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UNLEASHING THE COST SAVINGS OF OPTIMIZED ROAD ASSET MANAGEMENT TO MUNICIPALITIES

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Abstract: There is a persistent belief within the municipal sector in Canada that we will eventually solve the infrastructure investment deficit and be able to bring all our roads up to an acceptable standard. The reality is that this is unlikely to ever happen. However, in the meantime municipal expenditures on road rehabilitation assumes this to be the case and is largely based on a "worst first" approach. Under this strategy, the most deteriorated roads, which require total reconstruction, are a huge sink into which the largest proportion of municipal road budgets is poured. This paper presents the results of a recent survey on road assets preservation with 171 participants representing 45,000 km of paved road, 15% of Canada's population, and a wide range of municipalities by region and population. Next, the paper discusses a new approach to maintaining municipal road assets underpinned by a powerful analytical optimization tool originated by many years of research at the University of Waterloo. This decision support tool uses advanced mathematical programming to model big data and performs a multi-year analysis to maximize network performance over the entire planning horizon, considering all the municipal constraints. It allows the entire array of road preservation and rehabilitation treatments to be realistically modelled to give municipalities the ability to quickly see how much money they can save, or spend more wisely. To date, some 50 municipalities from across Canada have committed to helping to develop and implement this new software and are providing their roads data for analysis.

1 INTRODUCTION

The World Road Association states that: "Road infrastructure provides a fundamental foundation to the performance of all national economies, delivering a wide range of economic and social benefits." Preserving and maintaining Canada's transportation infrastructure is a necessary and expensive endeavor. The 2016 Canadian Infrastructure Report Card reports a $48 billion replacement cost for roads currently in poor condition, and a further $75 billion replacement cost for roads in currently fair condition. Further, the Report Card states that roads present one of the largest gaps between current and target rates of reinvestment, with a current reinvestment rate of 1.1% and a target recommended rate of investment at 2% to 3% as a percentage of asset replacement value. Current levels of spending are not adequate, the condition of our roads is declining, and municipalities need a more effective road network capital planning strategy. Data from the Association of Municipalities of Ontario (AMO, 2015) indicates that 67% of the roads in Ontario are under municipal jurisdiction, amounting to 140,000 km of public roads. It is estimated that the combined operating budget for these municipalities is in the range of $40 billion per year. Transportation is the single largest item, accounting for approximately 23% of the budget. If we conservatively assume that of this 23%, 15% is spent on road maintenance, then each 1% in savings attained provides an extra $60 million to be re-invested into our roads or other municipal assets. When determining the cleverest way to spend an annual road budget, consideration must be given to the full toolbox of road preservation and rehabilitation treatments, in conjunction with capital planning optimization strategies. Beyond financial savings, a good road capital plan can simultaneously deliver a higher level of service to the community and a safer road network.

Following over 30-years of experience designing rehabilitation of roads across Canada, it has become very clear that road rehabilitation is determined more by the need to improve operational safety and ride quality and not by the need to increase structural capacity to carry increased traffic loading. Pavement construction in Canada incorporates lots of good quality granular support. With the need to protect frost susceptible subgrades, granular subbase layers are increased in thickness. The trend has been to see distresses confined to the upper layers. Through the 80s and 90s, polymers were introduced to improve asphalt mix performance, and specialty rut-resistant mixes, such as stone matrix asphalt (SMA) was introduced from Europe. Subsequently, with the widespread adoption of Superpave, asphalt mix designs could be tailored to address specific performance requirements and enhance rutting or cracking resistance. The current municipal practice of placing major emphasis on major road rehabilitation and very little on preservation, defies the reality of current pavement technology. To devise a comprehensive capital plan, knowledge of the effectiveness of pavement preservation techniques is of critical importance to Municipal Councils, Finance Officers, and Public Works Directors. Most municipalities are hampered with limited renewal funding and can only strive to attain the best possible preservation of pavement infrastructure through the implementation of timely maintenance and rehabilitation programs. The definition of Pavement Preservation is "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations." (Source: FHWA Pavement Preservation Expert Task Group). A seminal paper by Galehouse et al. (Galehouse et al., 2003) listed the clear financial benefits of this approach to pavement asset management based on life cycle costing analyses. In addition to demonstrating the benefits, the paper listed the institutional barriers to implementation, as follows:

- Identifying a champion for the program
- Dealing with the paradigm shift from worst-first to best-first
- Gaining commitment from the top management
- Showing early benefits
- Selecting the right treatment for the right pavement at the right time

In addition, it identified other barriers from market place pressures (e.g. suppliers of pavement rehabilitation services concerned about loss of market share to cold-applied preservation treatments) and convincing the public (e.g. the public cannot understand why good roads are treated while old roads are being ignored). In the 14 years since this publication by Galehouse et al., very little progress has been made in the paradigm shift needed by agencies to adopt an enlightened attitude to pavement preservation strategies. Clearly, the barriers were real and not easily overcome. It is in this context and with a view to tackling the barriers to implementation head-on, that the optimization approach to pavement asset management, as presented in this paper, was developed.

The Transportation Association of Canada's (TAC) Primer on Pavement Asset Design and Management, highlights the importance of optimization in pavement management as it provides cost savings and enables an organized coordinated management strategy to evaluate performance, assess budgetary impacts and enhance pavement investments (TAC 2014). Without a capital planning tool to determine optimum allocation of capital, some municipalities will continue to use a "worst roads first" approach or struggle with an ineffective ranking process. Ranking or prioritization analyses are typically done on a yearly basis, dismiss the time dimension of the analysis and do not have the capability to analyze the impact of time delays on the overall allocation of budget and network performance. Another key limitation of ranking (or cost benefit analysis) is its inability to incorporate multiple constraints into the analysis. In reality, municipalities deal with fluctuating annual budget, shifting strategic objectives, minimum levels of service objectives, safety considerations, services access, a requirement for alignment with water/wastewater projects, and many other factors.

Optimizing allocation of capital in pavement management represents a complex problem (Abaza, 2007) that is very difficult to solve due to the exponential increase in the large number of decision possibilities (i.e. solution space), particularly when the problem is large. To handle complex combinatorial problems, the trend in the recent literature has been to use evolutionary optimization techniques, such as genetic algorithms (GAs) (Liu et al., 1997). GA-based techniques are inspired by the improved fitness of natural selection and the 'survival of the fittest' approach in living species. Using GAs, solutions (sets of values for the decision variables) are constantly generated and assessed based on a fitness function, which is derived from the objective function and the constraints, until the best solution is found (Goldberg, 1989). Many GA optimisation models have been introduced for life cycle analysis and renewal planning in different asset domains, including pavements (de la Garza et al., 2011), water/sewer networks (Halfawy et al., 2008), bridges (Elbehairy et al., 2006), building facilities (Rashedi & Hegazy 2014), groundwater remediation (Zou et al., 2009). While literature efforts provided useful models, their solution quality and speed greatly depend on problem size and model efficiency (Al-Bazi & Dawood, 2010). Increasing problem size significantly affects the optimization results and degrades the performance and takes huge processing time (Cook et al., 1997, Rashedi and Hegazy 2014). In the literature, little information has been reported on optimisation performance on various problem sizes; and none proved to be able to handle very large-scale problems. Therefore, performance degradation and the very large processing time are two serious drawbacks that need to be resolved before models can be put to practical use.

This paper describes a process that utilizes an advanced optimization tool for pavement management originated at the University of Waterloo and evolved through years of research that combined the effectiveness of GA models with the efficiency and speed of mathematical programming to tackle large-scale pavement management problems. Using the advanced optimization tool for pavement capital planning leads to a robust decision-making process that identifies the best possible course of action, while considering both the short-term needs and the long-term goals of a municipality. To date, some 50 municipalities from across Canada have committed to helping to develop and implement this advanced capital planning tool and are providing their roads data for analysis. This paper discusses some of the real-life examples of using the advanced capital planning optimization tool and the benefits gained by the municipalities and their communities through optimized road asset management.

2 ROAD PRESERVATION STATE-OF-PRACTICE AND CHALLENGES

The year 2016 saw the completion of the most comprehensive Canadian survey of municipal road maintenance practices ever undertaken (ISI, 2016). The 171 survey participants represented 45,000 km of paved road, 15% of Canada's population, and a wide range of municipalities by region and population. The survey was designed to identify the extent to which municipalities apply preventive maintenance treatments, to attain practical observations about treatment options and lifecycle gains, and clarify user perceptions about what constitutes best road maintenance practice. The survey established that 98% of respondents perceive preventive maintenance as an important and cost-effective approach to extend the service life of their pavements and to save the municipality significant capital investment in the long run. The survey further establishes that a majority of the municipalities do not apply preventive maintenance treatments (Figure 1) and have a widely varied understanding of when these treatments should be applied.

Respondents were asked what percentage of their municipality they believe is currently being maintained according to best practices. Figure 2 shows the survey's cumulative response on the application of chip seal, microsurfacing, and slurry seal to paved roads. For every major surface treatment type, less than 20% of municipal road networks are maintained in accordance with what respondents believe to be best practice.

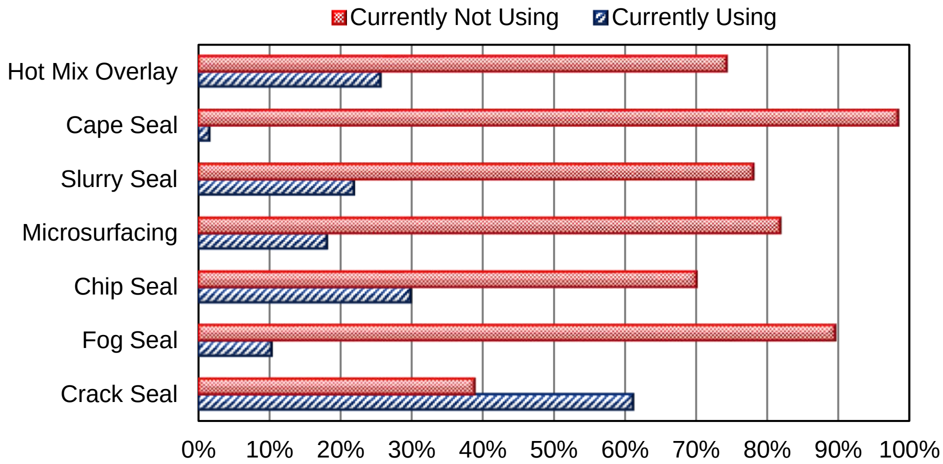

Figure 1: Application of preventive maintenance treatments across Canada

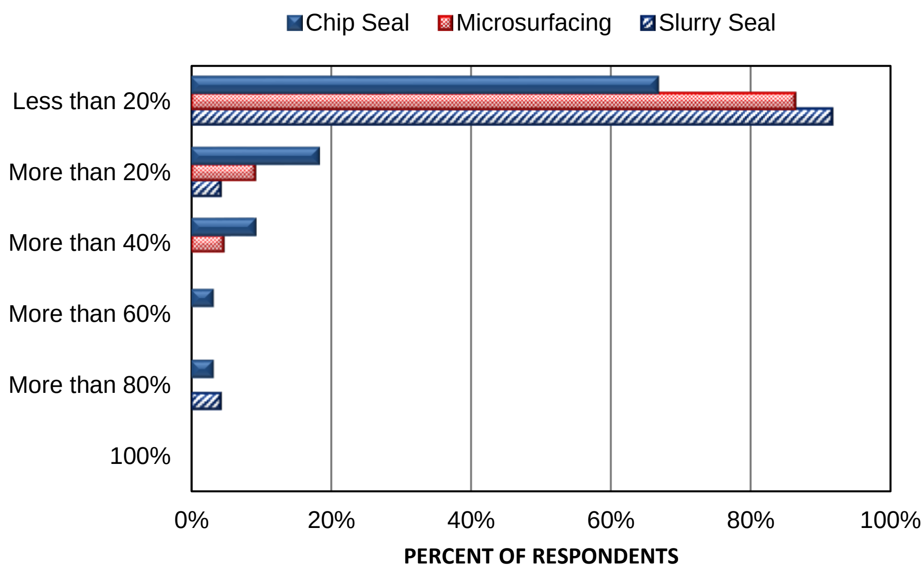

Figure 2: Application of preventive treatments according to best practices

In terms of benefit gains and cost savings, the majority of municipalities recognize preventive maintenance treatments as highly beneficial and cost-effective. Municipalities expect considerable cost savings, improved pavement condition and safety with preventive maintenance programs. Figure 3 shows the average costs and life cycle benefits municipalities expect from the application of different preventive maintenance treatments studied in this survey. As shown in the figure, treatments such as crack seal, slurry seal, chip seal, and microsurfacing can result in significant life cycle gain with a relatively low cost as compared to reconstruction methods. Incorporating the lifecycle gains and associated costs of various preventive maintenance treatments into a capital planning tool is therefore an essential component to demonstrate the financial impact of preventive treatments and provide an optimum and cost-effective plan for municipalities.

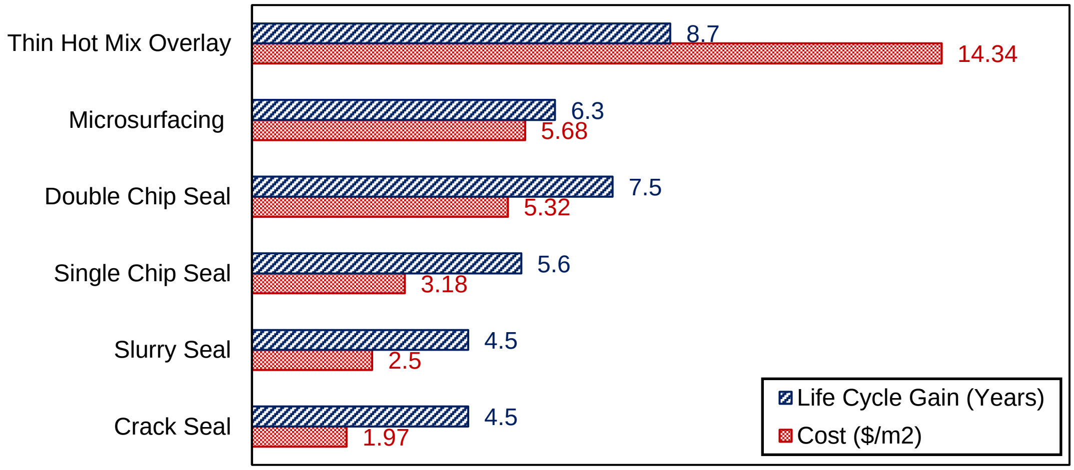

Figure 3: Average costs and benefits associated with different preventive treatments

3 BENEFITS OF OPTIMIZED ROAD ASSET MANAGEMENT

The contradiction between the clearly appreciated benefits of preventive maintenance and the inadequate application of preventive treatments in practice has deep roots. Municipalities may be overly reactive to community requests. Councils surely follow the advice of Roads Needs Studies, where engineering companies recommend repairing worst roads first for safety and other reasons, assuming an unlimited municipal budget. Deteriorated water or wastewater lines might necessitate road reconstruction for line replacement and take precedence over maintenance. Smaller municipalities often use Excel or simplistic pavement management programs which typically recommend projects based on a simple ranking process. Finally, many municipalities still operate on an ad hoc basis, arbitrarily selecting roads which need rehabilitation or reconstruction work without undertaking any analytical process whatsoever. The vast majority of smaller Canadian municipalities do not have the tax base to gain control over their infrastructure deficit, and will see a significant deterioration in the level of service being offered to their citizens over the next ten years without corrective action. Deteriorating services will accelerate population migration to larger municipalities and further undermine a smaller community's tax base. Although Provincial and Federal governments are now committing to substantially increased investment in infrastructure, much of it ends up in major urban centres where the greatest number of citizens are served.

A capital planning tool with optimization capability can maximize the overall performance of a network in terms of physical condition (or any other criteria) over a multi-year analysis horizon and provides municipalities with the best possible course of action in terms of timing and selection of different maintenance, rehabilitation, or reconstruction treatments considering all municipal goals and constraints. The improvements achieved through an optimized solution, which inevitably highlights the critical importance of preventive maintenance, can be translated into substantial savings. We can illustrate the financial folly of the pervasive road management practices with a simplified example. If we assume that it costs about $1 million to build one kilometer of road. Without any maintenance it will probably last about 20 years (Scenario 1). At that stage it will need major rehabilitation, costing about $500k. Thus by year 20, the municipality has spent $1.5 million in providing this 1 km of road. If we consider an alternative scenario (Scenario 2) where timely preservation treatments are applied, we again start with the same initial cost of $1 million. Then in years 5, 10, 15 and 20 we apply pavement preservation treatments comprising, for example, crack sealing and microsurfacing. Figure 4 demonstrates cost savings of $350,000 over the 20-year life of that 1 km of roadway.

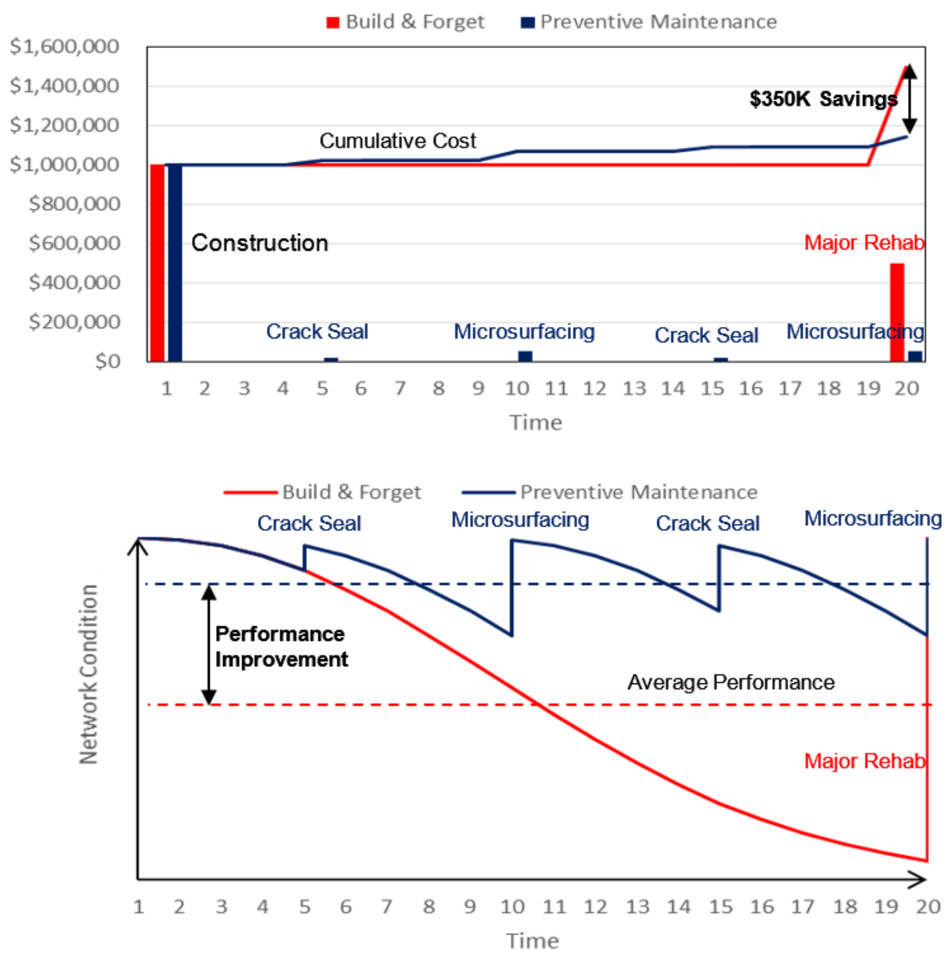

Figure 4: Pavement performance improvement and cost saving using preventive treatments

A municipal asset value is not solely based on its intrinsic value, but also on its ability to deliver a cost effective service to the public. In Scenario 1 above, after about year 12, the road condition is in rapid decline with extensive cracking, rutting and probably potholes. In Scenario 2 above, the road user has had a much better driving experience, since the quality of the road has been improved on a regular basis. The more frequent renewal of a road surface, also improves safety and reduces accidents, especially in wet weather. Studies have also shown that vehicle operating costs increase significantly as road condition deteriorates. Preservation maintenance treatments can be applied very quickly and can even be done overnight without significant disruption to traffic flows whereas major rehabilitation requires lane closures and detours that are highly disruptive. From an environmental perspective, a study by the Ministry of Transportation Ontario (Chan et al., 2013) also demonstrated that thin preservation treatments, such as microsurfacing and seal coats, use only about 15% of the energy and produce only 15% of the carbon emissions of more expensive rehabilitation treatments involving conventional hot mix asphalt.

When pavement asset management is optimized, we find that the frequency of selection of preservation treatments is increased dramatically. By moving to more timely and pro-active interventions, treatments are applied when the pavements are in better condition and so thin surfacings provide exceptional value for money. The most prevalent preservation treatments are: crack sealing, slurry seal, chip seal, microsurfacing, ultra-thin bonded friction course, hot-in-place recycling, and fiber-modified chip seal. In addition to providing lower cost additional service life in terms of cost per square meter per year, these treatments are significantly more sustainable than conventional pavement rehabilitation. A recent study by the Ministry of Transportation Ontario (Chan et al., 2013) presented a case study comparing the costs and sustainability benefits of 50 mm hot mix asphalt (HMA) mill and overlay treatment compared to a 10 mm microsurfacing application. Table 1 summarizes the comparison. The paper confirms that preservation treatments, not only save money but also have significant sustainability benefits in terms of lower emissions, lower energy consumption and less consumption of aggregate resources.

Table 1: Sustainability comparison of mill and overlay to microsurfacing (Chan et al., 2013)

Treatment	Expected Service Life (years)	Unit cost/service life ($)	CO_2 Emissions/2-lane km (t)	Energy Consumption (MJ)	Aggregate Consumption (t/year)
50 mm HMA mill and overlay	10	1.51	36	750,000	83
10 mm micro-surfacing application	7	1.00	6	106,000	20

The advanced capital planning optimization tool is proving able to attain a 7% to 17% capital savings on a municipal capital budget. The Town of Fort Erie, an Ontario municipality with an infrastructure deficit of $23 million and a roads capital budget of $2 million, was experiencing a continued deterioration of their network using a “worst roads first” approach. Under new infrastructure management and using the advanced capital planning optimization tool, Fort Erie can now maintain a consistently high network performance with 18% improvement by the end of the plan without additional expenditures. This improvement on network performance can be translated into $10 million in cost savings over the 10-year planning horizon. In other words, if Fort Erie had maintained its previous capital planning approach it would have had to spend $10 million more to be able to achieve the same level of performance the optimized capital plan produced. It is important to note that, as declining networks using conventional capital planning strategies reach their accelerated deterioration phase, performance improvement and cost saving implications grow significantly. It is therefore reasonable to assume that the worst-first or simple ranking processes have significantly magnified the Canadian road network infrastructure deficit, and will continue to do so without corrective action.

Another example is the Town of Iroquois Falls in Northern Ontario, with a population of around 4,600. An optimization analysis is performed on their paved road network with a total section length of 77.7 kilometers. The optimization objective was set to maximize the network overall performance considering municipal budget limits. The network overall performance represents the network performance considering network pavement condition index (PCI) in addition to all the other macro and micro policy factors and weighting, such as functional classes, surface types, roadside environments, traffic, service types, and other considerations, as set by the municipality. The network overall performance has a numerical value between 0 and 100, with 100 representing the best possible performance and 0 representing the worst possible performance. The analysis was performed to show the impact of an under-budget scenario resulting in network performance decay over a 10-year capital plan due to an inadequate level of funding (Figure 5). Next a recommended capital plan was developed to maintain the current level of performance as shown in Figure 5. This analysis showed that an annual investment of $250,000 is the minimum requirement to maintain the current level of performance. Finally, a target optimization was performed to achieve a performance PCI of around 65 (i.e., overall fair/good condition for the network). An annual budget of $1 million was determined to be required to achieve the target performance.

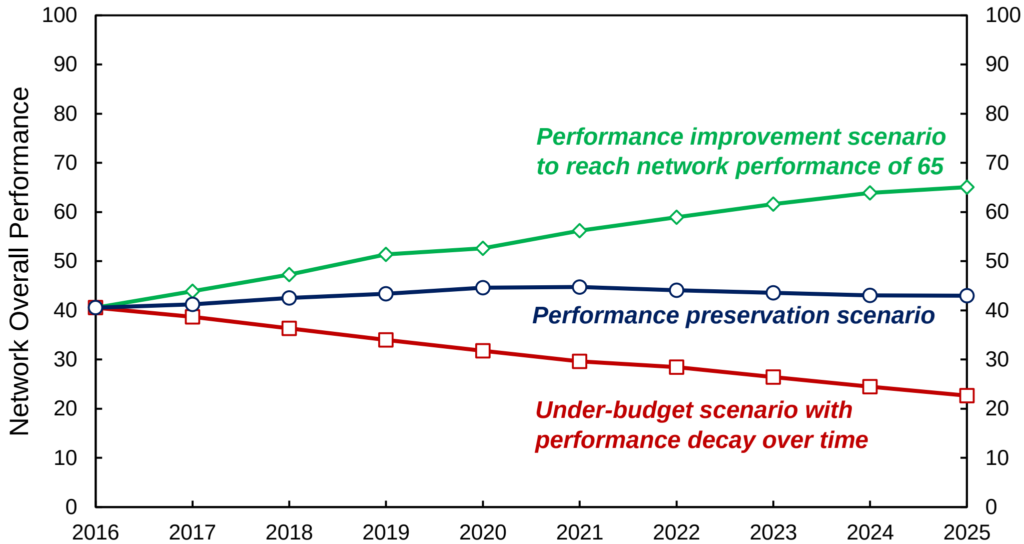

Figure 5: Scenario comparison results using optimization

4 CONCLUDING REMARKS

Road preservation treatments are not 'second class' options but an essential component of a well-managed road network. From an engineering perspective our municipal roads are generally very well built from a purely structural perspective. This is because in Canada we need to include thick granular layers to mitigate against frost action. So our roads deteriorate from the top down due to environmental exposure and traffic damage. Most road distresses are due to aging and brittle asphalt, low-temperature cracking, raveling, and loss of skid resistance. These distresses can be easily addressed by timely application of thin preservation treatments. When we look at costs, the folly of a 'worst first' policy is even more stark. Using a simple comparison and ignoring life cycle costing, the cost to add a year of serviceable life to a pavement by microsurfacing is about \$0.50/m^2, compared to about \$2.50/m^2 for full depth rehabilitation. So the fundamental shift that is needed in our approach to road asset management is to move away from spending the bulk of our road maintenance budgets on expensive rehabilitation treatments to spending it on extending the lives of our good roads.

This paper presented the results of a Canada-wide survey on road maintenance practices that included 171 survey participants represented 45,000 km of paved road, 15% of Canada's population, and a wide range of municipalities by region and population. The results show municipalities understand that proper preventive maintenance on their road networks delivers significant benefits and savings, yet only 20% of municipal roads are being properly maintained. This disturbing contradiction may be rooted in the fact that municipalities are being reactive to community requests; councils might be following the advice of Road Needs Studies, where engineering companies recommend repairing worst roads for safety and other reasons, assuming an unlimited municipal budget; water/wastewater projects are forcing capital budget expenditures on specific roads; and simplistic pavement management systems with a worst-first approach are used to prioritize capital projects.

This paper also discussed the benefits and results of using an advanced capital planning optimization tool for pavement management based on optimization technology originated at the University of Waterloo. Optimization can result in a step improvement in road network condition with the same investment and a shift to greater use of road preservation treatments. Over time, an optimized capital plan will result in much less reliance on major rehabilitation and leads to improved sustainability by lower emissions, lower energy consumption and less consumption of aggregate resources. Optimization also helps cash-strapped municipalities to achieve practical, implementable and defensible road network capital plans based on the municipality's budget, and service level objectives. The advanced capital planning optimization tool presented in this paper is proving able to attain a 7% to 17% capital savings on a municipal capital budget and help communities to gain control over their infrastructure deficit, improve prospects for municipal self-sufficiency, and protect the safety and life quality of citizens.

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