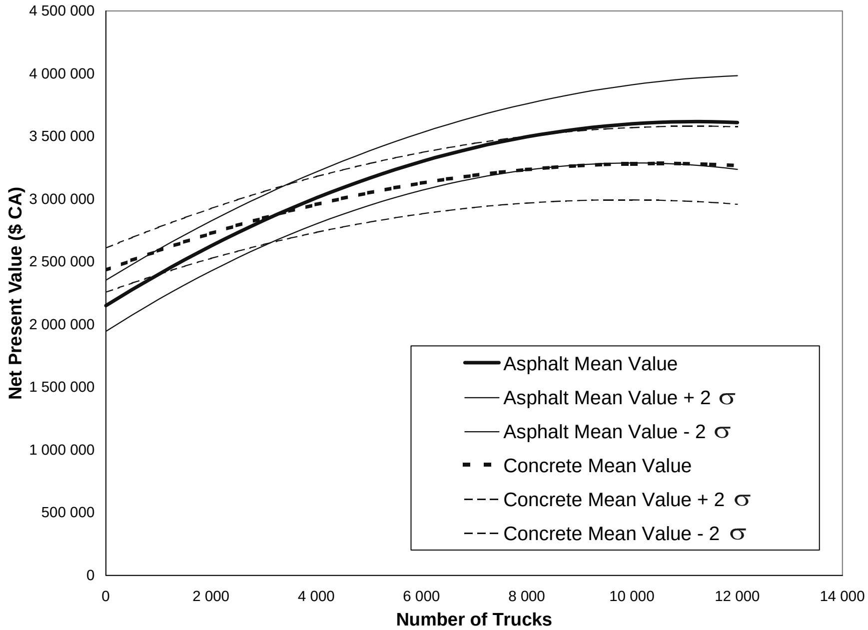

Figure 4. Example of regression curves, including variability, for the "Local 3 lanes" category

The mean values (μ) and standard deviations (σ) of the NPV for selected levels of truck traffic calculated from the regression equations for the "Local 3 lanes" category are listed in Table 8 for each pavement type.

Table 8. Regression results for the "Local 3 lanes" category.

	Asphalt Pavement		Concrete Pavement	
Trucks / day	μ_A (000$CA)	σ_A (000$CA)	μ_C (000$CA)	σ_C (000$CA)
0	2 150	102	2 433	88
2 000	2 626	99	2 726	99
4 000	3 091	104	2 957	111
6 000	3 299	115	3 127	122
8 000	3 496	132	3 235	133

Dominance Tests. Given the large area of the break-even zone and its probabilistic nature, some kind of statistical test was required to decide between alternatives. Dominance tests allow an evaluation of the extent to which one alternative can be dissociated from the other. It represents the probability that the NPV of an alternative may be greater or less than that of the other.

The dominance level may range from 0 to 1. A value of 1 means that one alternative totally dominates the other, while a dominance of 0 means that this alternative is totally dominated by the other. A dominance level of 0.5 means that each of the two alternatives has a 50% probability of dominating the other, which is the same as saying they are equivalent. By convention, within the framework of this study, a dominance of 1 means that the NPV of the concrete pavement alternative for a given case has a 100% probability of being greater than the NPV of the asphalt pavement alternative, while a dominance of 0 means that it has a 0% probability of being higher. Usually, a dominance over 0.85 or under 0.15 is considered significant, to the advantage of either alternative.

The dominance level is calculated by application of the normal distribution to the difference between the regression mean values of both alternatives for each truck traffic level. Thus, the standard normal distribution parameters defining the dominance level are as follows:

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-u^2/2} du$$

where:

$\Phi(z)$: Dominance level, i.e., probability that the NPV of the concrete pavement alternative is greater than the NPV of the asphalt pavement alternative

$$z = \frac{\mu_C - \mu_A}{\sigma}$$

$$\sigma = \sqrt{(\sigma_C)^2 + (\sigma_A)^2}$$

μ_C, σ_C: Mean value and standard deviation for concrete

μ_A, σ_A: Mean value and standard deviation for asphalt

The results of the dominance level calculations for the "Local 3 lanes" category are shown in Table 9 for selected levels of truck traffic.

Table 9. Dominance levels for the "Local 3 lanes" category

Trucks/day	Dominance $\Phi(z)$
0	0.982
2 000	0.760
4 000	0.365
6 000	0.152
8 000	0.082

Multiple Criteria Analysis

In parallel to the LCCA, a multiple criteria analysis was performed to account for a certain number of factors that are not easily quantifiable in monetary terms. This tool is normally used at the project level, since more details are known, but at the network level the number of criteria that can be evaluated is very limited.

After examining several potential criteria, the most significant ones retained were road de-icing and pavement marking. These factors certainly involve a cost difference between the alternatives, but also differences that are difficult to quantify regarding their impact on user safety, organization of operations, and network condition monitoring. The result of the multiple criteria analysis favored the asphalt pavement alternative in a proportion of 60 points to 40. However, it was estimated that the factors considered should only have a weight of about 10% in the decision compared to the LCCA results.

Determination of the Respective Concrete and Asphalt Networks

Allocation Criteria. In a first try, dominance levels of 0.85 and 0.15 were used to visualize what the dedicated networks would look like. By definition, this exercise would identify three networks: a preferred one for asphalt pavements, with a dominance of 0.85 or more, a preferred one for concrete pavements, with a dominance of 0.15 or less, and a gray zone for dominance levels between 0.15 and 0.85. At the end of this exercise, the results were plotted on a map to assess the scope and geographic distribution of these networks. The concrete pavements would have totaled 401 km while the gray network would have totaled 3138 km. The gray network was much too big, requiring many additional studies at the project level to identify the best alternative, and actually making the entire approach pointless. Moreover, several concrete pavement sections were isolated from each other, which presented several disadvantages, particularly regarding the discontinuity of maintenance operations and the scattering of expertise.

Another possibility would have been to subdivide the network based on a dominance level of 0.50. Such an option has the merit of establishing a clear situation from the outset, with no gray network. However, this path was not chosen either, because it was considered by the policy steering committee that a gray network would encourage competition and innovation, and also because it allows local conditions to be considered in more detail at the project level than at the network level.

It was therefore agreed to set the dominance limits at levels that would remain significant while keeping the gray network to a manageable size. Moreover, so that the results of the multiple criteria analysis favoring asphalt pavement would also be taken into account, it was considered that the concrete pavement alternative should be a little more dominant than the asphalt alternative to be considered equivalent.

The dominance limits finally chosen for the determination of the dedicated networks are as follows:

- Dominance of 0.35 or less: concrete (white network).
- 0.35 < dominance < 0.60: concrete or asphalt (gray network).
- Dominance of 0.60 or more: asphalt (black network).

All sections of the pavement network were classified in one of the 4 regression categories. For this purpose, pavements located near major urban centers were classified in the local traffic regression categories while pavements located in more rural areas were considered in the transit traffic categories. The 1996 traffic survey data served as a basis for the exercise, since they were the most recent official data.

Figure 5 shows an example of determination of the number of trucks for the allocation criteria of the "Local 3 lanes" category and Table 10 presents the values for all 4 regression categories.

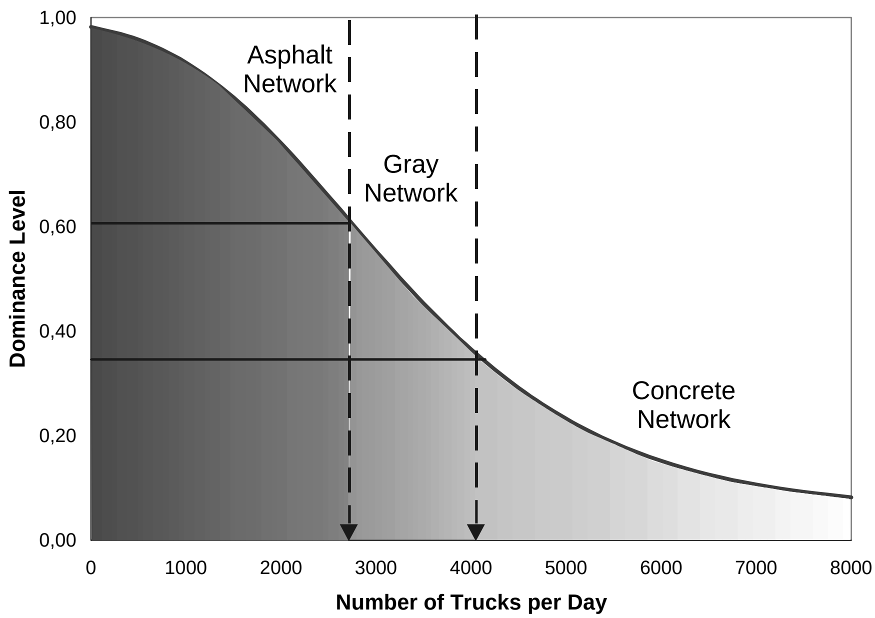

Figure 5. Dominance curve for the "Local 3 lanes" category

Table 10. Allocation criteria in number of trucks per day.

Dominance		0.60	0.35
Expressways 3 lanes or more in one direction	Local	2 700	4 000
	Transit	0	3 000
Other Roads	Local	3 700	N.A.*
	Transit	4 200	8 000

*: The number of trucks per day corresponding to this dominance level exceeds the values encountered on the network

Network Allocation. Application of the Table 10 criteria to all the pavement sections of the road network made it possible to define a dedicated concrete pavement network of 761 km and a gray network of 364 km, while the rest of the network is dedicated to asphalt pavements. The road sections constituting these networks were plotted on a map. The dedicated concrete and asphalt pavement networks were reasonably continuous and only slight adjustments were necessary. The continuity of the concrete pavement network, because of its specificity, was particularly desired to homogenize pavement behavior, facilitate winter and summer maintenance operations, simplify the management of pavement surveys and monitoring, and allow a concentration of specialized personnel in the regions concerned.

The gray network consists of several discontinuous sections and it was agreed that these sections should not exceed 30 km in length and ought to be immediately adjacent to a concrete pavement section, to avoid the eventual presence of isolated concrete sections resulting from the analysis at the project level.

Figure 6 shows part of the MTQ road network around the Montréal region, where most of the concrete pavements are located. The dedicated networks are distinguished by their associated colors: white, gray and black.

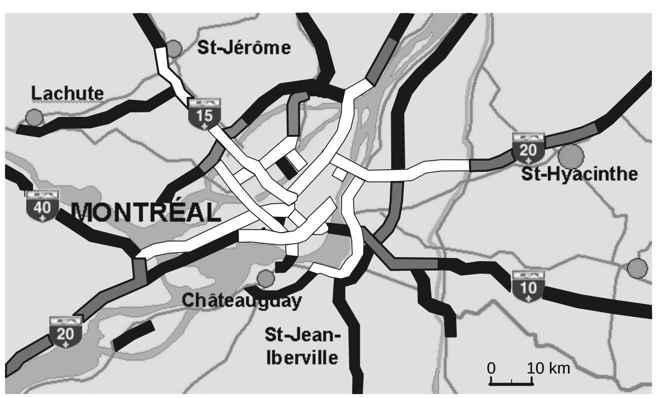

Figure 6. Map of the Montréal region

Policy Application

Details. The Departmental Policy on Pavement Type Selection [1] not only identifies the respective pavement type networks but also specifies detailed instructions for its application. For example, if an existing pavement is not of the same type as indicated by the new network allocation, the change in pavement type will only occur when a reconstruction or major rehabilitation is required, whichever of the three networks is involved. Treatments normally included in the pavement life cycle before major rehabilitation therefore remain associated with the existing pavement type.

The guidelines are a little more elaborate concerning the gray network:

- During the preparation of major rehabilitation projects, detailed studies are necessary to select the appropriate pavement type.
- These studies must involve LCCA, including work zone user costs, and multiple criteria analyses adapted to each project's specific conditions.
- These studies are under the responsibility of the territorial administrative unit, but must be validated by the Pavement Service of the Pavement Laboratory Directorate, which is responsible for ensuring a coherent approach throughout the province of Québec.

New pavements are treated like the gray network for all expressways having three lanes or more per direction and for other expressways or national highways where the average AADTT over the first 10 years is least 3 500. All other new pavements are to be in asphalt.

Application assessment. From its inception in 2001 this policy has lived up to MTQ's expectations. Experience has proven the approach well-founded since pavement types are assigned based on technical and economical criteria, a minimum market is secured for both pavement types and a uniform selection process has been implemented for "gray" zones and new pavements analyses. Two gray zone analyses were performed up to now, one favoring concrete and the other favoring asphalt. Two derogations to the concrete network were granted in asphalt for exceptional reasons: in the first case the project length was very short and would be included in a much larger concrete pavement reconstruction project within 10 years, and in the second case the future truck traffic is expected to decrease considerably because of the construction within five years of a new expressway close by. The pavement type selection for this new expressway project is in the process of being analyzed in accordance with the new policy.

Asphalt and cement industries accepted the policy as a good beginning, both openly wishing to increase their own part of the network sooner or later. This policy is scheduled for review on a five year basis but it would not seem very practical to change the pavement type distribution a lot since the "black" and "white" networks are essentially continuous in the existing policy and ideally the "gray" zones should not be shifted much, especially those already analyzed.

Conclusion

The study carried out made it possible to determine, for each section of the pavement network, the respective probabilities that asphalt or concrete would be the alternative with the lowest Net Present Value for the foreseeable construction, maintenance and rehabilitation costs over a 50-year period. The use of dominance tests led to the determination of three networks, one dedicated to concrete pavements ("white" zone), one dedicated to asphalt pavements ("black" zone), and one where further analysis is required at the project level ("gray" zone).

The concrete pavement network obtained largely corresponds to MTQ's existing one and the few exceptions can generally be explained by specific contexts. This gives credibility to the approach followed, and therefore the final result was well received by MTQ authorities and the industry.

Work zone user costs should be taken into account in future analyses, including the calculation of their remaining service life values. A more flexible traffic growth model in the LCCA software would also be desirable to better reflect the AADT leveling off once the road capacity is reached instead of always increasing exponentially, or a command should be available to limit the maximum traffic value. This study has demonstrated the importance of these matters but the good news is there are now tools to do it, notably FHWA's RealCost software.

Although, work zone user costs were not taken into account in this study, it was observed that they correlated well with the total traffic volume while construction costs rather correlated with the volume of trucks. This makes no difference for "gray" zone analyses but may complicate the regression analyses quite a lot for the allocation of pavement type networks if considering work zone user costs.

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