INTEGRATING PAVEMENT AND ASSET MANAGEMENT IN FUNCTIONAL AND OPERATIONAL TERMS

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ABSTRACT

Several management systems, notably for pavements, bridges and maintenance, have preceded asset management by several decades. However, there is substantial interest in asset management as an overriding concept which draws on the principles of business, technology, economics and other disciplines in a systematic, integrated manner. Accordingly, a generic framework for asset management, which incorporates three basic levels, strategic, network or system wide and project or site specific, and which is applicable to any component system, is put forward in this paper.

Pavement management, as a component system, has a long record of success and operational reality behind it which can and has been beneficial to the development of asset management. These benefits derive from the pavement management process itself and from implementation experience.

If asset management and its component systems are to function in a coordinated and effective way, an integration platform is required. This paper suggests that three key elements need to be included in such a platform and they are locational referencing, asset valuation and level of service.

Finally, the paper identifies a number of opportunities for innovations and advancements in asset management and the component systems at the technical, economic/technical and institution and user levels.

INTRODUCTION

Asset management is a concept and/or process of key interest in many transportation agencies. Both the Transportation Association of Canada (TAC) and the U.S. Federal Highway Administration (FHWA) have, for example, published "Asset Management Primers". Another example is the Transportation Research Board's transformation of its Asset Management Task Group to full committee status in January, 2004.

Reasons for the interest in asset management include a belief that applying corporate business principles, including proper financial and management accounting methods, will lead to more efficient and cost effective transportation program delivery. An issue to be reconciled, however, is that the private sector has a profit motive, while a plethora of objectives and demands face public sector agencies.

Another issue is the existing but generally separate management systems for pavements, bridges, maintenance, traffic congestion, safety, etc. While it is recognized that these component systems must be integrated into an overall asset management strategy, the reality of actually carrying out that integration is much more difficult.

This paper first provides some background on the concept of asset management and then reviews the ways in which asset management as a strategic level activity, has benefited from the operational experience of the component systems such as pavement management. It then describes how the strategic level of asset management "translates" into the operational, network level management system through an integration platform. A case example of an urban arterial network is used to illustrate the concept.

Finally, the paper discusses the future opportunities for innovations and advancements in asset and pavement management systems.

CONCEPT OF ASSET MANAGEMENT

Early initiatives in asset management

Roads as assets with monetary value began to receive explicit recognition in about the late 1980's or early 1990's; e.g., the Australian initiative [NSW 1992]. More broadly, "asset management", with attendant valuation of the asset and minimization of depreciation, carries a comprehensive connotation to administrators in road authorities, particularly those with an accounting, business or finance background. For example a study in New Zealand indicated a replacement asset value of NZ $20 billion for their 93,000 km road network [Williamson 1994, Toleman 1994]. Another study of Alberta's provincial highway pavements indicated a (replacement) asset value of $5.38 billion with a depreciated (i.e., current condition) asset value of $3.39 billion [Cowe Falls et al 1994].

In Canada, for example, Saskatchewan adopted asset management guiding principles [Sask 1994], which included a budgeting methodology based on an objective assessment of needs, condition information data collection on an objective and repeatable basis, maintenance and rehabilitation as preservation within a broad total asset management framework, and being able to predict performance.

Further initiatives include the Sept., 1996 FHWA/AASHTO Executive Seminar on Asset Management [FHWA 1997], the formation of an FHWA Office of Asset Management in 1999, various State and Provincial task forces or offices of asset management, publication of asset management primers by TAC and FHWA [TAC 1999, FHWA 1999], a combined FHWA/AASHTO Workshop on Asset Management in Phoenix, Dec., 1999 [AASHTO 2000], and various sessions at TRB and other conferences.

Definitions (Asset Management or Infrastructure Management?)

Both terms, asset management and infrastructure management, have been widely used. Essentially, they should convey the same meaning, since the management of infrastructure assets is involved. While [Hudson, et al 1997] considered both terms for their book on Infrastructure Management, their choice was considered to be "more descriptive of the process that covers public infrastructure assets". Nevertheless, asset management seems to be the choice for many transportation authorities.

In any case, definitions of asset management that have been put forward include the following:

> "Asset management is a comprehensive business strategy employing people, information and technology to effectively and efficiently allocate available funds amongst valid and competing asset needs" [TAC 1999].
>
> "Asset management is a systematic process of maintaining, upgrading and operating physical assets cost-effectively. In the broadest sense, the assets of a transportation agency include physical infrastructure ...... as well as human resources (personnel and knowledge), equipment and materials, and other items of value" [AASHTO and FHWA 1997].
>
> "Total Asset Management (TAM) is a comprehensive and structured planning process for developing capital and recurrent programs and budgets. It aims to focus on customer and community needs, provide quality services and a commitment to excellence to ensure that assets remain productive" [RTA 1996].

Framework for asset management

A "Generic Asset Management System", put forward by [FHWA 1999], is shown in **Figure 1**. While it is termed a "System", it is really a framework because a system should be an operational entity.

Included with Fig. 1 are some of the key questions which are associated with the system components. It is stressed in [FHWA 1999] that the specifics of any given system would have to suit the agency involved and that any asset management system should be flexible enough to respond to changes in any variables.

Actually, if asset management is a process which involves three basic and interrelated levels, strategic, network or system wide and project or site specific, as subsequently described, then Fig. 1 incorporates elements of all three levels but does not indicate any boundaries for these levels.

Levels of asset management and overall framework

Asset management can conveniently be viewed as functioning at three distinct levels:

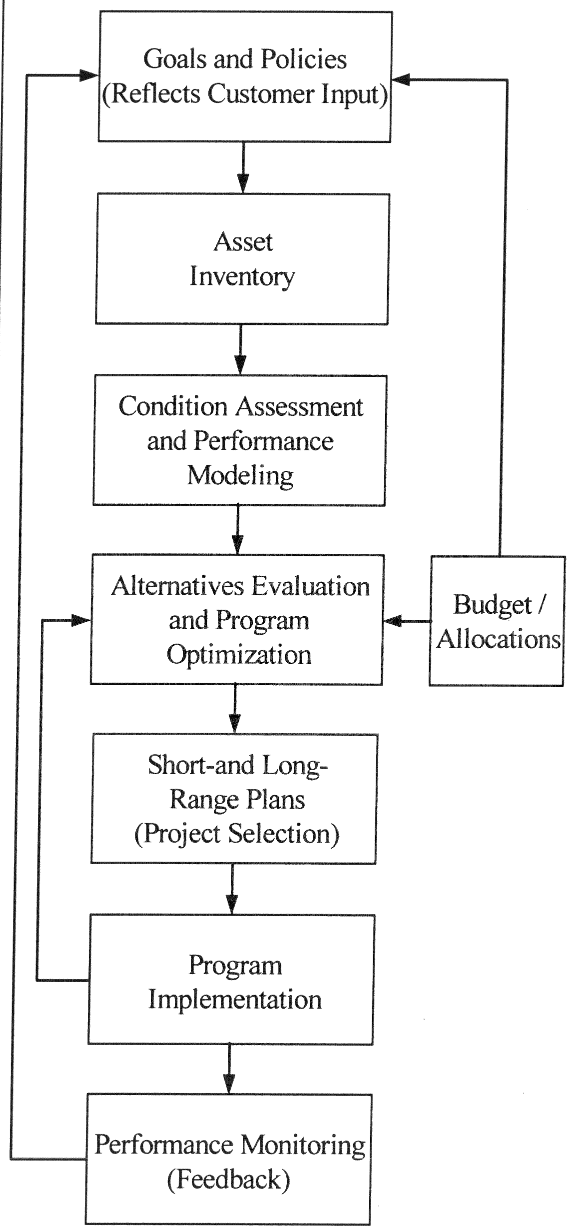
- Strategic level where various social, political, economic and environmental factors are considered, public input occurs, long range financial forecasts are carried out and desired or specified levels of service (LOS) and safety for the system or network as a whole are defined as well as cost estimates to meet the LOS and safety targets. Current and future asset values should be established.
- Network or system wide level where alternative programs are considered, performance estimates are made and life cycle cost analysis (LCCA) are used to determine an optimal program for given budget(s) or funding.
- Project level where LCCA and other relevant factors are used to identify and implement the most economically effective alternative for a project/link/site specific area.

All three levels must fit within the agency's business scope and/or plan to be acceptable, useful, practical and understandable. For example, the City of Edmonton articulated a "Corporate Business Plan" (June 26, 2001, available on their web site) and their infrastructure strategy fits within that plan [Siu and Cloake 2001].

An overall framework for asset management has been defined in a TAC project, as illustrated in **Figure 2** [Cowe Falls and Haas 2000]. It has some similarities to the framework of Fig. 1 and is stated to be "--- generic in nature and allows flexibility to accommodate individual agency needs, resources and policies", as has been the approach for many years in pavement management systems [RTAC 1977, Haas and Hudson 1978, Haas et al 1994, TAC 1997 However, it explicitly recognizes the valuation component, in contrast to Fig. 1. This is considered to be an essential element of any asset management system in the TAC approach. Moreover, it identifies the strategic and network levels as distinct. A third level, project or site specific is only identified in Fig. 2 but is subsequently considered in more detail.

A GENERIC ASSET MANAGEMENT SYSTEM

SYSTEM COMPONENTS



KEY QUESTIONS

- What is our mission? What are our goals and policies?
- What is included in our inventory of assets?
- What is the value of our assets? What are their functions? What services do they provide?
- What was the past condition and performance of our assets? What is the current and predicted future condition and performance of our assets?
- How can we preserve, maintain, or improve our assets to ensure the maximum useful life and provide acceptable service to the public?
- What resources are available? What is the budget level? What is the projected level of future funding?
- What investment options may be identified within and among asset component classes? What are their associated costs and benefits?
- Which option, or combination of options, is "optimal?"
- What are the consequences of not maintaining our assets? How can we communicate the impact of the condition and performance of our assets on the system and end user?
- How do we monitor the impact of our decisions? How do we adjust our decision-making framework when indicated?
- How can we best manage our assets in order to least inconvenience the monitoring public when we repair or replace these facilities?

Figure 1 Generic Asset Management System Components and Key Questions [FHWA 1999]

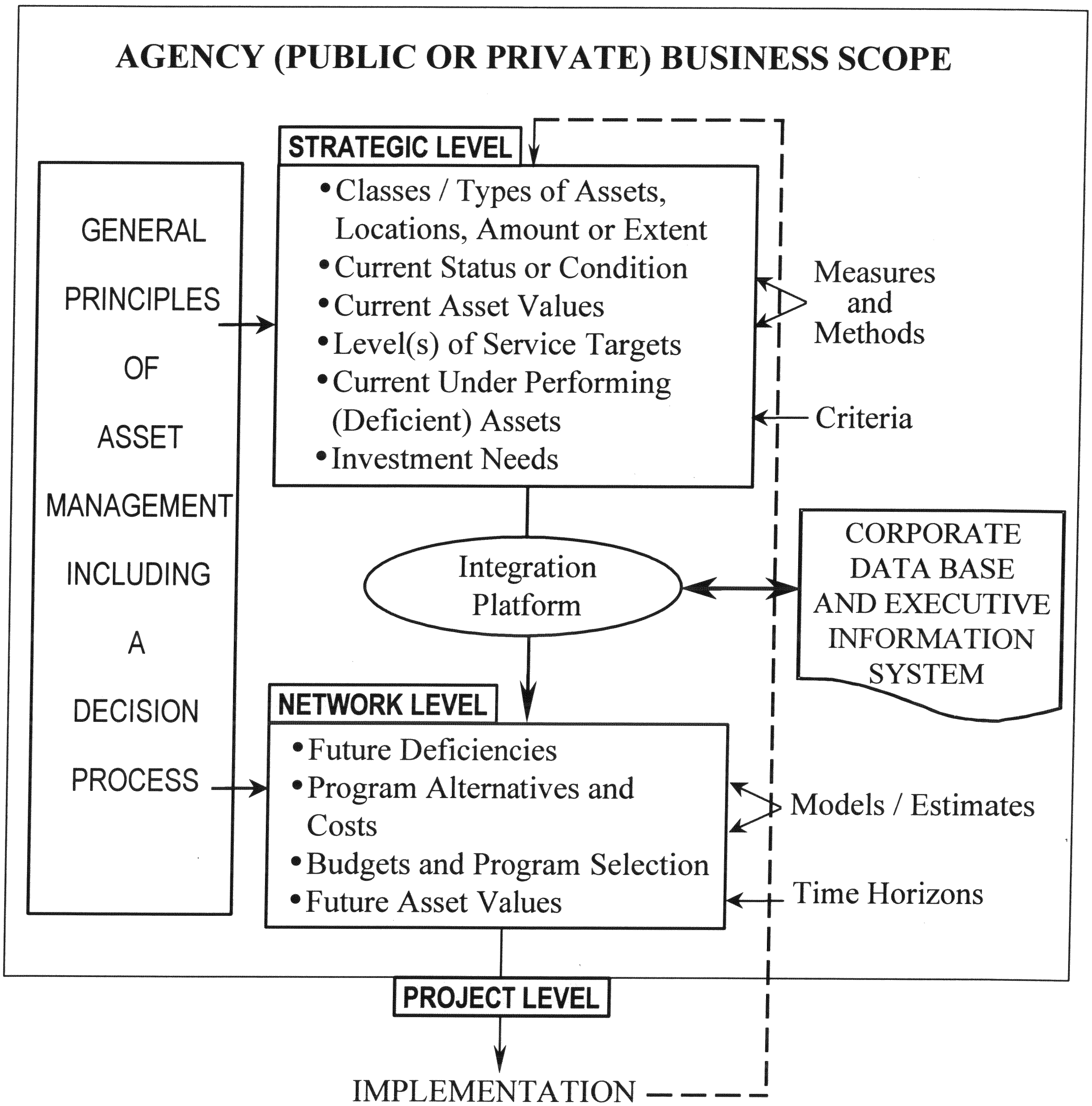


Figure 2 Overall Framework for Asset Management

Adapted from [Cowe Falls and Haas 2000]

The framework of Fig. 2 is largely based on experience with infrastructure and asset management systems. It recognizes or incorporates agency goals and policies in the "Business Scope" noted in the framework.

The framework of Fig. 2 is also generic in that the strategic level could incorporate all the component management systems of the agency (Pavement Management, Bridge Management, Maintenance Management, Traffic and Safety Management, etc.), with the network level being (generically) applicable to any of these component systems. To effect a proper integration between the strategic level and the component systems requires an integration platform, which has been identified in Fig. 2. This is further discussed in a subsequent section.

PAVEMENT MANAGEMENT AS A PRIMARY COMPONENT SYSTEM IN ASSET MANAGEMENT

Pavement and bridge management systems cover by far the largest asset value for most agencies. They have undergone extensive development over several decades and the process and the component technology are well documented in numerous references. For example, pavement management is the subject of several books [RTAC 1977, Haas and Hudson 1978, Haas et al 1994, TAC 1997].

One of the most comprehensive definitions of any component system is that provided in the Pavement Design and Management Guide [TAC 1997]. Excerpts follow:

> "The basic purpose of a pavement management system is to achieve the best value possible for the available public funds and to provide safe, comfortable and economic transportation. This is accomplished by comparing investment alternatives at both the network and project levels, coordinating design, construction, maintenance and evaluation activities, and making efficient use of existing practices and knowledge.
>
> All decision levels are important to efficient management. It is important that a pavement management system recognize these levels, that it is understandable to the people involved and that it is appropriate to the administrative structure of the agency making use of it".

The relationship between asset management and pavement management was discussed in TAC 1997]. The expectation was that current and future generations of engineers and administrators will increasingly become exposed to the concept and terminology of asset management. A major conclusion was the following:

> "In summary, asset management in total is broader than pavements (it includes bridges and other fixed assets), and there is some new or modified terminology, but the basic principles are quite compatible with what has been developed and applied as pavement management".

There has been a perception by some people though, that the two concepts are really different. In fact, however, the early initiatives in asset management in Australia and New Zealand [NSW 1992, McGuire et al 1994], and still today in both countries [Yeaman 2000], use the term asset management to essentially mean the management of pavements, bridges, signs and signals, etc. As well, it may be noted that FHWA has indicated their interest in asset management is an outgrowth of their pavement management programme [WH 2000].

Commonalities and Issues

Considering the frameworks of Figs. 1 and 2 (overall asset management), it is possible to identify a number of common elements, as described in detail in [Cowe Falls et al 2001].

This comparison clearly illustrated that all the key management components are common, in a generic sense, to both asset management and component systems such as pavement management, which supports the conclusion in [TAC 1997].

However, going beyond generic commonalities reveals the following:

- There are some issues to be resolved in the current concepts and applications of asset management and component management systems. Asset management concepts are essentially still just concepts for many agencies
- The development and implementation of asset management systems can benefit from pavement, bridge and other management experience gained over the past several decades.

Some of these issues or differences, which pavement, bridge and other management systems have resolved to at least some degree, as well as differences which could be better recognized in the component management systems include the following:

- Asset management to date seems to be defined almost exclusively as a strategic or network level framework. However, the component systems, pavement management, bridge management, etc. operate at both the network and project levels. The issue and/or challenge for asset management is whether it should be a framework only or an operational process at all levels. If the latter prevails, then there is an associated buy-in issue from other than senior administrative levels in an agency.

- It should be clearly recognized that an asset management system in no way replaces component or individual management systems. For example, almost every state or provincial DOT in Canada and the U.S., as well as most local agencies, currently have some form of pavement management system in place and most have a bridge management system. About half use a maintenance management system. An asset management system must effectively integrate these existing systems into a broader corporate strategy of obtaining maximum return on investment yet not lose their accuracy [Haas and Raymond 1999a].

- Comprehensive, integrated asset management systems are not likely to replace (component) management systems for specific types of infrastructure. However, the appropriate role of transportation system level asset management in managing these specific types of assets, and vice versa, need to be resolved.

- While the concept of asset management is based largely on private sector business principles, it should also be recognized that the profit motive drives the private sector, whereas delivery of services for which users pay indirectly or not at all is paramount in the public sector. On the other hand, there is an increasing trend to long term, performance based privatization of whole systems such as road networks in countries like New Zealand and Australia [Haas and Raymond 1999b]. This may well require some changes to the way asset management systems and individual systems, like pavement management, which have been developed for public sector application, are used by the private sector.

HOW ASSET MANAGEMENT DEVELOPMENT HAS BENEFITTED FROM PAVEMENT MANAGEMENT EXPERIENCE AND ADVANCES

The development and implementation of asset management systems can and has benefitted from the experience and strides forward that have already been made in pavement management, bridge management, and maintenance management. At the same time, however, it is clear that an asset management system must provide improved interfaces among these and other various functions within an agency. It must also improve information flow within the agency and from the agency to the constituent or customer.

The following can be of particular benefit:

1. *Explicit recognition of the "users" of asset management systems.* In public sector pavement management systems, for example, three classes of users have been defined in [TAC 1997] as elected representatives, administrators and technical staff. Each type or class of user has certain decision support requirements, as described in detail in [TAC 1997]. While there is some overlap, it has been already demonstrated that pavement management is not just for administrators. In order to function successfully, it has to rely on and serve people ranging from the technical staff person who plans and carries out a data acquisition program to the elected representative who approves or modifies a budget request. This classification of users and identification of their decision support requirements should be generically applicable to asset management systems.

2. *Key things learned from over three decades of pavement management.* These relate to the process itself and to the implementation of pavement management systems, as summarized in **Table 1** [Haas 1998]. Again, these things should be generically applicable to asset management systems. For example, having a sound technology base and sufficient and reliable data is relevant to any management system.

3. *Implementation guidelines.* The guidelines for pavement management system implementation have been well described in [TAC 1997]. These are basically generic and should again have a high degree of relevance to asset management system implementation.

Table 1 Three decades of learning from pavement management

After [Haas 1998]

From the P.M. Process	From PMS Implementation and Use
• A generic framework can be used to describe the P.M. process • Existing and new technology can be organized within the framework • The framework allows flexibility for different models, methods and procedures • There are two basic operational levels of P.M.: network and project • A sound technology base is essential to the P.M. process • The P.M. process inherently assumes good coordination and communication across activities and within the agency	• The implementation of a PMS should be staged, with useable products after each stage • Successful PMS implementation relies on key players and top level agency commitments • User acceptance and understanding is enhanced by staging • There are three basic levels of PMS users: legislative (indirect), administrative and technical • Optional strategies almost always exist and should be evaluated on a life-cycle basis • Sufficient and reliable data is essential to an effective PMS • A PMS can assist in determining the replacement or depreciated asset value of pavements

INTEGRATION PLATFORM

An integration platform between the strategic and network levels has been identified in Fig. 1. It must also of course interface with and/or be part or the Corporate Data Base.

The basic purpose of an integration platform is to tie together in a common, useable, effective and understandable way the overall strategic level with the component, network level management systems. In other words, a rational comparative basis should exist not only for information reasons but also to make objective decisions.

While integration platform development is in an evolving state, and while the development of a truly comprehensive platform has not yet been achieved, the following key elements should be included:

- Locational referencing, through a Geographic Information System (GIS)
- Asset valuation
- Level of service/classification system

Locational referencing is an obvious integration element, and there is a wealth of information available on GIS. In fact, numerous commercial products are available in this area. The second and third elements, however, have not yet apparently been used for asset management integration purposes.

Asset valuation was the subject of an initial study for TAC [Cowe Falls and Haas 2000] but not proposed at that time for asset management integration. Since then a comprehensive comparison of asset valuation methodologies, including the Government Accounting Standards Board

Statement 34 in the United States (GASB 34), has been carried out by [Cowe Falls 2004]. This work has demonstrated that major differences exist between methodologies, and that Written Down Replacement Cost is generally the most consistent and applicable methodology for highway assets. Moreover, it has suggested that "Asset Valuation, therefore, holds great promise as the integration mechanism for total optimized asset management".

The third element or mechanism, a level of service or classification system has received considerable attention in the City of Edmonton's Infrastructure Strategy [Siu and Cloake 2001; Cloake and Siu 2002]. It involves 12 main categories of infrastructure assets, ranging from Drainage to Roads to Waste Management Facilities, and an extensive number of sub categories. The City uses a five point ranking, A, B, C, D and F (indicating very good, good, fair, poor and critical, respectively), which is applied to each of three classifications: physical condition, demand/capacity and functionality. For any combination of infrastructure category (or sub category) and classification, there is a "translator between A, B, C, D and F to a numerical scale. Thus, A, B, C, D and F are in essence Levels of Service (LOS). A detailed, generic description is provided for each of these LOS for each of the three classifications [Cloake and Siu 2002]. These descriptions are intended to be applicable to any of the 12 main categories and the sub categories of infrastructure assets. In effect, what the City has done comprises one of the three key elements of an integration platform.

For example, a study carried out on Edmonton's network of sidewalks established a Visual Condition Index (VCI) scale for the A to F levels of service, as shown in Table 2. This is only for the physical condition classification since expenditure/investment decisions on sidewalks would be almost exclusively based on condition. It was also possible in the study to develop LOS/VCI performance prediction models from a historical data base. This enabled estimates to be made of needs for various funding scenarios for the medium term (20 years) and long term (50 years). As well, it enabled estimates to be made of performance and asset value for these funding scenarios.

Classifications for the City's primary highway network are given in Table 3. Again, the same LOS scheme (A to F) has been used. The "translator (Pavement Quality Index, PQI) is applicable to this category of infrastructure. In other words, the translator is unique to the infrastructure category, but the LOS concept is consistent across all categories.

Table 2 Physical Condition Ratings for City of Edmonton's 4000 km Plus Network of Sidewalks After [Haas et al 2003]

LOS	"Translator"	Mature Neighbourhoods	Suburban Neighbourhoods
A(V. Good)	VCI 4.5-5.0	18.5%	46.2%
B (Good)	VCI 3.9-4.4	32.0%	32.3%
C (Fair)	VCI 3.2-3.8	32.5%	17.0%
D (Poor)	VCI 2.1-3.1	16.3%	3.8%
F (Critical)	VCI 1.0-2.0	0.7%	0.2%
VCI is Visual Condition Index			

Table 3 Ratings for Physical Condition and Demand/Capacity Classification, City of Edmonton Primary Highway Network After [Cloake and Siu 2002]

Physical Condition			**Demand/Capacity**		
LOS	**"Translator" 1**	**Percent of Network**	**LOS**	**"Translator" 2**	**Percent of Network**
A (V.	PQI 8.1-10.0	18.0%	A (V.	V/C<0.25	8.0%
Good	6.1-8.0	47.0%	Good)	0.25<V/C<0.50	29.0%
B (Good)	4.1-6.0	33.0%	B (Good)	0.50<V/C<0.75	36.0%
C (Fair)	2.1-4.0	2.0%	C (Fair)	0.75<V/C<0.90	15.0%
D (Poor)	0.0-2.0	0.0%	D (Poor)	V/C>0.90	12.0%
F			F		
(Critical)			(Critical)		

1 PQI is Pavement Quality Index [TAC 1997]
2 VC is Volume/Capacity Ratio

CASE EXAMPLE

This is a highly summarized example but it serves to illustrate some of the major aspects of pavement management integration with asset management. It involves a small network of 270 lane Km of pavements in a Canadian city. Performance models have been developed for these pavements, with equivalent single axle loads (ESAL's), layer thicknesses and subgrade strength as independent variables. Pavement Quality Index (PQI) is the dependent variable, with a trigger level of 4.5.

The program period is 10 years, and a discount rate of 4% has been selected for the life cycle analysis. Treatment alternatives consist of milling and overlay, and crack sealing at 5, 10 and 15 years since the last rehabilitation. Unit costs are not provided herein as they are not necessary for what the example seeks to show. Three budget levels were considered: $0 per year, $0.5 M per year and $1.0 M per year. A program was available to calculate an optimal set of treatments and timing for these three budget levels. Summary results of the average PQI distribution over the 10 years is given in Table 4. Also shown in this table, and graphically in Figure 3, is the accumulation, or reduction (depending on budget levels), of needs. It is clear that a $0 budget level would result in a very substantial increase of needs or deficient Km over the 10 years, while both the $0.5 M and $1.0 M per year budget levels would in fact result in a reduction in needs.

Asset value calculations, using a replacement value of $100/sq m (an approximate current cost figure) were carried out and the results are summarized in Table 5, as well as graphically in Figure 4. Written Down Replacement Cost (WDRC) was used as the basis for the calculations. It is clear that a $0 budget scenario would result in a substantial loss of asset value, while the two other budget levels would result in an increasing asset value.

So with regard to the Fig. 2 framework for asset management and subsequent discussions, the foregoing example covers some of the major elements of both strategic and network levels (asset condition, level of service in terms of PQI, asset values, and program alternatives). As well, the PQI and asset value calculations represent two of the three major elements of an integration platform. The third element, locational referencing exists for the example but is not provided herein.

Table 4 Ten Year Needs List for the Case Example Network

	$0 Budget		$0.5 M per Year		$1.0 M per Year	
Year	**Ave. PQI**	**Km of Needs[1]**	**Ave. PQI**	**Km of Needs [1]**	**Ave. PQI**	**Km of Needs[1]**
1	5.3	138	5.6	128	5.7	122
2	5.2	146	5.7	120	5.9	114
3	5.0	154	5.8	114	6.0	112
4	4.9	170	6.0	106	6.3	101
5	4.7	178	6.1	96	6.4	93
6	4.6	194	6.1	98	6.6	90
7	4.5	199	6.1	101	6.7	85
8	4.4	213	6.0	101	6.8	82
9	4.2	221	6.1	101	7.0	80
10	4.1	234	6.2	98	7.2	72

[1] These are the Km which are at or below a "trigger level" of PQI = 4.5

Table 5 Asset Values[1] for the Case Example Network

Year	**$0 Budget Asset Value**	**$0.5 M per Year Asset Value**	**$1.0 M per Year Asset Value**
1	$63 x 10^6	$67 x 10^6	$68 x 10^6
2	62	68	70
3	59	69	71
4	58	71	75
5	56	72	76
6	55	72	78
7	53	72	79
8	52	71	81
9	50	72	83
10	49	74	85

[1] Written Down Replacement Cost Basis

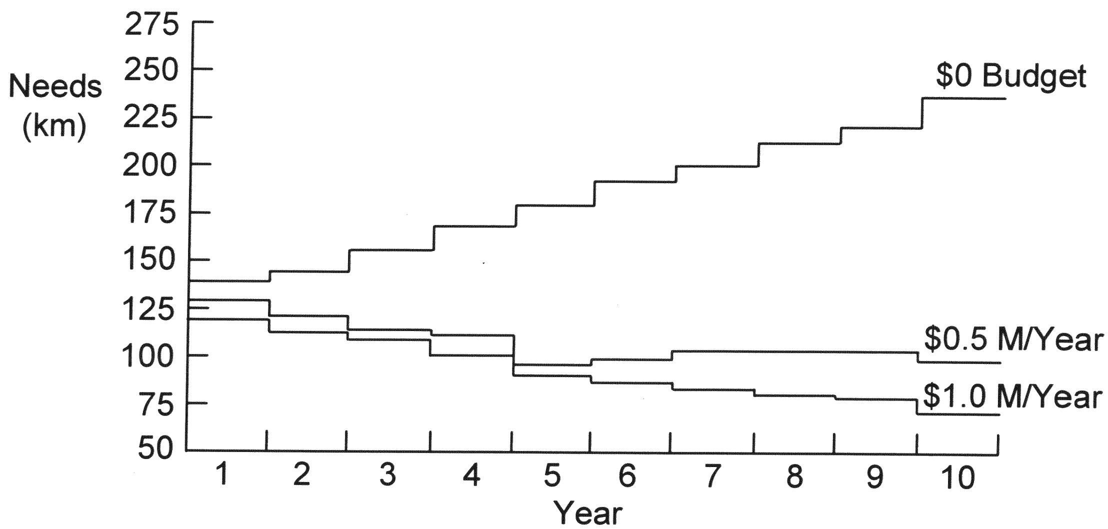


Figure 3 Needs Distribution for Three Budget Levels, Case Example

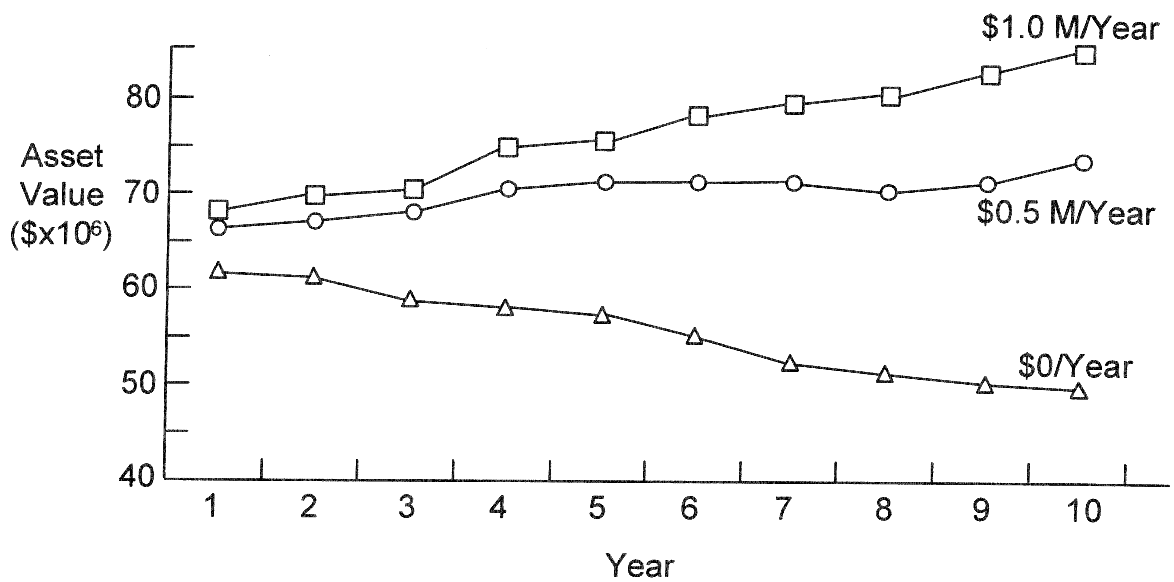


Figure 4 Change in Network Asset Value for the Case Example

FUTURE OPPORTUNITIES

There are many good opportunities for innovations and advancements in asset management. They can conveniently be categorized as Technical, Economic/Technical and Institution and User, as shown in Table 6. Also provided is the associated degree of risk in realizing a payoff, and whether the expected payoff will be short, intermediate or long term. While Table 6 is subjective, it can serve to provide guidance to agencies, both public and private, practitioners and researchers in developing and improving their asset management systems.

Table 6 Opportunities for innovations and advancements in asset management systems (AMS) Adapted From [Haas 1998]

Opportunity	Degree of Risk High (H) Medium (M) Low (L)	Expected Payoff Short Term (S) Intermediate (I) Long Term (L)
A. Technical		
1. Longer lasting asset components (pavements, bridges, etc.).	L	L
2. Long term performance specifications	M	L
3. Better performance models	L	I
4. Automation and new technologies in construction and maintenance	M	S to I
5. Implementation of SHRP products	M	S to L
6. Efficient model calibration procedures	L	S
7. Strategic Network – Project level integration	L	S
8. Reliability concept at the network level	L	I
B. Economic/Technical		
1. Adapting AMS of publicly owned assets to privatization	M	S
2. Objective life-cycle integration and optimization of all component assets in the AMS	M	S
3. Improved technical capabilities	L	S to L
4. Quantifying technology improvement payoffs	L	S to L
5. Incentive programs for new and better technologies	L	S to L
6. Grant funding for high risk, innovative ideas	H	L
7. Ensuring stability and adequacy of technical research funding	L	L
C. Institution and User		
1. Visual, interactive, on-line AMS capabilities	L	S
2. Explicit recognition of AMS "clients"	L	S to L
3. Adapting the AMS to agency	M	S to L
4. Retaining component management systems as distinct modules in the AMS	L	L

CONCLUSIONS

The following conclusions apply to this paper:

1. Asset management is receiving increased attention in public sector transportation agencies.
2. A framework exists to describe the overall concept and elements of asset management. This framework is essentially the same, in a generic sense, as that for other, component management systems. It incorporates three levels: strategic, network or system wide and project or site specific.
3. Pavement management is a primary component system in asset management. As well, the development of asset management has clearly benefitted from pavement management experience and advances.
4. An integration platform for asset management and its component systems should include the following major elements: locational referencing, asset valuation and level of service.
5. Many good opportunities exist for innovations and advancements in asset management and component systems at the technical, economic/technical and institution and user levels.

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