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Effective Management of Performance Based Maintenance Contracts (PBMC) by Adopting Asset Management Concepts

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Abstract: PBMC (performance-based maintenance contracts) provides incentives and/or disincentives to the contractor to achieve desired outcomes or results. In other words, the concept of PBMC is to pay a contractor based on the actual results (performance or LOS (level of service)), not on the performed work. PBMC does not detail to the contractor how, when, or where to do the work. Instead, it specifies performance standards or targets for measurable outcomes and sometimes outputs. There are several benefits from implementing PBMC. Higher LOS, i.e., better quality, potential reduction in agency costs and downsized maintenance workforce are among these benefits. Also, there are several challenges facing the implementation of PBMC. One of the most complex challenges that relates to both the agency and contractor, and in some cases to the public, is how to manage LOS in an objective manner and to demonstrate that policy goals and objectives regarding quality of life expectancy are achieved without any increase in the LCC (life cycle cost) of the assets. This challenge, along with many other challenges, can be addressed through the adoption of an AM (asset management) approach. AM approach facilitates the long-term planning based on the current and future conditions and desired LOS. In addition, AM provides the necessary tools to objectively monitor LOS, and hence the contractor performance, which will contribute to the success of the implementation of PBMC.

Key words: Transportation project, maintenance, PBMC.

1. Introduction

Road maintenance work is typically contracted out based on the amount of work being measured and paid for on agreed rates for different work items, i.e., price contracts. By contrast, PBMCs (performance-based maintenance contracts) define minimum conditions of road, bridge, and other transportation assets that have to be met by the contractor. PBMC provides incentives and/or disincentives to contractors to achieve desired outcomes or results. In other words, the concept of PBMC is to pay a contractor based on the actual results (performance or LOS (level of service)), not on the performed work. PBMC does not detail to the contractor how, when, or where to do the work. Instead, it specifies performance standards or targets for measurable outcomes and sometimes outputs. Performance measures that are commonly used in PBMC include two main components: measures for LOS and measures for response time.

There are several benefits from implementing PBMC. Higher LOS, i.e., better quality, potential reduction in agency costs and downsized maintenance workforce are among these benefits. Although these benefits and other attractive reasons to implement PBMC are real, there are some expected challenges that have to be addressed to achieve them. These challenges are related to agencies, contractors and the public. One of the most complex challenges that relates to both the agency and contractor, and in some cases to the public, is how to manage LOS in an objective manner and to

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demonstrate that policy goals and objectives regarding quality of life expectancy are achieved without any increase in LCC (life cycle cost) of the assets.

Typical objectives of PBMC include providing the agency with full services that intended to preserve and keep the selected network of assets, e.g., roads, at LOS higher than a minimum acceptable level with as low as possible disturbance to traffic and with the controlled LCC of the assets included in this network without jeopardizing the value and long-term performance of these assets. In simple terms, the agency is looking for a guaranteed minimum performance or LOS with very low risk on the agency side and at the same time preserves the value of the assets included in the scope of this project. An option that satisfies the desired LOS but has negative long-term impacts on the value of the assets is not desired. These objectives can be only achieved by adopting an AM (asset management) approach that facilitates the long-term planning based on the current and future conditions and desired LOS. In addition, AM provides the necessary tools to objectively monitor LOS, and hence the contractor performance, which will contribute to the success of the implementation of PBMC.

1.1 Brief Overview of PBMC Worldwide History

There were a variety of early efforts to implement PBMC in the world. For example, in USA, California had an effort to implement PBMC for public streets in the late 1970s, however lawyers stopped this effort [1]. Similarly, a pilot implementation for the Pennsylvania DOT (Department of Transportation) was planned in the early 1980s, but labor union and tort liability issues stopped it [1]. More recently Virginia, Texas, and Florida have used PBMC on a large scale, including fence-to-fence maintenance contracts on Interstate highways. Texas and Florida have used PBMC for rest area contracts and the Maryland SHA (State Highway Administration) recently did as well [1]. The District of Columbia entered into a PBMC for 75 miles of the NHS (National Highway System) within its jurisdiction [2]. New Mexico entered into a performance-based warranty contract on State Route 44 (renamed US-550). The contractor failed to deliver to New Mexico a quality product and was required to repair the highway under the warranty provisions [1].

In Canada, the BCMoTH (British Columbia Ministry of Transportation) conducted a pilot PBMC in 1988. The provinces of Ontario, New Brunswick and Alberta followed suit with performance-based contracts of their own [3]. PBMC has become widespread in South America. The first major PBMC occurred in Argentina in 1995 and is known as CREMA (Contrato de REcuperacion y MAntenimiento), which means Contract for Rehabilitation and Maintenance. The initial CREMA was structured to first rehabilitate part of the network; simultaneously, maintenance under performance-based specifications began on the other sections of the network under the CREMA contract and then was expanded to the rehabilitated sections of road. Today, PBMCs cover 44% of Argentina’s roadway network. Based on Argentina’s success, Uruguay followed suit and so did the city of Montevideo on its main city streets. Other Latin American countries have followed Argentina’s and Uruguay’s lead and adopted or have begun to adopt some form of PBMC. These include Brazil, Chile, Colombia, Ecuador, Guatemala, Mexico, and Peru [3].

PBMC has been prominently used in Australia, New Zealand, England, and Finland. Sydney, Australia, sought to use PBMC to maintain its city roads beginning in 1995. Subsequently, New South Wales, Tasmania, and Southern and Western Australia have used performance-based and hybrid contracts [4].

The use of PBMC is accelerating throughout the world. Sweden, Netherlands, Norway, France, Estonia (now 100% of national roads), Serbia and Montenegro (8% of national roads), South Africa (100% of national roads), Zambia, Chad (17% of all season roads) and Philippines (231 km of national roads) are using PBMC [3]. According to the World Bank, preparations have begun for PBMC in Albania, Cape Verde, Chad, Madagascar, Tanzania, Burkina Faso, India, Cambodia, Thailand, Indonesia, Vietnam and Republic of Yemen [2].

1.2 Anticipated Benefits from PBMC

There are several possible benefits from implementing PBMC. These benefits can be summarized as follows [3, 5, 6]:

- Higher LOS, i.e. better quality and better roads
- Potential reduction in agency costs
- Focus on customer-oriented measures, rather than on inputs and outputs
- Response policy goals and objectives regarding quality of life initiatives
- Downsized maintenance workforce
- Lower liability to the agency, shifting risk to the contractor
- Response to policies and strategic plans regarding outsourcing more maintenance work
- Constraints on operating expenditures budget
- Do more with less workforce
- Better control on the cash flow needs because PBMC typically based on fixed costs and lump sum contracts
- A defensible way to secure maintenance budgets
- Encourage innovation by allowing the contractor the freedom to use any method to meet performance specifications rather than have to adhere to method specifications

1.3 Challenges Facing PBMC

Although there are many attractive reasons to implement PBMC, there are some expected challenges that have to be addressed. These challenges can be summarized as follows:

- Culture changes are required from all parties involved, specifically contractors
- A more costly and longer procurement process
- Inadequate experience with PBMC or a negative experience on the first trial
- Lack of training
- Challenges in estimating in-house and contractor costs
- Insufficient contractor capacity
- Inability to achieve sufficient competition
- Potential bonding or warranty requirements
- Incomplete or inaccurate asset inventory and condition data
- Concern over loss of control over methods, equipment, and material used
- Concern that life-cycle costs will increase
- Fear that privatization will result in large numbers of staff having to leave government

2. AM Approach

2.1 Background

AM is a strategic approach, driven by policy goals and objectives and relies on systematic assessments of asset performance and cost in making decisions on future actions [7]. AM provides the tools or methods that can assist decision makers in finding cost-effective strategies for providing, evaluating, and maintaining transportation assets in serviceable condition. AM is designed to provide objective information and useful data for analysis so that managers can make consistent, cost-effective, and defensible decisions related to the preservation of transportation assets. Key characteristics of AM include:

- Policy-driven—Resource allocation decisions are based on policy goals and objectives.
- Performance-based—Policy objectives are translated into system performance measures.
- Options and tradeoffs analysis—Funds allocation is based on the impact on achieving relevant policy objectives.
- Decisions based on quality information.
- Monitoring provides clear accountability and feedback.

TAM (transportation asset management) applications are typically limited to only one mode of transportation, such as roads or aviation. There are several components for TAM of any single transportation mode. For example, a highway AM system may include the following sub-systems:

- PMS (pavement management system)
- BMS (bridge management system)
- ROWMS (right of way management system)
- MMS (maintenance management system)

PMS is the most mature and advanced sub-system. A PMS is a tool through which good management practices can be employed to improve the quality and performance of highway pavements and minimize their LCCs. The basic purpose of a PMS is to make the best possible use of available funds to provide a safe, comfortable, and economically viable pavement network. It should also provide information effectively, quickly, and cheaply for decision makers within the highway agency. Information from the PMS can be used by decision makers in many areas that include planning and programming, design, maintenance, evaluation, and research [8, 9].

A PMS can be used to make decisions at both the network and project levels. Pavement management at the network level deals with summary information related to the entire highway network. Typical uses of network-level pavement management include:

- Establishing rehabilitation programs, setting policy, and justifying budget requests.
- Establishing priorities for maintenance, rehabilitation, and reconstruction.
- Obtaining feedback on pavement performance to provide input into pavement design, construction, and maintenance activities.
- Determining the best solution through LCCA (life cycle cost analysis) when considering several alternatives [10]. Fig. 1 shows an example of three different alternatives and the expected performance under these three alternatives. In typical LCCA, the cost of each alternative is determined along with the benefit, which is the additional number of service years due to implementing each alternative. Models are used to quantify the additional number of service years in terms of dollars.

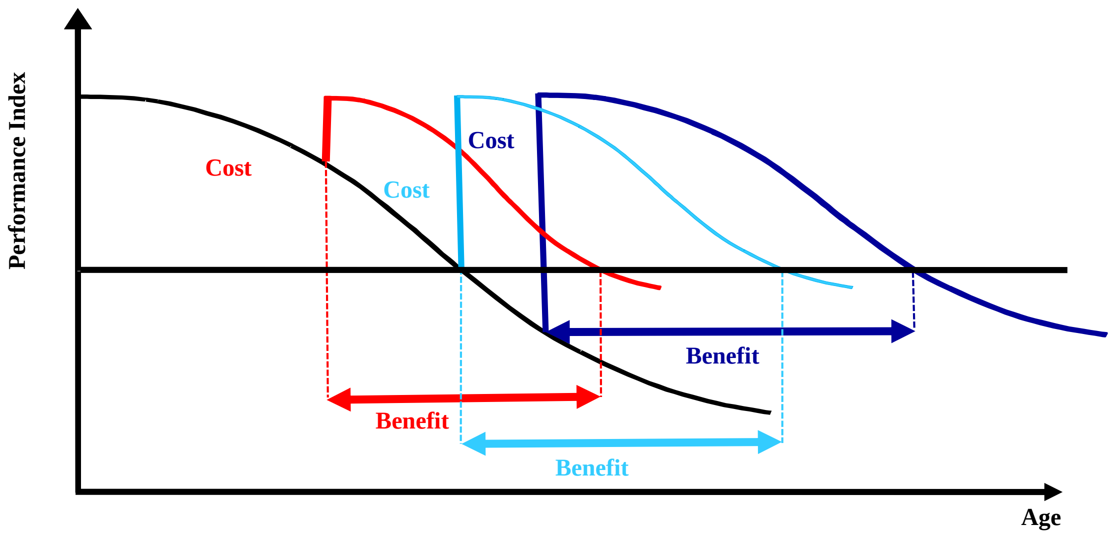

Fig. 1 Benefit-cost of different alternatives.

2.2 Benefits of TAM

Public, and in some cases private, money is involved in maintaining and expanding networks of transportation assets, such as pavements. It is always desired to achieve the best possible value of the invested funds. One of the many advantages of TAM is to facilitate this achievement. Other advantages include:

- Improved decisions through consideration of all relevant factors and alternatives in a coordinated manner.

- Increased efficiency of planning, design, construction, and maintenance programs due to coordinated management of all interrelated activities.
- Facilitation of training: a well-organized, properly documented management system can become a powerful educational tool for less experienced staff members.

In more specific terms, overall network investment decisions can be improved, for example, through exploration of policy options based on a comprehensive, coordinated evaluation of all project costs and benefits. Detailed design for projects can be improved by the capacity to consider all factors and alternatives in a systematic and efficient manner. Maintenance management can be enhanced by analyzing effectiveness and needs in coordination with investment programming, design, and construction considerations. In essence, a PMS will help decision makers to find optimum strategies to provide and maintain their pavement network in a serviceable condition.

2.3 Application of AM Concepts in PBMC

One of the main objectives of typical PBMC is to provide the agency (owner) with full services that intended to preserve and keep a selected network of assets, such as roads, at LOS higher than a minimum acceptable level with as low as possible disturbance to traffic and with controlled LCC of the assets included in this network without jeopardizing the value and long-term performance of these assets. In simple terms, the agency would like a guaranteed minimum performance or LOS with very low risk on the agency side and at the same time preserves the value of the assets included in the scope of this project. In other words, an option that satisfies the desired LOS but has negative long-term impacts on the value of the assets is not desired.

This objective can be best achieved by adopting an AM approach that will facilitate the long-term planning based on the current and future conditions and desired LOS. AM is a strategic approach that is driven by policy goals and objectives and relies on systematic assessments of asset performance and cost of different candidate options in making decisions on future actions. AM will allow:

- Preserving the huge investments made in building the assets under consideration
- Selecting integrated maintenance priorities and cost-effective programs to provide the public with safe, smooth and economic facilities
- Meeting the project goals with respect to LOS and performance targets without negatively impacting the value of the assets included in the contract.
- Monitoring the performance of the roads included in the contract, continuously, which will provide clear accountability and feedback.

Therefore, adopting an AM approach in PBMCs will ensure that the roads included in PBMC are managed, maintained and operated in a safe condition and at the desired LOS. In addition, AM approach will help in increasing the efficiency and cost-effectiveness, and therefore will allow achieving the best value for investment (money) without allowing any deterioration in the overall asset condition and value.

Services typically included in PBMCs can be grouped into three service groups:

- Maintenance (corrective, preventative or emergency)
- Improvement Works (rehabilitation and upgrades)
- Management of Performance

The three service groups are translated into short- and long-term goals. Short-term goals may include items such as no potholes or cracks > 5 mm. On the other hand, long-term goals are driven from the agency's objectives, such as keeping the roads in safe and smooth condition during the PBMC period. This safe and smooth condition is a long-term objective, not a goal, that needs to be translated to realistic, achievable and measureable goals, which are done through KPIs (key performance indicators).

3. KPIs

The first step in converting long-term objectives to long-term goals is to select the appropriate KPIs that are used to translate the agency's desired long-term goals, e.g. safe and smooth, to a set of measurable performance goals [11-13].

KPIs are a vital component of any AM system. The application of AM principles and practices requires adopting a strong performance-based approach to agency management and resource allocation. Performance-based approaches can strengthen both external accountability and the effectiveness of internal agency decision-making. External accountability is improved by using performance measures to provide a clear and compelling rationale for budget requests and to regularly communicate progress in achievement of stated policy and programmatic objectives. Internal agency effectiveness is enhanced by using performance measures to provide a technical basis for decisions and a greater degree of focus, consistency, and alignment in decision-making and operational management across the agency.

System preservation describes the condition of the transportation assets and actions needed to keep them in good condition. Measures are typically specific to the type of asset. Common performance measures include those describing the physical condition of the asset, such as extent or severity of distress and performance indices that combine a number of condition measurements or that relate to user perceptions of condition, such as pavement DI (distress index) or rideability index for pavements; BHI (bridge health index) and asset condition index. Also, non-technical measures, such as asset value, are commonly used. In addition to CE (cost effectiveness), another performance measure typically used for maintenance is the LOS of maintenance and response time to emergencies.

3.1 Candidate KPIs

There are two levels of KPIs in AM, component and system-wide levels. The component level KPIs are specific for one of the AM components, such as pavements or brides, and used in the analysis performed for the specific asset to prepare M&R (Maintenance and Rehabilitation) programs. On the other hand, the system-wide KPIs are common among all components. System-wide KPIs are used as common measures that can be used to assess the future and current condition of all assets based on different funding scenarios, such as RSL (remaining service life).

3.2 Component Level Performance Measures

The component level analysis, such as pavement management analysis, starts with using the available data and current condition to predict the future condition of each asset/section within the network assuming that no M&R activities are implemented (Do Nothing). The predicted condition is then compared with the appropriate trigger level to identify the sections/assets that will be triggered within the analysis period (triggered sections). The triggered sections are sent to the appropriate decision tree to identify the candidate M&R activities based on the condition of the asset/section for each year during the analysis period [14]. The result of this step is a matrix that includes all triggered assets/sections along with the candidate M&R treatments for each year of the analysis period. The CE of each M&R activity in this matrix is then calculated and used in the prioritization or optimization of the M&R program [15].

As can be seen from the above, performance measures are used at the component level in three areas:

- To trigger the needs for M&R
- To identify candidate M&R treatments
- To determine the effectiveness of M&R treatment

3.3 Criteria to Choose Component Level KPIs

The selected component level KPIs have to satisfy the following criteria [16]:

- Cover all aspects of asset performance, such as functional performance versus structural performance
- Detailed enough to allow the selection of the appropriate maintenance and rehabilitation treatments through decision trees.
- Provide true pictures of the network current and future performance, needs for maintenance and

rehabilitation and gaps under different funding scenarios.

- Allow tradeoffs analysis within each individual system component
- Allow monitoring the effectiveness of different scenarios and compare them with a benchmark scenario (budget scenario, alternative delivery scenarios, change is specifications scenarios, etc.)
- Predictable under different funding scenarios and conditions

3.4 Candidate Component Level KPIs

3.4.1 PMS

A comprehensive PMS would include some measures of both functional and structural pavement condition, along with the severity and extent of surface distresses. One unique use of surface distress data, in addition to converting the measurements into a single predictable index, is the determination of maintenance and pre-rehabilitation needs, such as crack sealing and patching. Typically, all these measures are then combined in an overall single performance index that is used in the economic analysis portion of PMS. The following sections provide a brief background of common pavement performance measures [17].

3.4.1.1 RI (Roughness Index)

Ride quality is the most important performance parameter in the opinions of road users. Since ride quality is subjective, several correlation studies have been performed to correlate ride quality and indices that can be objectively measured. Traditionally, ride quality used to be evaluated in terms of a PSI (Pavement Serviceability Index). However, many highway agencies around the world adopted the IRI (International Roughness Index) as the reporting index for ride quality. It is worth mentioning that IRI was developed by the World Bank in 1982 [18]. As a result, some highway agencies use only IRI to monitor and predict the functional performance of their pavements, while other agencies use IRI, along with an agency-specific normalized RI to get around the uniqueness of the IRI scale. As an example, IRI data can be re-scaled to fit a 0.0 to 1.0 scale, with 1.0 being a perfect section and 0.5 being a trigger for rehabilitation [19]. This re-scaling would result in an RI that can be used to evaluate the current roughness condition and can be predicted.

3.4.1.2 DI

Visual inspection is the most popular pavement evaluation method and is commonly used to monitor pavement performance. Visual inspection provides information about the type, severity, and extent of pavement distresses, see Fig. 3. This information is a good indicator of how the pavement has performed to date. Also, it helps in selecting the appropriate maintenance activity. Issues related to visual inspection include the subjectivity of the measurements, repeatability, and the time and labor effort required to complete the survey at the network level. In addition, visual inspection is mainly concerned with visible symptoms and not necessarily with the cause or source of the problem.

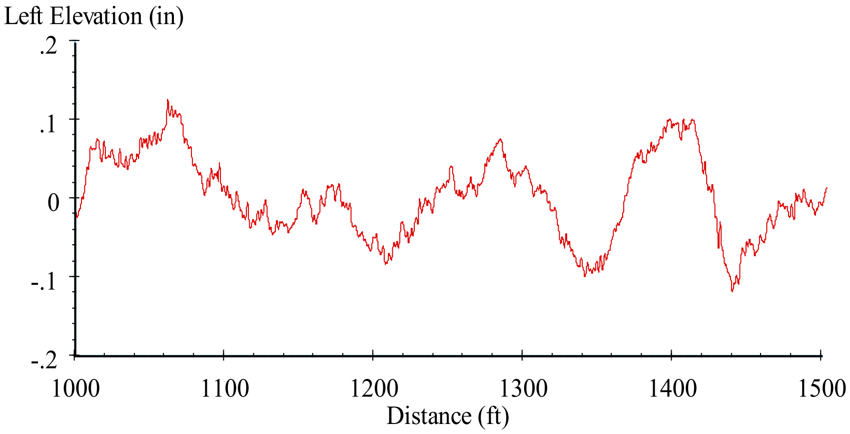

Fig. 2 Longitudinal roughness.

Fig. 3 Surface distresses.

Since pavement sections are expected to have different combinations of distresses (type, severity, and extent), detailed surface distress data, such as cracking and rutting, are converted to a single normalized index representing the overall distress condition of a section. This conversion allows sections with different distress types, severities, and extents to be compared. Many DIs use a point-deduct system, i.e. a perfect pavement would have a score of 1.0 on a 0.0-1.0 scale, with points deducted from the perfect score based on the distress type, severity and extent. Prediction models are commonly used to predict the future DI [19].

3.4.1.3 SAI (Structural Adequacy Index)

Structural performance is a major component of PMS and has significant impact on the funds required to keep the network at the desired LOS. Deflection testing using FWD or other equipment is used for structural evaluation of pavements. FWD data go through a back-calculation procedure to estimate the effective structural condition of the pavement structure, as well as the individual layers. These outcomes have been used before to calculate a SAI that describes the current structural condition and can be used to predict the future structural improvement needs. Fig. 4 shows an example of SAI models for different pavement rehabilitation strategies [20].

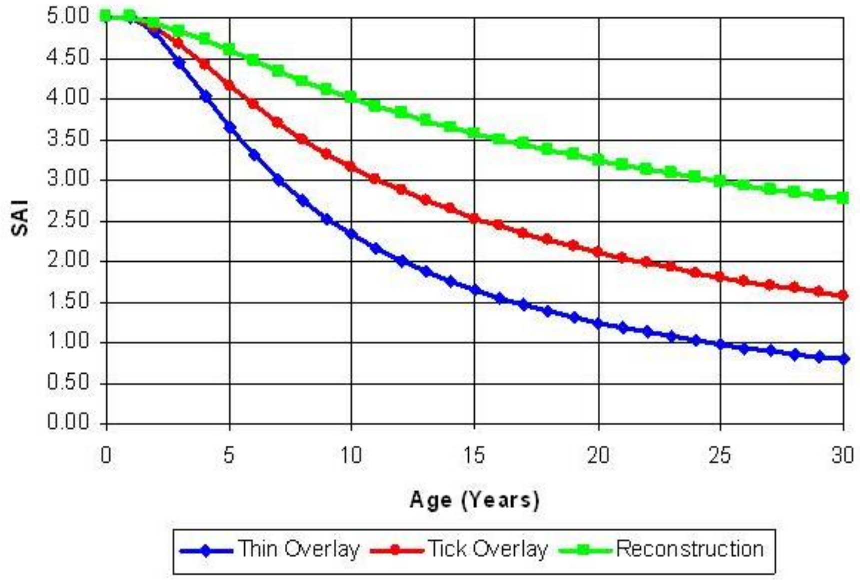

Fig. 4 SAI for different rehabilitation activities [20].

3.4.1.4 IFI (International Friction Index)

Significantly low skid numbers may contribute to an increase in the number of wet accidents. The IFI, developed in the PIARC International Experiment [21], is calculated from a measurement of pavement macro texture and wet pavement friction. The IFI allows the comparison and harmonization of texture and skid resistance measurements. IFI also allows for the harmonizing of friction measurements with different equipment to a common calibrated index. This practice provides for harmonization of friction reporting for devices that use a smooth tread test tire. IFI consists of two parameters that report the calibrated wet friction at 60 km/h (F60) and the speed constant of wet pavement friction (Sp) [21].

3.4.1.5 OPI (Overall Performance Index)

An OPI is calculated as a function of the other indices (RI, DI, and SAI) [19]. An OPI provides a good picture of the current pavement condition and is typically used in the economic analysis portion of PMS. Since it is a single measure, it allows sections with different functional and structural conditions to be compared. OPI would be also used to compare, rank, and set priorities for different pavement sections within the network. In general, OPI is not predicted but rather calculated from the predicted individual performance indices (RI, DI, and SAI) [17, 19].

3.4.2 BMS

3.4.2.1 BHI

Typical bridge inspection program includes visual assessment of several elements of the bridge, which includes:

- Deck
- Superstructure
- Substructure
- Channel & Channel Protection
- Traffic Safety

These elements are evaluated and assigned a score from 0 (failed) to 9 (excellent). A BHI is then can be calculated directly from bridge element data [22]. This measure may range from 0 to 100, with a value of 0 indicating a bridge with all of its elements in the worst defined condition, and a value of 100 indicating a bridge with all of its elements in the best defined condition. BHI is useful for characterizing the physical condition of a bridge or set of bridges. It tends to be highly correlated with the Sufficiency Rating, which also is measured on a scale from 0 to 100. However, BHI excludes consideration of functional characteristics that are included in the Sufficiency Rating.

3.4.2.2 Bridge Sufficiency Rating

Bridge sufficiency rating is a computed numerical value that is used to determine eligibility of a bridge for receiving federal funds in USA [23]. The sufficiency rating formula result varies from 0 to 100. The formula includes factors for structural condition, bridge geometry, and traffic considerations. The sufficiency rating formula is contained in the December 1995 Edition of the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, USA [24] (Fig. 5). A bridge with a sufficiency rating of 80 or less is eligible for federal bridge rehabilitation funding. A bridge with a sufficiency rating of 50 or less is eligible for federal bridge replacement funding.

3.4.3 ROW Management System

3.4.3.1 Asset Condition Index

For assets other than pavements and bridges, there are no standard performance measures. Visual condition data are typically collected and can be converted to asset condition index that describes the current condition of the asset and the current needs for maintenance and rehabilitation. This index can be used to determine the future needs for maintenance and rehabilitation, but only based on the asset age.

3.4.4 Work Order System

3.4.4.1 Incident Response Time

One of the measures of the efficiency of the maintenance operation is the incident response time. The average incident response time can be calculated and used to monitor the performance of the in-house maintenance operation or that of the maintenance contractor in alternative delivery contracts, such as performance based contracts.

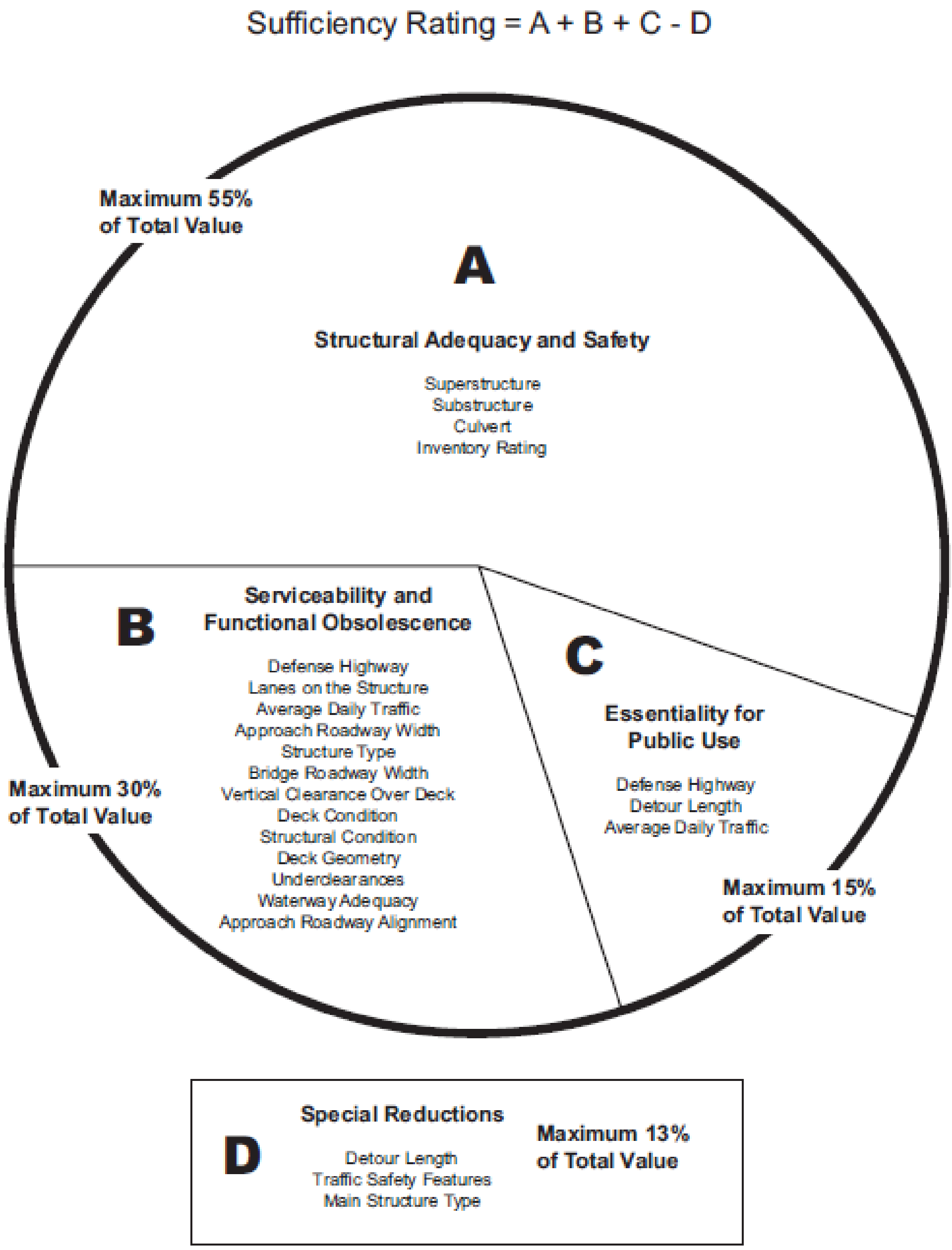

Fig. 5 Bridge sufficiency rating [24].

3.4.5 Maintenance Management System

3.4.5.1 Maintenance LOS

A maintenance LOS indicator can be used to monitor the performance of the maintenance operation, in-house or contractors for alternative delivery contracts, such as performance based contracts. An index that is function of the outstanding maintenance work, such as lineal feet of damaged guardrail, number of signs in poor condition etc., can be used for this purpose.

3.5 System Level Performance Indicators (Dual Indicators)

System level performance indicators are typically calculated from the component level performance indicators in an aggregated fashion. As explained earlier, the system level performance indicators have to satisfy many criteria, such as be feasible, consistent for different assets and allow tradeoffs analysis across different assets. The following is a list of the suggested system level performance indicators. It is worth mentioning that these indicators are dual indicators that can be used at the component level, as well as the system level.

3.6 Criteria to Choose System-Wide KPIs

System-wide KPIs have to satisfy the following criteria:

- Selected KPIs have to be meaningful
- Allow tradeoffs analysis across different assts/projects
- Provide measures for the effectiveness in delivery of programs and achieving desired goals
- Reflect a broad and balanced set of perspectives that cover key policy goals and objectives, i.e., policy-sensitive
- Feasible and can be monitored with sufficient accuracy and reliability
- Predictable under different scenarios
- Consistent for different geographical areas or parts of the network to allow comparisons and aggregation
- Consistent for different types of physical assets
- Allow target setting in conjunction with an analysis of required resources to meet those targets
- Allow analysis to quantify the impact of investment levels on future performance
- Provide early indications of progress towards the desired targets

3.7 Candidate System-Wide KPIs

3.7.1 RSL

RSL can be calculated for all assets under different funding scenarios, such as DN (Do Nothing) as shown in Fig. 6. As can be seen from this figure, the asset starts at excellent condition at age of zero (new condition). The asset condition deteriorates with time until it reaches a trigger level (dotted line in Fig. 6). RSL is defined as the time left before an asset condition reaches the trigger level (dotted line in Fig. 6). It is a homogenous measure that can be predicted and consistent among all asset types. It is a meaningful measure and reflects policy decisions/objectives. RSL allows analysis to quantify the impact of investment levels on future performance and can provide early indications of progress towards the desired targets.

3.7.2 CE

Cost efficiency can be measured and monitored using CE. CE provides an indicator for the return of investment. For example, if an alternative will cost "$x" and will result in "y" additional years of service life, while another alternative will cost "$a" and will result in "b" years. The alternative that will provide lower cost per an additional year of service life would be more cost effective. In other words, if Alternative "I" will

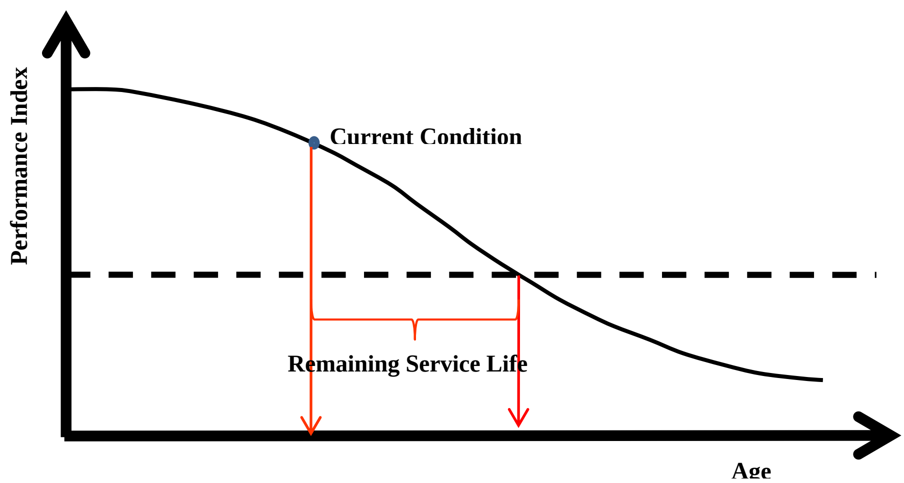

Fig. 6 RSL.

cost $2 million and will result in extending the service life of a pavement section by 8 years, while Alternative "II" will cost $3.5 million and will result in extending the service life of a pavement section by 15 years, then the cost of each additional year of service life for Alternatives I and II would be $250,000 and $233,334, respectively. In this example, Alternative II is more cost effective because it provides lower cost to achieve the same goal.

There are two approaches for calculating the effectiveness of a decision, which are the increase in service life, in terms of years or the total improvement of the performance, in terms of the area located between the expected performance curves before and after implementing the decision, as can be seen from Fig. 7. The main difference between the two approaches is that the second approach takes in account the quality of service during the expected service life.

CE can be measured for all levels of decisions made on any asset type. The level of decisions ranges from a routine maintenance decision (activity) to different funding scenarios and investment plans.

3.7.3 AV (Asset Value)

The total value of different assets under different funding streams is another system level performance indicator. AV is a homogenous measure that can be predicted and consistent among all asset types. It is a meaningful measure and reflects policy decisions/objectives.

3.7.4 Backlog

Backlog is defined as the portion of the network that is in need for maintenance or rehabilitation. Backlog can be measured in terms of percentage of network, or in terms of Dollars, which is consistent among all asset types. It is a meaningful measure that reflects policy decisions/objectives and allows analysis to quantify the impact of investment levels on future performance. It is worth mentioning that these KPIs have been successfully used before.

Fig. 8 shows a sample of the application of these KPIs. In this figure the expected service life is used as KPI for different rehabilitation strategies, which are rehabilitation using different asphalt mix types (AC1 and AC2) or recycle the existing pavement (RAP (recycled asphalt pavement)). In this figure, the impact of the three strategies on performance in terms of structural, distress and roughness service lives is shown. As can be seen from this figure, RAP provides the maximum improvement from the distress point of view, while AC provides the maximum improvement from the roughness and structural point of views. The next step in the analysis is to convert the three single measures (distress, roughness and structural) to overall measure that accounts for the three single measures. This overall measure is a weighted based on the importance of the single measures, which varies from one agency to another.

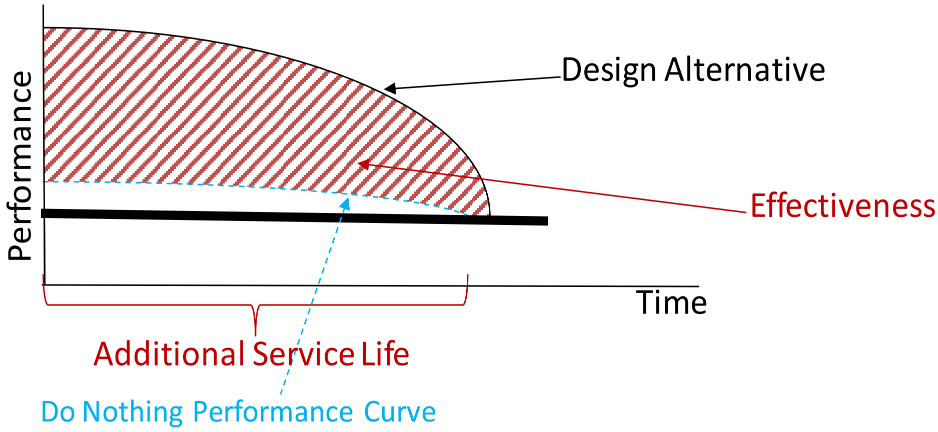

Fig. 7 CE.

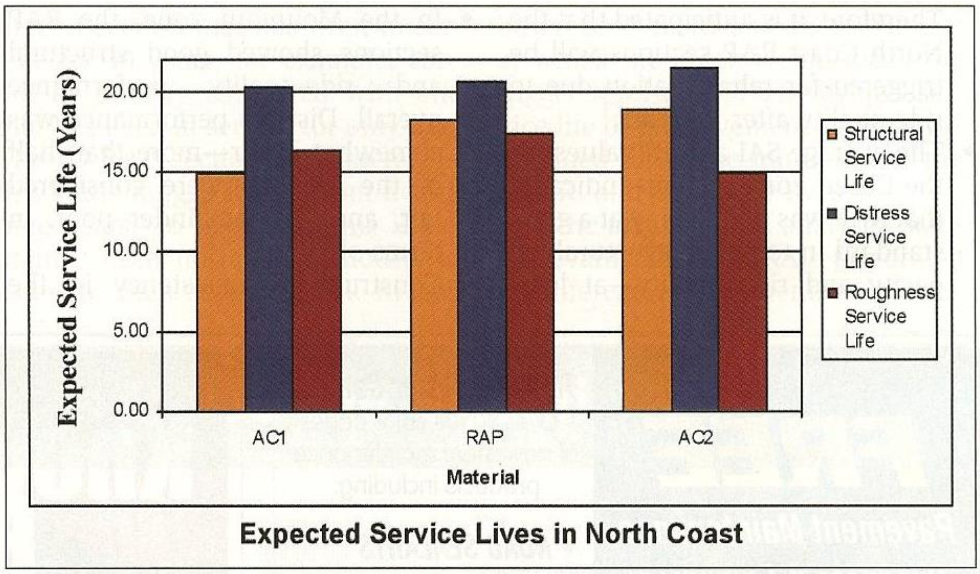

Fig. 8 Example of remaining service lives [19].

4. Implementation of AM Approach

The following are the main tasks (steps) that are followed to implement AM approach in PBMC, see Fig. 9.

4.1 Office Data Collection

This includes collecting inventory data along with all the relevant data attributes. The relevant data attributes may include, geometric data, traffic data, maintenance and construction histories, previous performance records, etc. The inventory data are typically collected from records and existing databases that have reasonable quality data. Some data validation may take place during field surveys.

4.2 Visual Inspection for Corrective and Emergency Maintenance

Frequent visual inspections are needed to identify the needed corrective maintenance repairs.

4.3 Condition Data (Performance Measures) Collection and Analysis

This includes collecting data needed to calculate different KPIs (component level and system-wide).

4.4 Predicting Future Condition

The KPIs are calculated based on the current condition and predicted for future years using a set of performance predication models. The predicted KPIs are then used to identify the future maintenance needs, hence estimating the cost of the future maintenance actions for budgeting purposes.

4.5 Current and Future Needs

This includes identifying the current and future M&R needs based on the desired LOS (condition/performance) and the predicted condition. Several scenarios are always considered in the analysis, which include:

- Investigate the use of preventive approach
- Flag potential performance concerns, i.e., provide advanced warning on potential performance issues.
- Determine the cost-effectiveness of different activities in the candidate multiyear M&R programs

The outcome of this analysis is a multi-year improvement plan that lists all the needed improvements to achieve the desired LOS, performance levels (KPIs), timing of the implementation of these improvements. It is worth mentioning that this multi-year plan takes into consideration different options and alternatives

4.6 Economic Analysis

All the above data, along with performance and budget constraints, will be used to perform economic

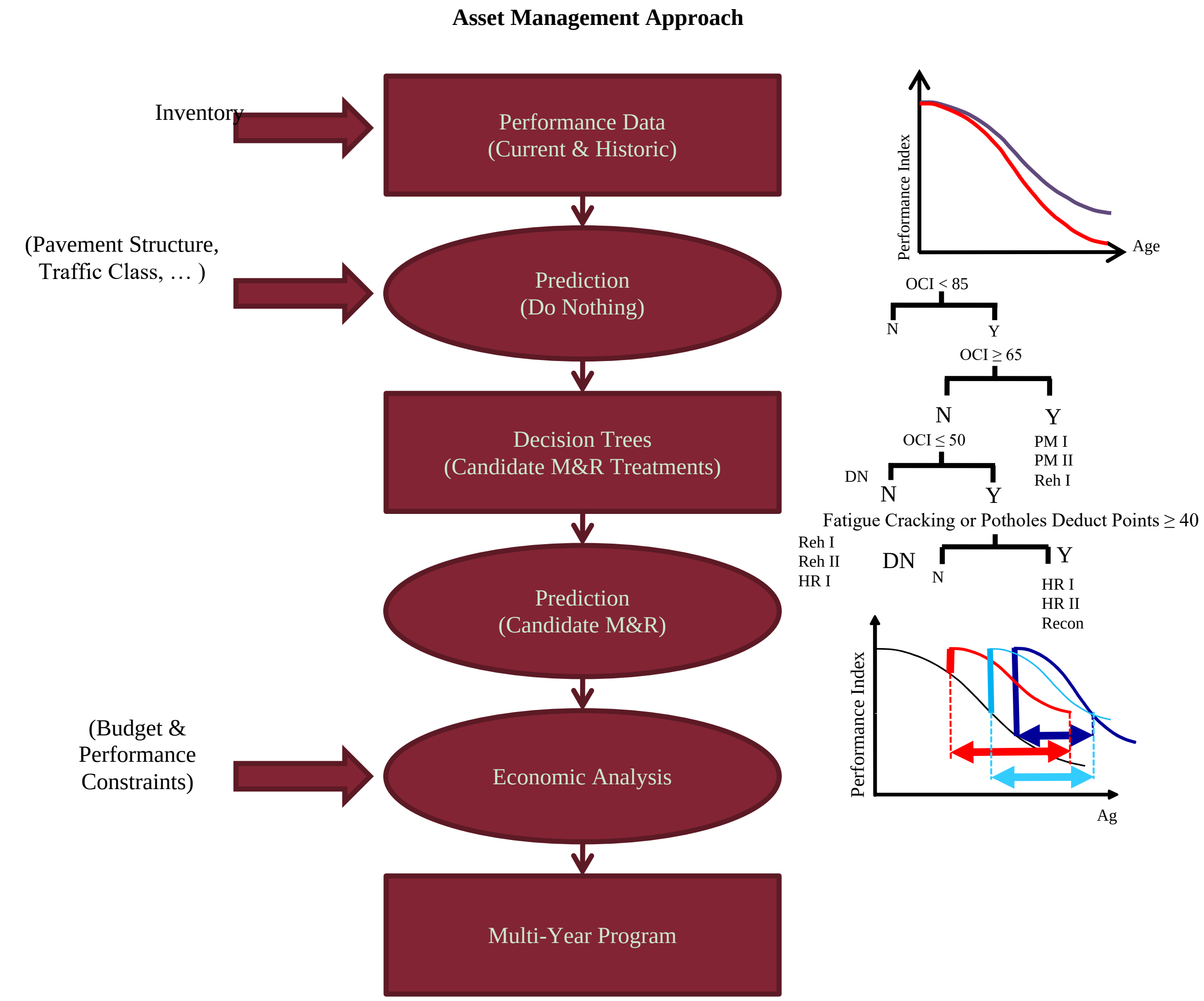

Fig. 9 AM approach.

analysis to select the optimum M&R plans. This analysis is required mainly for Improvement Works and Management of Performance Services.

• Perform economic analysis to select the economically best option that satisfies the performance (KPIs) and LOS requirements.

• Perform "What if" scenarios and predict the future condition under different funding scenarios, such as:

(1) For a given yearly budget what is the excepted condition/performance?

(2) How much money is needed to reach a certain condition/performance in a given year?

(3) What is the impact of different cash flow scenarios on the expected condition/performance and on the total cost of maintaining the condition at desired levels?

5. Summary

AM provides the tools required to effectively manage PBMCs (performance based maintenance contracts). These tools allow a full control on the performance of the assets during the duration of PBMCs, as well as full control on LCC of these assets [25]. As a part of AM approach, agency objectives, such as safe and smooth roads, are converted to measurable performance goals, such as Skid Number and IRI. These goals are monitored and predicted. Multi-year maintenance and rehabilitation programs are prepared to ensure that these goals, and hence agency objectives, will be met during PBMC. Applying AM concepts in managing PBMCs is beneficial to all parties involved in such contracts, owner and contractor.

One of the vital steps in adopting AM approach in managing PBMCs is the selection of the appropriate KPIs. There are two levels of KPIs in AM, component and system-wide levels. The component level KPIs are specific for one of the AM components, such as pavements or brides, and used in the analysis performed for the specific asset to prepare M&R programs. On the other hand, the system-wide KPIs are common among all components and used as common measures to assess the future and current condition of all assets based on different funding scenarios, such as RSL. Typical steps involved in implementing AM approach in PBMC include office data collection, visual inspection for corrective and emergency maintenance, condition data (performance measures) collection and analysis, prediction of future condition, identification of current and future needs and economic analysis.

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