Integrated Roadway Asset Management

Milos Posavljak, M.A.Sc., P.Eng., Univeristy of Waterloo, Ontario Ministry of Transportation

Susan L. Tighe, PhD., P.Eng., University of Waterloo

Paper prepared for presentation

at the Asset Management Session

of the 2014 Conference of the

Transportation Association of Canada

Montreal, Quebec

Abstract

In 2007, for the first time in history, global urban population surpassed 50 % of the total. Movement of goods and service accessibility is essential for sustainability of the post-industrial society. Roadway networks remain an essential means of achieving economic growth. Aging infrastructure and increasing traffic loading pose a challenge to roadway managing agencies. Long term investment planning is a means which agencies look to apply in creating infrastructure asset management plans. A key challenge is balancing bridge and pavement funding needs such that the state of the network allows for efficient, safe and reliable movement of people and goods.

This paper examines an Integrated Roadway Asset Management (iRam) approach to long term investment planning. Trade-off analysis between the bridge and pavement sub-assets is inherit as the bridge network is integrated into the pavement network. Development of the Structural Integration Factor (SIF) is instrumental in converting structures to equivalent pavement sections, such that a homogenous pavement network represents both sub-assets. iRam is subsequently a mutually inclusive (MI) approach of investment planning, compared to current industry practice where pavement and bridge needs are planned through mutually exclusive (ME) organizational processes.

Two 10-year investment plans for a model network were developed and compared. iRam outperformed the ME approach in maximizing roadway network performance, optimization of funds, and organizational effectiveness. A theoretical organizational implementation plan for iRam is developed.

Further development of iRam is suggested through incorporation of safety and operational performance indicators.

Chapter 1 - Background

Consideration of the historical and current context is crucial in the selection of the most optimal path to future roadway asset management. The beginning of the 20^{th} century marks the start of modern roadway construction; while its end sees the shift of primary work from new to rehabilitative construction. With the urban world population surpassing the mark of 50 % [1] of the total in 2007, societal sustainability is critically dependent on roadway networks. A safe, reliable and sustainable roadway network is an asset which allows for efficient movement of goods and people within its serving region. Economic growth is dependent on good pavement infrastructure. In Canada, 90 % of all goods and services are transported via trucks [2].

Governments allocate significant capital to the end of achieving sustainable economic growth and societal prosperity. A part of this value is allocated to the means necessary for the end, one of which is the roadway asset. The paper focuses on the technical and organizational aspects necessary to ensure maximized future roadway asset performance through optimization of available funding.

Cross-asset funding allocation between pavements and bridges is developed in this paper. The concept of one objective performance measure for both pavements and bridges is introduced. Seven years of practical work experience at the Region of Waterloo Municipality and the Ministry of Transportation of Ontario (MTO) was key to the development of this concept.

Transportation agencies have been able to store and access asset information in electronic databases for over a quarter of a century. Foreseeing significant future needs of roadway networks, implementation of latest information technologies and asset management processes is widely viewed as a necessity of the industry. The organizational aspects of updating agencies' legacy systems are explored.

For the technical aspect, an "integrated" approach through conceptual conversion of the bridge network into the pavement network is proposed. Subsequently the name of the process is "Integrated Roadway Asset Management" (iRam). Two 10 year investment plans for a model roadway network are developed for comparison purposes of the current planning method and iRam. In this paper, the roadway network is referred to as the "asset" while the pavement and bridge networks are referred to as "sub-assets". This is mainly due to the essential physical cohesion necessary between the two in order for a roadway network to exist.

1.2 Purpose

To compare two prioritization methods for a 10-year investment strategy plan of a model roadway network, including:

- mutually exclusive bridge and pavement sub-asset planning;
- mutually inclusive bridge and pavement sub-asset planning.

Discuss organizational implementation of the latter.

1.3 Scope

The paper involves comparison of long-term investment planning methods:

- Alternative A – a mutually exclusive annual budget and treatment for bridges and pavements

- Alternative B – a mutually inclusive annual budget and treatment for bridges and pavements through iRam

The Bridge Condition Index (BCI) and the Riding Comfort Index (RCI), are assumed performance indicators for bridges and pavements, respectively.

Organizational analysis is based on six years of work experience in operational, tactical and strategic positions within the Provincial Highways Management Division within the Ministry of Transportation of Ontario; and eight months at the Regional Municipality of Waterloo Region. Service life assumptions for maintenance, preservation and rehabilitation treatments are derived from MTO sample data as well as from published Canadian and American academic sources.

A fictional model roadway network is derived from the analysis performed on a sample of MTO's historical cost and rehabilitation data.

The Structural Integration Factor (SIF) allows for direct sub-asset trade-off between pavements and bridges. This new approach involves mutually inclusive budgeting and treatment of bridge and pavement networks. A potential means of single objective optimization for the one roadway asset is developed as the BCI is integrated into RCI.

Table 1 contains the assumed deterioration rates for pavement and bridges.

TABLE 1: Assumed Deterioration Rates

Pavement Deterioration	Bridge Deterioration
0.123 RCI unit / year	1.0 BCI unit / year

The 0 to 7 year slope of an RCI deterioration curve from the Transportation Association of Canada - Pavement Design and Management Guide [3] was used to derive the RCI rate of deterioration.

The BCI rate was derived through the study of sample data, focused on:

- time from bridge construction;
- time from construction to rehabilitation; and
- time to planned rehabilitation.

The analysis yielded an assumed rate of 1.0 BCI unit per year. The rate generally corresponds to MTO observed time durations for bridges to reach good, fair, and poor states.

Considering a typical service life design of 50 + years for structures, BCI standardization is relatively recent compared to pavement-condition-indices standardization. As increasing quantities of bridge service life data become available from maturing portions of bridge networks built in the 1960s and 70s, potential for BCI standardization increases. Current practice in this area is variable [4].

The following section explains the improvement methods applied to each sub-asset.

Chapter 2 - Treatment Characteristics

Realization of a long term investment plan with optimized treatment alternatives for each individual project is highly unlikely. While a life cycle cost analysis suggests the optimal treatment and timing at the individual analysis level for each pavement section or bridge, restricted funding prevents network basis realization.

In iRam, the individual project level treatments are not compared explicitly amongst each other; they are separated into three major groups:

- routine maintenance;
- preservation; and,
- rehabilitation.

The subsequent prioritization process selects one of the categories for each sub-asset project, with the goal of maximizing network performance through optimization of funds. The resulting construction sequence assumes optimal treatment implementation at the project level, determined through project life cycle cost analysis.

The method corresponds to the typical structure of a roadway managing agency, which includes operational, tactical, and strategic units. Communication between the operational and tactical units typically includes treatment specific terms such as “resurfacing”, “pulverization” etc.; while communication between the tactical and strategic units mainly includes the three terms mentioned above: routine maintenance, preservation, and rehabilitation. The Transportation Association of Canada Pavement Asset Design and Management Guide provides examples of treatments within each of the categories [5]. Long term planning typically occurs at the strategic-tactical line of communication; therefore the paper uses the three categories of roadway asset improvement to develop a 10-year program.

Tables 2 to 5 contain treatment triggers, treatment improvements, and condition ratings.

TABLE 2: Pavement Treatment Triggers

Treatment	Riding Comfort Index (RCI)	Trigger Value
Routine Maintenance	6.4 to 7.4	< 7.5
Preservation	6.3 to 4.5	< 6.4
Rehabilitation	4.4 to 3.0	< 4.5

The International Roughness Index (IRI) values from the 6th International Conference on Managing Pavements [6] were modified to derive the RCI scale shown in the Table 2. Increased sub-asset performance is indicated by higher values. The minimal threshold ranges from 3 to 3.75 RCI, for rural collector and the arterial roadway, respectively.

Developed by analyzing MTO sample bridge data, Table 3 shows the bridge treatment triggers.

TABLE 3: Bridge Treatment Triggers

Treatment	Rehabed Previously BCI	Trigger Value	Unrehabed BCI	Trigger Value
Routine Maintenance	59 to 68	< 68	70 to 84	< 84
Preservation	48 to 58	< 58	55 to 69	< 69
Rehabilitation*	34 to 47	< 47	30 to 54	< 54

** replacement*

The BCI condition rating and corresponding treatment selection have been developed independently for iRam purposes. The structural sub-asset is divided into two categories: unrehabed and rehabed previously. The resulting investment strategy yields increased sensitivity towards untreated areas of the structural network.

Table 4 contains the associated condition improvements of the three improvement categories.

TABLE 4: Condition Improvement of Treatment

Treatment	RCI Improvement	BCI Improvement
Routine Maintenance	0.615 units	5 units
Preservation	1.845 units	15 units
Rehabilitation	up to 8.73 units	up to 100 units

It is assumed that routine and preservation treatments extend the lives of both sub-assets by 5 and 15 years, respectively. Rehabilitation increases the condition rating to 8.73 and 100 units for pavements and bridges, respectively.

Table 5 shows the condition ratings.

TABLE 5: Ministry of Transportation Ontario Ride Rating Guide [7]

RCI	Condition
8 to 10	Excellent
6 to 8	Good
4 to 6	Fair
2 to 4	Poor
0 to 2	Very Poor

When the above treatment triggers are superimposed on the condition scale, the resulting approach is an overall preservation strategy for the network, rather than worst first. The very poor rating is assumed to be part of the poor category and is therefore omitted in subsequent analysis.

The following section introduces a means of integrating bridges into pavements.

Chapter 3 - Structural Integration Factor (SIF)

The Structural Integration Factor (SIF) aims to provide a reliable means of long-term trade-off analysis between the two sub-assets, such that the overall roadway asset performance is maximized.

SIF uses the monetary system to derive an appropriate metric for the integration of the bridge network into the pavement network. Specifically, the monetary values attributed to the common terms of routine maintenance, preservation, and rehabilitation. Tables 6 and 7 contain the average MTO values.

TABLE 6: Average Structural Treatment Costs

Structural Treatment Type	Cost ($) per squared metre
Routine Maintenance	555
Preservation	1663
Rehabilitation	2998

TABLE 7: Average Pavement Treatment Costs

Pavement Treatment Type	Cost ($) per squared metre
Routine Maintenance	31
Preservation	56
Rehabilitation	104

The following steps determine the SIF: 1) Averaging of each treatment cost for bridges. 2) Averaging of each treatment cost for pavements. 3) Determining the bridge to pavement cost ratio for routing maintenance. 4) Determining the bridge to pavement cost ratio for preservation. 5) Determining the bridge to pavement cost ratio for rehabilitation. 6) Averaging of all three ratios. The result in step 6 is the SIF.

To integrate a bridge into the pavement network or convert it into an equivalent pavement section (EPS), the bridge deck area is multiplied by SIF. Upon integration of all bridges, and prior to long term planning, iRam requires the BCI scale adjustment to the RCI scale via division by a factor of ten (10). Finally, the decreasing of the RCI deterioration rate by 50 % for the EPS which are structures in reality is required. This reduction corresponds to first significant rehabilitations occurring at the 15 year mark typically for pavements, and the 30 year mark typically for bridges.

Through the use of the monetary system, the SIF theoretically accounts for the labour, and material difference between constructing a structure and an equivalent pavement section.

The following section contains analysis of the alternatives.

Chapter 4 - Analysis: Mutually Exclusive (ME) vs. Mutually Inclusive (MI) iRam Approach

This section compares two 10-year roadway network investment plans. The first is developed through current industry practice where bridge and pavement needs are determined through a mutually exclusive process in separate organizational units. The second is the iRam approach of inherently trading-off pavements and bridges, with the goal of maximizing performance of the one roadway asset; expressed with one unified measure for both pavement and bridge networks.

A budget of \$ 90 M for the pavement and \$ 30 M for the bridge sub-asset per year was used. Consideration of lower budgets yielded significant portions of the network performing below minimum thresholds for unacceptable time durations. A sum of \$ 120 M is in the equal order of magnitude to MTO allocations for a similar size network as the model network used in this research. Treatment of portions of the network below minimum thresholds first, followed by high traffic volume sections and bridges was the strategy applied in the semi-automatic Microsoft Excel programming of treatments.

The following section compares the resulting network condition distributions of the two methods applied

4.1 Condition Distribution Comparison

This section compares the poor, fair, good, and excellent condition distributions of the mutually exclusive and the mutually inclusive iRam approach of long term roadway investment planning.

Figure 1 illustrates the poor condition distribution for pavements and bridges.

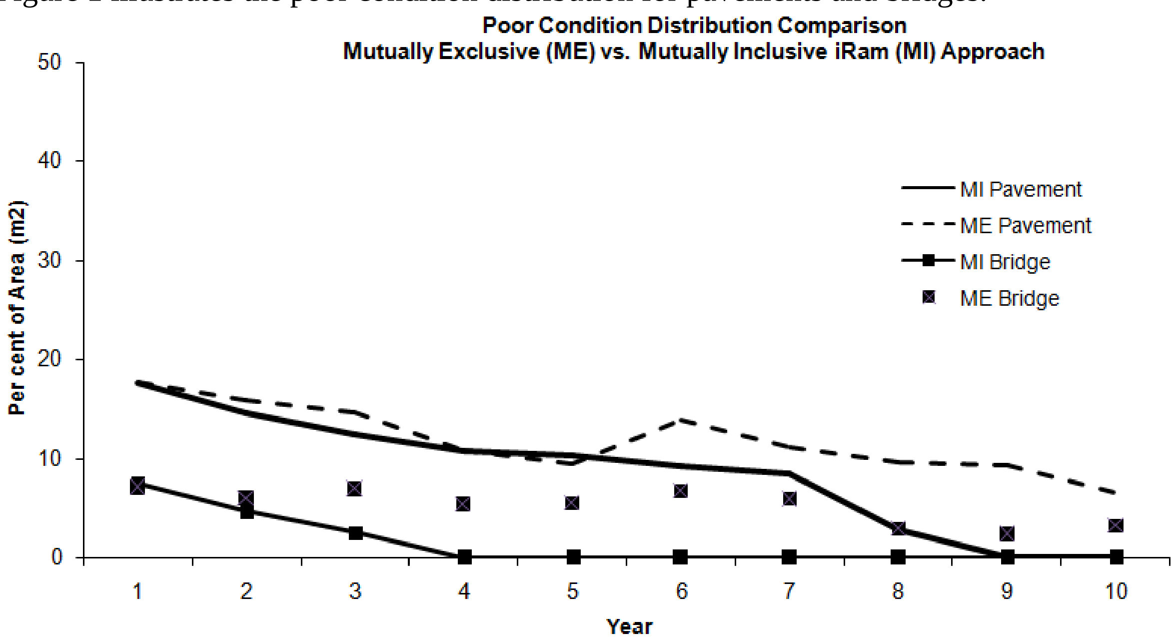

Figure 1: Poor Condition Network Distribution Comparison

For the pavement network, other than in years 4 and 5, the MI approach outperforms the ME with respect to minimizing poor pavement area. The condition is completely eliminated by year 9, while ME continues to hover around the 10 % mark. MI outperforms the ME approach with respect to the bridge network condition as well, as the condition is eliminated in year 4. The ME method fails to eliminate the poor bridge network condition within the 10 year frame.

Figure 2 illustrates the fair condition distribution for pavements and bridges.

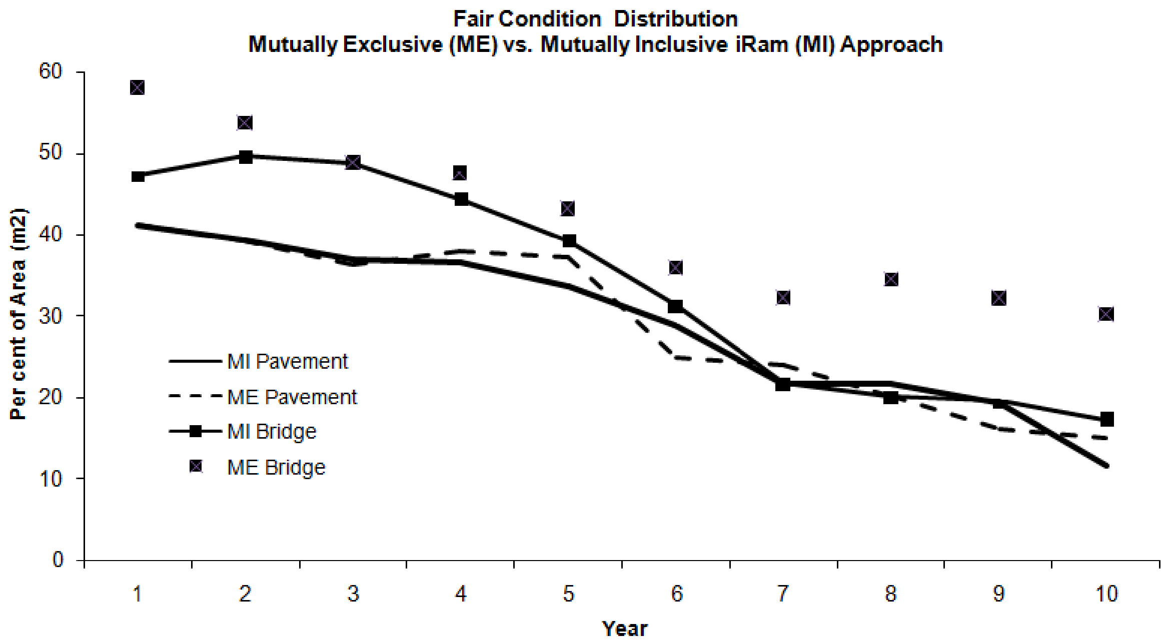

Figure 2: Fair Condition Network Distribution Comparison

For the pavement network, both planning approaches yield a very similar distribution over the ten year span. A closer examination of the curves, shows the MI outperforming the ME approach in years 4, 5, 7, and 10; while the ME yields lower fair network percentage in years 6 and 9 only. The bridge curves exhibit similar curvature over the analysis period; however, MI planning yields consistently a lower fair bridge network percentage; as was the case with the poor condition distribution.

Figure 3 illustrates the good condition distribution for pavements and bridges.

The methods exhibit very similar shapes of the curves for the pavement sub-asset. The ME planning method consistently yields higher percentage of good network condition, except for the final year. The MI bridge network planning yields a higher percentage of good condition from year 7 to 10, while the ME method exhibits higher good condition of the network in years 5 and 6.

Figure 4 illustrates the excellent condition distribution for pavements and bridges.

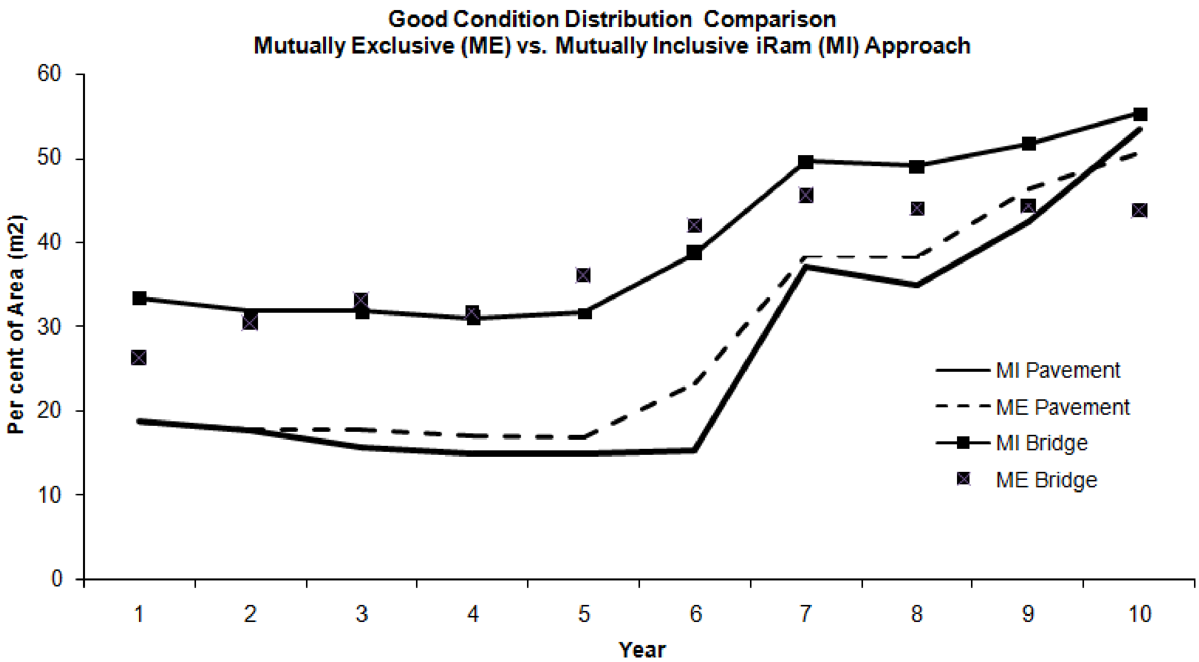

Figure 3: Good Condition Network Distribution Comparison

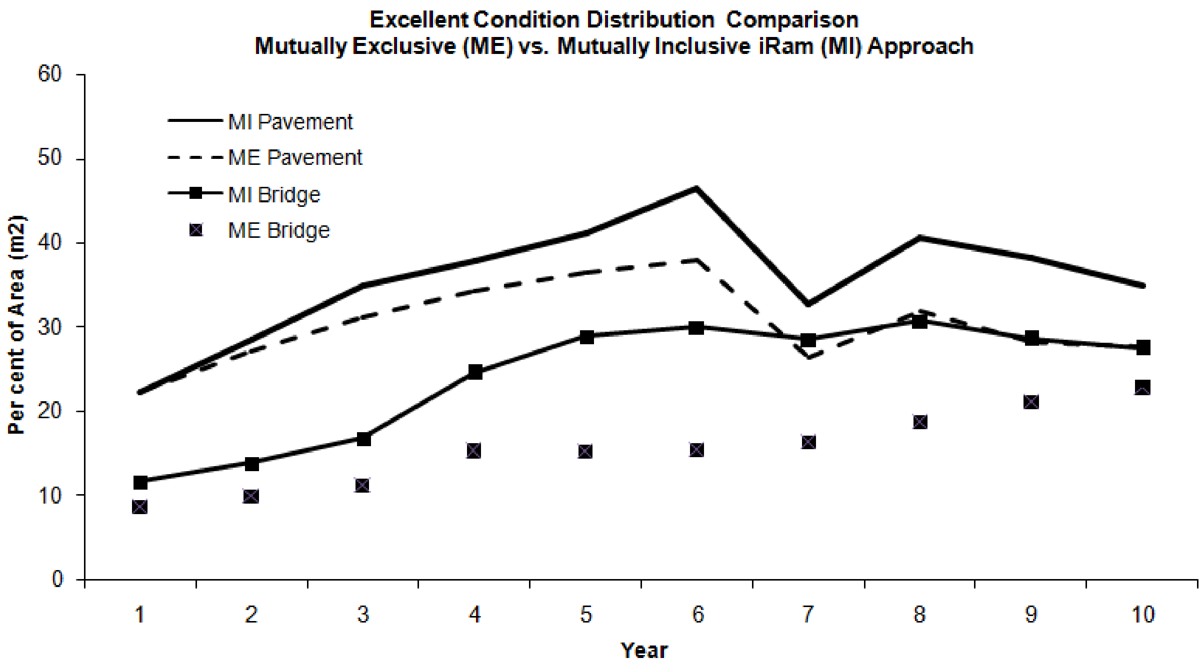

Figure 4: Excellent Condition Network Distribution Comparison

Both methods exhibit very similar shapes of the curves for the pavement sub-asset. The MI planning method consistently yields higher percentage of excellent network condition, reaching a maximum difference of approximately 10 % in year 8. The MI bridge network planning yields a higher percentage of excellent condition for the analysis period, reaching a maximum difference of approximately 15 % in year 6.

With respect to network condition distribution for the pavement network, MI planning method of iRam outperforms the current practice, ME method, in minimizing poor and fair network condition, and maximizing excellent condition network distribution. The ME method yields higher good condition network distribution over the analysis period. This may suggest that the ME outperforms the MI approach; however, this is not the case. The lacking percentage of good network area for MI is actually part of the excellent category. This can be observed through the mirror images of the good and excellent curves in Figures 3 and 4, respectively.

Overall, the MI approach of iRam results in higher roadway network condition distribution over the analysis period.

Figure 5 shows the average performance curves for the two methods.

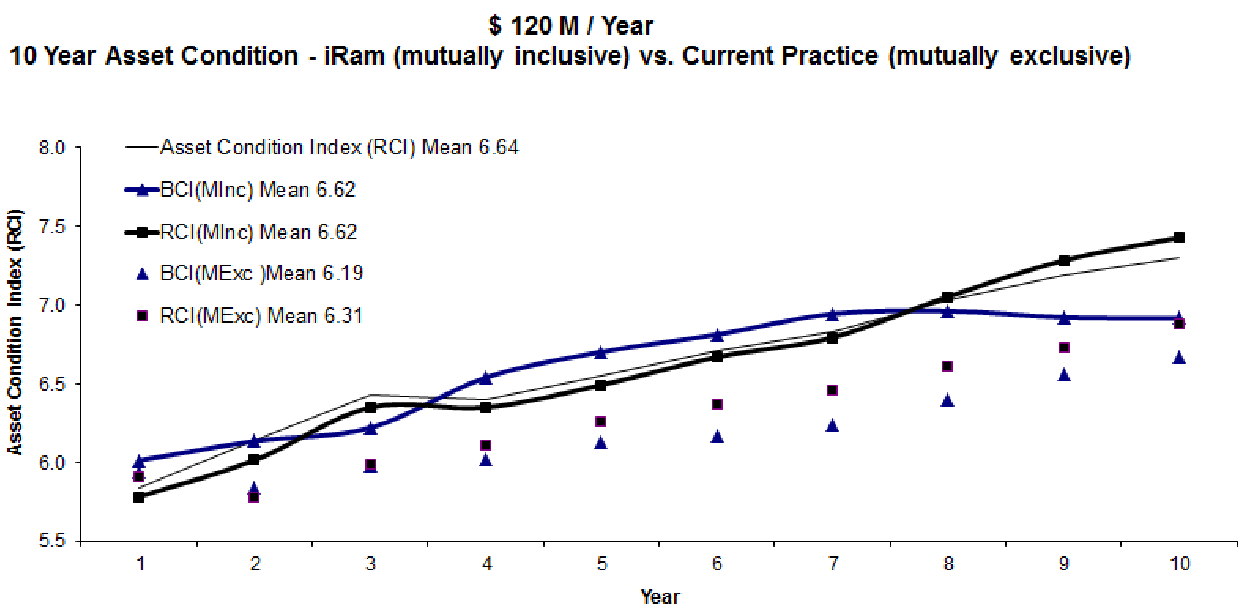

Figure 5: Average Network Performance Comparison

The MI method of planning consistently yields a greater average network performance for both sub-assets. The RCI indicator is illustrated as being the overall roadway condition index, since the BCI is integrated into RCI for the iRam approach. The BCI index is scaled down by a factor of ten in order to compare bridge, pavement, and roadway performance on one graph. The overall asset condition index curve closely follows the pavement curve as pavement composes the majority of the network's surface area. The graph illustrates iRam's ability to yield higher performance of roadway network compared to the conventional mutually exclusive method of sub-asset investment planning, with the same annual budgetary constraint.

The following section discusses the economic analysis of the two methods applied

4.2 Economic Analysis

Table 8 contains the economic analysis of the two alternatives.

Table 8: Economic Analysis of Alternatives

Long Term Planning Method	Pavement Present Worth ($ M)	Bridge Present Worth ($ M)	Total Present Worth ($ M)	Good and Excellent Area Yield (meters squared)	Good and Excellent Meters Squared Yield / $ 1000
(A) Mutually Exclusive (ME) Sub-Asset Approach	641	219	860	12,019,471	13.98
(B) Mutually Inclusive (MI) One Asset iRam Approach	771	170	941	13,577,466	14.44

The present worth values of the total 10-year spending for the pavement network, the bridge network, and the total roadway asset are shown in the first three columns, respectively. iRam yields higher pavement network and lower bridge network allocation compared to the ME planning approach. iRam's total allocation is 9 % higher, averaging to 0.9 % per year over the analysis period. A populist view may quickly conclude this to be an inefficiency, however, this is not the case.

Public agencies' flexibility suffers in balancing long term budgets between the two sub-assets. This is not an organizational defect of any particular agency, but rather an inherit risk of maximizing accountability and transparency with respect to public infrastructure spending. The process of doing so typically involves an increased level of directives, policies, and procedures. This increasing level of bureaucracy generally impacts the organizational processes adversely with respect to flexibility. With decreased ability to absorb uncertainties such as varying approved budgets, the risk of potential debt incurrence due to unused funds and sub-optimal performance of the roadway asset increases. Further aggravation of flexibility derives from the need to adjust long term prioritization needs through two separate organizational processes, one for each network. Finally, assuming the necessary adjustments can be executed in a timely manner, the lack of a non unified performance measure for both sub-assets lacks the means of interpreting whether the adjustments will yield maximized roadway network performance. As such increasing organizational capacity to deliver a budget which carries higher needs than the original, will likely prove difficult to justify to senior management and the political stratosphere.
With this difficulty in sight, agencies may take on an increasingly conservative outlook with respect to long term needs projection to avoid the possibility of not being able to deliver the program due to constrained organizational capacity. Insufficient operational capacity would inevitably result in unused fund debt incurrence. On the other hand, a tendency to underestimate

future roadway improvement requirements may lead to sub-optimal network performance, as well as influxes in required funding to bring the performance back to par.

iRam introduces greater flexibility with respect to budget balancing across the two sub-assets. Provided that construction projects have minimal values of magnitude which dictate the edge "roughness" of annual expenditure curves, iRam is able to maximize the edge "smoothness" as all bridge and pavement projects are optimized within one organizational unit, one "bucket" or source of funds, and one performance measure. This yields a greater project value programmed, as shown by the average 0.9 % increased budget projection per year. The ME approach had the same annual allowance of $ 120 M per year, but yielded lower programmed value. As a result, iRam yields a greater roadway network area in good and excellent condition as shown in the second last column. The last column can be interpreted as investment effectiveness of the two approaches. iRam yields a greater good and excellent network area per every $ 1000 spent at 14.44 m^2 compared to 13.98 m^2 via the current practice approach of mutually exclusive pavement and bridge planning needs.

iRam's unified roadway network performance measure would likely increase the effectiveness of the agency – political leadership communication with respect to organizational capacity adjustment requests. Provided that the new measure is an already established pavement performance indicator, iRam's industry wide implementation duration would be minimized. The agencies would not have to familiarize themselves with completely new indicators but rather use their existing pavement indicators.

In conclusion, iRam's mutually inclusive method outperforms the current practice of mutually exclusive long term investment planning for pavements and bridges. The following points outline the key advantages of iRam:

- maximized roadway network performance;
- maximized optimization of funds;
- increased agency flexibility of handling uncertainty; and,
- improved agency – political leadership communication effectiveness.

The following section examines iRam's organizational implications.

4.3 Organizational Context – Mutually Inclusive versus Exclusive

For an asset management system to be effective, the umbrella for the asset management system must incorporate multiple business units and operations to achieve agency objectives [2].

A simple formulation of an organization is a finite number of positions with a specific goal. The number of positions in a roadway managing agencies varies according to the size of the network overseen, while the assumed goal is to provide a safe, reliable, and sustainable transportation network.

At the macro level, the goal is achieved through the flow of information between the asset and the organization. Subsequently, potential iRam implementation will take place within the established information flow. In order to minimize potential service interruptions, assessment of upstream and downstream organizational processes is advantageous. A study of 80 roadway managing agencies shows that they all communicate their organisational structures through the use of images. The images include charts showing different units in a “silo” arrangement view. Since the core information flow takes place across organizational units, this is not an effective means of illustrating the different processes necessary in providing a safe, reliable, and sustainable roadway network. An illustration of the core information flow between the asset and the funding source significantly increases the reliability of assessments aimed at identifying organizational impacts of new process / technology implementation. In order to illustrate iRam’s impact on organizational processes, an illustration of the cross-functional information flow was developed; shown in Figures 6 and 7.

The processes are contained within the box, while the text on top of the box indicates the unit in which it takes place. The images are also used to explain the concept of its mutual inclusiveness with respect to considering bridge and pavement needs, which is noted below the box. Provided similar size and complexity of roadway network, it is likely that other managing agencies use a similar cross-functional flow.

Operative units are shown from step 1 to 4, while tactical and strategic are shown in steps 5 and 6, respectively. Operational processes include sub-asset data collection and its conversion to construction projects. The term “prioritized” is not indicative of a specific method, which is at the discretion of the specific managing agency. Step 6 shows the strategic unit which distributes funding upon request from the appropriate source. Funding constraints are also defined at this strategic level. The diagrams imply a network which is for the purposes of management divided into regions, which are further divided into areas. It is important to note that none of the processes illustrated in Figure 6, consider pavements and bridges as a unified asset in the development of a long term investment plan. Targeted literature reviews and practical experience indicate lack of the same in current organizational process employed by managing agencies.

Figure 7 is identical to Figure 6; however, steps 5 and 6 are now noted as “mutually inclusive”. The effects of iRam on the organizational process result in the previously mutual exclusive process for bridges and pavements to become inclusive. The bridge networks integration into the pavement network, results in a homogenous network which can be optimized with one objective function. This process inherently trades-off pavement and bridges with the goal of maximizing the overall performance of the roadway asset. Although iRam is shown taking place at the regional level, it can be applied to a specific area or the entire roadway network. Step 6 now results in funding distribution and constraining according to a cross-asset optimized plan. iRam impacts when and which project to deliver, rather than by which means to deliver it.

Cross organisational coordination yields most effective planning and decision-making. An appropriate starting point to implementing asset management processes is an organizational assessment [8]. Effective promotion of new asset management processes such as iRam includes approaches on individual basis rather than via e-mail or memo.

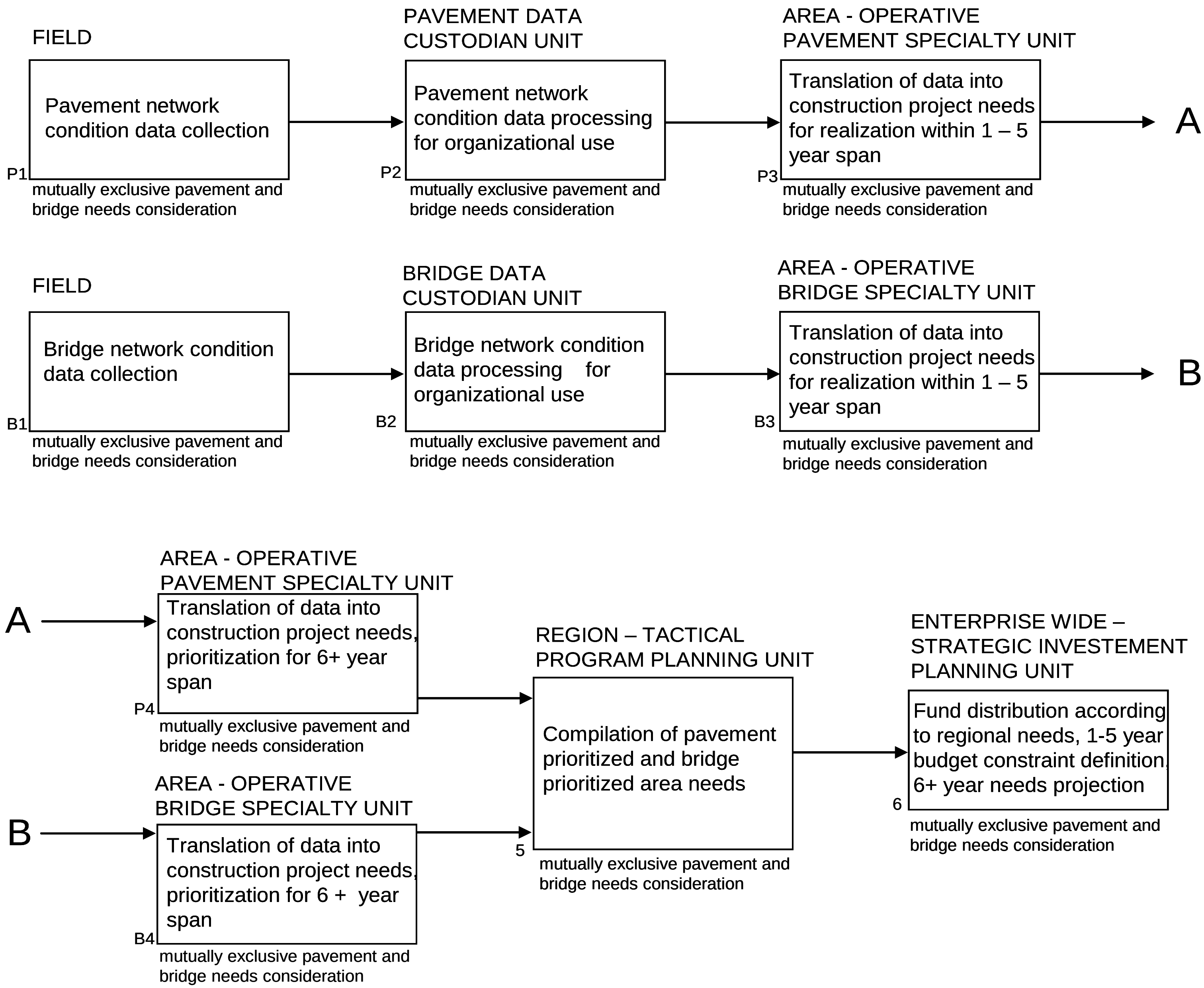

Figure 6: Mutually Exclusive Process – Current Pavement and Bridge Sub-asset Investment Planning Process [9]

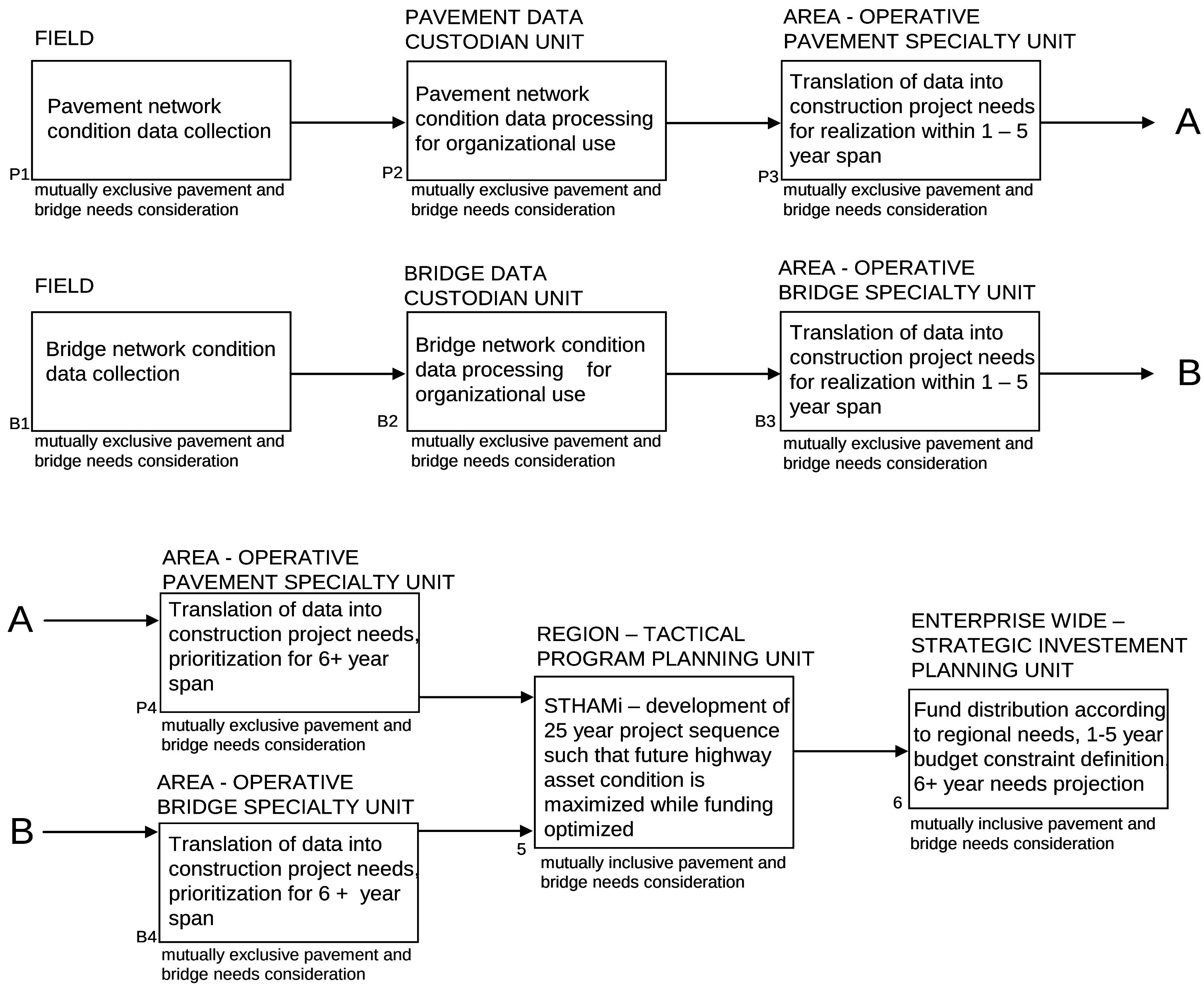

Figure 7: Mutually Inclusive Process – Proposed Pavement and Bridge Sub-asset Investment Planning Process [9]

Concentrating on what the process will allow the agency to do rather than what the promoter will do, will likely yield increased result effectiveness [10]. Furthermore, lessons learned from other industries can significantly aid implementation of organizational asset management processes into existing ones. In the early 1990s, implementation of computers into automobile manufacturing was assumed as the absolute way of increasing the bottom line. Subsequent academic research showed the opposite, as organizational process assessment and modification was required prior to computer implementation. Exclusion of such a step deterred from goal achievement associated with computer integration into existing managing processes. The issue was essentially organizational rather than technological [11].

Through application of SIF long term investment planning can be executed within one organizational unit. Such an arrangement would not impact any of the existing processes within the operational pavement and structural units, since the core of investment planning is done through the tactical and strategic units of an agency. The existing project delivery level processes would not be modified, but would rather be fed a long term project sequence via iRam.

In Canada 70 % of provincial agencies use a planning horizon of 3 to 5 years [2]. If the term "planning horizon" entails a projected lump sum value of future needs, iRam has the potential to interpret it as an optimal sequence of projects. Furthermore, it has the potential to provide the agencies with an effective means of expanding their 3 to 5 year planning horizons to 10 + years.

Chapter 5 – Conclusions and Recommendations

In order to effectively manage aging roadway infrastructure with increasing traffic loading, long term investment planning is necessary. Agencies face the challenge of developing long term investment plans such that network performance is maximized, while funding is optimized.

Organizational and technical concepts of the paper are based upon practical experience in operational, tactical, and strategic positions within two managing agencies; over a period of seven years. Organizational concepts expressed are derived from related undergraduate instruction at the University of Waterloo, as well as from a literature review on organizational theory and operational analysis. Roadway asset management literature review includes material from academia, associations, managing agencies, individuals, and private firms.

Historical costing data was used to develop the SIF factor which allows for integration of the bridge network into the pavement network. This results in a homogeneous pavement network, which includes equivalent pavement sections which are in reality structures. The Bridge Condition Index (BCI) is also integrated into the pavement Riding Comfort Index (RCI). Hence, the RCI becomes the unified performance measure for both sub-assets. This integrated roadway asset management (iRam) approach has the goal of maximizing long term performance of the one roadway asset network through optimization of funds.

iRam's essence is that it considers bridge and pavement needs through a mutually inclusive planning process. It was used to develop a 10-year investment plan for a model roadway network, which was then compared to a 10-year investment plan developed through current practice; or a mutually exclusive planning approach for pavements and bridges. iRam outperformed the conventional approach in maximizing roadway network performance, optimization of funds, and organizational effectiveness.

The following future steps are recommended to improve iRam and roadway asset management practice in general:

- increasing structural integration factor's sensitivity for varying economic environments;
- research of bridge condition index standardization; and,
- incorporation of safety and operational performance measures.

References

1. The World Bank. (n.d.). Retrieved March 1, 2014, from http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS/countries/1W?display=graph
2. Tighe, S. (Ed.). (2011). *Pavement Asset Design and Management Guide (Draft).* Ottawa: Transportation Association of Canada.
3. Haas, R. (Ed.). (1997). *Pavement Design and Management Guide.* Ottawa: Transportation Association of Canada.
4. McGee, R. (2002). *Bridge Management Systems — the State of the Art.* Sydney: Austroads Inc.
5. Tighe, S. (Ed.). (2013). *Pavement Asset Design and Management Guide.* Ottawa: Transportation Association of Canada.
6. Transportation Research Board. (2004). *AFD10 - 6th International Conference on Managing Pavement: Pavement Management Investment Analysis Challenge.* Washington, D.C.: Author.
7. Chong, GJ, WA Phang, and GA Wrong., (1989). Manual for Condition Rating of Flexible Pavements: Distress Manifestations, Report SP-024, R&D Branch, Ministry of Transportation, Ontario.
8. U.S. Department of Transportation. (2007). *U.S. Domestic Scan Program Best Practices in Transportation Asset Management Scan Report.* Washington, D.C.: Federal Highway Administration.
9. Posavljak, M., (2013). *Strategic Total Highway Asset Management Integration*. Diss. Waterloo: University of Waterloo.
10. Burns, P. (Ed.). (2010). Successfully Promoting Asset Management. *AMQ International Strategic Asset Management*, 301: 2-8.
11. Duimering, R., Safayeni F., & Purdy L. (1993). Integrated Manufacturing: Redesign the Organization before Implementing Flexible Technology. *Sloan Management Review, 34(4)*, 47-56.