Quantify the Benefits of Implementing Asset Management

By

Daisuke Mizusawa
Doctoral Student
University of Illinois at Chicago
College of Urban Planning and Public Affairs
412 South Peoria Street, Suite 340 CUPPA Hall
Chicago, Illinois 60607-7036
Tel (312)-996-2667
Fax (312)-413-0006
E-mail: dmizus1@uic.edu

and

Sue McNeil
Professor
University of Illinois at Chicago
College of Urban Planning and Public Affairs
412 South Peoria Street, Suite 340 CUPPA Hall
Chicago, Illinois 60607-7036
Tel (312)-996-9818
Fax (312)-413-0006
E-mail: mcneil@uic.edu

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ABSTRACT

It is expected that Asset Management (AM) improves transportation agencies’ performance in terms of the performance of their assets while it reduces agencies’ cost for maintenance and rehabilitation (M&R). In a worst-case scenario without AM, M&R costs would continue to increase over time because of infrastructure deterioration caused by increases in the vehicle miles of travel, the increase in heavy trucks, aging infrastructure, and inappropriate M&R strategies. At the same time, the performance would degrade because M&R cannot catch up with the pace of deterioration of infrastructure and an agency cannot afford to invest in the additional M&R needed due to budget constraints. Ultimately, the degradation in performance will translate to increased user costs. After implementing Asset Management Systems (AMS), appropriate M&R identified using the decision support tools in the AMS may improve performance and reduce costs simultaneously. Also, it is noted that there would be a reduction in user and external costs because appropriately maintained roads provide a better driving environment for users, thus reducing operating costs, crash costs, travel time costs, and environmental impacts.

Yet, there are several barriers to implementing AMS in agencies. Cost is an especially critical issue and barrier. Without showing that benefits of AMS implementation exceed costs for AMS implementation and operation, implementation will not occur. In particular, upper-level managers are interested in benefits that can be translated into monetary values, because they need to justify their investment in AMS. Therefore, it is imperative to quantify the benefits of AMS implementation and demonstrate that the benefits exceed the implementation and operating costs, in order to disseminate and implement AMS in agencies.

The objective of this research is to quantify the benefits of AMS implementation. First, the research begins by identifying various benefits produced by implementing AMS and costs for implementing AMS from different stakeholders’ perspectives in order to understand AMS implementation. After that, it reviews methods to quantify the benefits of AMS implementation studied by researchers. Also, it explores other infrastructure evaluation studies such as transit and ITS applications. Reviewing the methods forms a framework for developing methods of quantifying benefits. Throughout the examination of the methods, it discusses pros and cons of each method. Finally, the paper outlines a generic method for quantifying and evaluating benefits of AMS implementation.

Keywords: Asset Management, benefits, before and after, regression, benefit-cost
INTRODUCTION

Asset Management (AM) is defined as a systematic process of maintaining, upgrading, and operating physical assets cost-effectively using an inventory of assets, a method of assessing current condition or performance, a process for determining needs, tools to evaluate and select appropriate strategies to address the needs and methods to evaluate the effectiveness of each strategy (1). Asset Management Systems (AMS) provide a holistic approach to strategic decision making, which combines different management elements such as pavement management systems (PMS) and bridge management systems (BMS), based on a consistent evaluation manner, in order that agencies can trade off investment across the different elements. Also, AMS help agencies to understand the implications of different investment options (2).

For transportation agencies, it is expected that AM improves agencies’ performance in terms of the performance of their assets while it reduces agencies’ cost for maintenance and rehabilitation (M&R). In a worst case scenario without AM, M&R costs would continue to increase over time because of infrastructure deterioration caused by increases in the vehicle miles of travel, the increase in heavy trucks, aging infrastructure, and inappropriate M&R strategies. At the same time, the performance would degrade because M&R cannot catch up with the pace of deterioration of infrastructure due to the reasons aforementioned and an agency cannot afford to invest in the additional M&R needed due to budget constraints. Ultimately, the degradation in performance will translate to increased user costs. After implementing AMS, appropriate M&R, identified using the decision support tools, including condition prediction models and economic analysis tools in the AMS, may improve performance and reduce costs simultaneously. Also, it is noted that there would be a reduction in user and external (non-user) costs because appropriately maintained roads provide a better driving environment for users, thus reducing operating costs, crash costs, travel time costs, and environmental impacts.

Yet, there are several barriers to implementing AMS in agencies. A TRB Asset Management Peer Exchange addressed five barriers: 1) existing legacy data system; 2) organizational issues (cultural resistance, lack of defined goals and objectives, and lack of communication); 3) technological issues (lack of analysis tools and process, methods to quantify benefits, and tailoring AMS for different agency); 4) lack of educational tools; and 5) costs (3). Cost is an especially critical issue and barrier. Without showing that benefits of AMS implementation exceed costs for AMS implementation and operation, implementation will not occur. In particular, upper-level managers are interested in benefits that can be translated into monetary values (4), because they need to justify their investment in these tools. Also, methods to quantify benefits are required to justify AMS implementation using public resources. Therefore, it is imperative to quantify the benefits of AMS implementation and demonstrate that the benefits exceed the implementation and operating costs, in order to disseminate and implement AMS in agencies.

The objective of this research is to quantify the benefits of AMS implementation. First, the research begins by identifying various benefits produced by implementing AMS and costs for implementing AMS from different stakeholders’ perspectives in order to understand AMS implementation. After that, it reviews methods to quantify the benefits of AMS implementation studied by researchers. Also, it explores other infrastructure evaluation studies such as transit and ITS applications. Reviewing the methods forms a framework for developing methods of quantifying benefits by focusing on PMS, one AMS application, as a preliminary experiment. Throughout the examination of the methods, it discusses pros and cons of each method. Finally, the paper outlines a generic method for quantifying and evaluating benefits of AMS implementation.

BENEFITS AND COSTS OF AMS IMPLEMENTATION

The benefits realized from implementing AMS (4, 5, 6, 7, 8) can be classified in terms of nine categories, created by OECD (7), and four different stakeholders’ perspectives, identified by Haas et al. (6). These benefits are summarized in TABLE 1. As TABLE 1 shows, each level has different benefits depending on
the objectives of the stakeholder groups.

The objective of elected representatives is to guide civil systems including infrastructure in the right direction by monitoring agencies‘ performance. Since AMS help agencies to conduct business cost-effectively, the elected representatives receive strategic benefits through justification of M&R programs and assurance of the best expenditure of funds.

Within agencies, there are two levels of implementation of AMS: tactical level of top management and operational level at technical levels. On one hand, top management has to not only lead agencies to their goals determined by a strategic plan and public comments, but also maximize their assets‘ performance while minimize their expenditure. On the other hand, the objective of technical people is to maintain, upgrade, and operate physical assets using expert skills and knowledge. AMS implementation helps agencies achieve these objectives. The indirect effects are recognized in the improvement of communication and knowledge in various administrative and operating elements.

Lastly, the public can be divided into two groups: users and non-users. Road users use infrastructure as the built environment that supports their business and life without any risks and costs. They may be satisfied with reliable, improved assets (e.g., safer and smoother road surface) maintained through the decision support provided by AMS. Also, they will have benefits from savings in user costs, consisting of travel time, vehicle operation, and safety, thanks to the smooth surface which allows increasing driving speed, for example. Non-users want to maintain a good living environment (e.g., less air pollution and noise coming from highways). Since AMS will provide better driving conditions as mentioned above, non-users may appreciate reduced air pollution, noise, and annoyance due to traffic congestion which is caused by deteriorated and disordered infrastructure.

Those benefits are not produced as soon as AMS are implemented, but are accrued through the usage of AMS in agencies‘ business. Although it is difficult to articulate when the benefits are produced by AMS, many agencies have recognized that the existence of the benefits (3). However, there is no rule of thumb to quantify the benefits. Although several researchers (4, 5, 9) have quantified them, the methods used are inconsistent and have limitations in counting whole benefits coming from AMS, especially qualitative benefits such as communication, satisfaction, and externalities. Hence, agencies have introduced a variety of performance outcome indicators to measure the benefits, in other words, how much agencies’ business such as operation, maintenance, and construction using AMS responds to the needs from public and how much that is efficient and effective.

Compared to the benefits, costs for the implementation of AMS are easier to quantify as summarized in TABLE 2 (5, 6). The direct costs are of data acquisition, system software and hardware installment, and system development and operation at agencies. Also, there are indirect costs such as indirect labor, indirect material, and fixed costs. In addition, there would be costs for the public due to the improved assets maintained through the decision support provided by AMS. Although the example of safer and smoother road surfaces addresses the benefits in user and external costs, we may have a completely different picture. Smoother surface allows road users to drive faster, thus causing serious traffic accidents and higher emission level and then increasing safety and external costs. Otherwise, it may induce additional traffic and aggravate traffic congestion, thus increasing travel time, emissions and noise. Furthermore, people may suffer from delay, emission, and noise along M&R sections where frequent preventive M&R programs recommended by AMS are incurred. Due to the uncertainties of people’s behavior and perception corresponding to the improved assets, it is difficult to quantify the costs for the public.

**RESEARCH QUESTION**

Elected representatives and agencies expect that AM improves agencies’ asset performance while it reduces their cost for M&R. Also, the public may anticipate better driving and living environment as a result of AM. Therefore, this research focuses on three fundamental questions:

1. Do the benefits of implementing AMS exceed implementation and operating costs?
2. Does an agency increase productivity and decrease costs with AMS?
3. Do the public realize user and external cost reductions due to AMS implementation?

First, we will verify the cost-effectiveness of AMS implementation to justify agencies disseminating and implementing AMS with support from representatives, upper-level managers and the public. Once the cost-effectiveness is demonstrated by quantifying the benefits, it is easy to persuade the representatives, managers and public to disseminate and implement AMS among agencies.

Second, we will investigate the efficacy of AMS. Since agencies have been suffering or will suffer from budget constraints and deterioration of infrastructure, they would like to know how much they can increase their productivity and decrease M&R costs with AMS. Agencies can concretely explain the efficacy of AMS and achieve their accountability to representatives and the public.

Third, public benefits, that is, reduction of user and external costs, have to be analyzed since agencies provide social benefits to the public and are responsible to explain the benefits different from agency benefits to them. If agencies are successful in providing a positive result, they can implement AMS with the approval of the public.

LITERATURE REVIEW

This section summarizes analysis methods to quantify and analyze benefits of implementations of both PMS as one of AMS and other applications including Transit and Intelligent Transportation Systems (ITS) derived from six research papers. As shown in FIGURE 1, the methods are divided into three parts: before and after analysis, regression analysis, and benefit-cost analysis. The methods are explained as follows.

Before and After Analysis

Before and after analysis compares agencies’ performance such as asset condition, benefits, and costs before and after PMS implementation. This analysis is based on the assumption that asset performance after implementation is better than that before implementation. For example, Smadi (4) observed differences between actual Pavement Condition Index (PCI) derived from survey and virtual PCI calculated by PMS during before and after PMS implementation phases. Then, he compared the differences to see how close actual PCI gets to virtual PCI. Also, he estimated unit monetary value for one PCI from PCI difference and budget difference between actual work program and virtual program recommended by PMS at the before phase and applied the value to the after phase to calculate budget difference at the time. The concept is that if the PCI difference becomes smaller between the virtual and actual after PMS implementation, agencies’ pavement program has been improved due to the effect of PMS. He concluded that the pavement program has been improved and Iowa DOT gained benefit equivalent to $5 million over a 5-year period after PMS implementation.

Cowe Falls and Tighe (5) also used before and after analysis in their benefit-cost analysis. They collected data on the availability of rehabilitation funds, Pavement Quality Index (PQI), network length, and vehicle kilometers traveled (VKT), for both the before and after PMS implementation phases. Then they estimated savings on replacement cost of pavement (i.e., agency benefit) and vehicle operating costs (i.e., user benefit) under the condition where the rehabilitation costs and VKT are consistent between the two phases. Using the savings as benefits, PMS development and operating costs, and survey equipment costs in benefit-cost analysis later, they finally calculated a benefit-cost ratio to demonstrate that benefits of PMS implementation exceed its costs. They found that pavement asset value for Alberta Transportation increased $550 million and PQI increased 0.5 for entire road network after PMS implementation.

Hudson et al. (9) also employed before and after analysis using regression models, consisting of roughness index and pavement age, to capture how pavement lasts longer due to the effect of PMS. They showed that pavements last 2.0 years or 13.5% longer on the average due to the advent of pavement management and the development of PMS before reaching a tolerable roughness level. The increase of pavement life was used as benefits, that is, savings in agency costs in benefit-cost analysis.
Regression Analysis

Regression analysis models the relationships among variables and provides the degree of independent variables’ influences on dependent variable by coefficients. There are two types of regression analysis in the literatures as follows:

Estimation of Benefit and Cost Attributes

One is a regression model to estimate benefit and cost attributes which represent the degree of benefits and costs of intervention. For example, Hudson et al. (9) built regression models showing the relationship between roughness and age for before and after PMS implementation phases. Then, as addressed above, they found that pavements last 2.9 years or 13.5 % longer due to the effect of PMS.

Also, Weinberger (10) used regression analysis to explain how consumers value light rail transit (LRT) in terms of the value of real property. Her model includes distance to transit as an independent variable to see how much the distance affects property lease price. If the coefficient of the distance is positive, LRT makes the price increase. The increase can be thought as benefit of LRT in terms of real estate companies, people living there, and local government. The result showed that, properties that lie within 0.8 km of a light rail station command higher lease rates than other properties after controlling for variables such as length and type of lease, building improvements, and so on.

Assessment of Productivity

The other is a regression model to assess productivity of intervention. Gillen et al. (11) measured impact of Advanced Vehicle Location (AVL), one ITS application, using total factor productivity (TFP) for public transit over a period of time. They determined that TFP aggregates outputs on the basis of their revenue contribution and inputs on the basis of their relative importance to total costs in order to calculate the overall transit agency productivity as a function of these quantities. They used multiple regression models using several independent time series variables including an AVL dummy variable so that they could address the impact of AVL in TFP, the dependent variable. They revealed which variables have significant influence and how much the influence on productivity performance for public transit systems is, and then addressed the benefits of AVL, that is, the increase of productivity using the coefficient of the AVL dummy variable. In the analysis, they considered three TFP measures: total passenger trips, total passenger miles, and total vehicle revenue miles.

Benefit-Cost Analysis

Benefit-cost analysis is used to see cost-effectiveness of a program, that is, whether benefits produced by a program exceed its costs. Ran et al. (12) simulated six scenarios which have different automated highway system (AHS) corridor types and AHS vehicle percentages using benefit-cost analysis in order to prioritize them based on net benefit. They calculated time saving for benefit, and preparation costs of roadway, AHS infrastructure and in-vehicle equipment for costs over 20 years by applying a discount rate. The scenario which has largest net benefit is most preferable.

Although benefit-cost analysis is usually used to prioritize alternatives including do-nothing for project evaluation, it is used to verify a project’s cost-effectiveness as well. If the cost-effectiveness is verified by the analysis, the project is eligible to be executed; otherwise, it should be terminated. Cowe Falls and Tighe (5) verified PMS implementation. They used savings in agency and user costs between before and after PMS implementation phases for benefits; and PMS development and operating costs, and survey equipment costs during before PMS implementation phase for costs, in order to calculate a benefit-cost ratio. They found that the ratio is larger than 82, and then some savings within the expenditure of $235 million in rehabilitation and new construction would have occurred from PMS.
Hudson et al. (9) also calculated a benefit-cost ratio, using savings in agency costs for benefits, PMS development, operation, and equipment costs from before PMS implementation phase to after PMS implementation phase. The result showed that a benefit-cost ratio is 33 and there would be a saving of $270 million using minimum confidence interval values.

In summary, the three analysis methods are reviewed to understand how to quantify benefits of implementation of both PMS and other applications. Throughout the literature review, it is recognized that each method has the pros and cons listed in TABLE 3.

FRAMEWORK

The objective of the research is to quantify benefits of AMS implementation. In order to build a generic method for quantifying the benefits, we will focus on PMS as a preliminary experiment. Based on the three research questions, a framework for a generic method is explained to address these questions. It triangulates the three methods addressed above to obtain richer insight into PMS implementation as shown in FIGURE 2.

Descriptive Analysis Using Before and After Analysis

At first, it is important to recognize that trends of agency’s performance (e.g., pavement condition, budget, and expenditure) and exogenous effects (e.g., economy, traffic volume, and environment) in addition to agency’s profile in terms of asset, organizational structure, legislature, PMS, and so on. The descriptive analysis can analyze the second research question by showing the various trends using performance indicators between before and after PMS implementation.

There are two advantages in this analysis. First, indicators can address qualitative benefits using surveys with scoring systems, although the surveys are cumbersome. Second, it is simple and can be tailored for any agencies based on available data. On the other hand, there are two disadvantages. One is that indicators cannot reflect whole benefits at the same time. It is required to employ multiple indicators in the analysis. The other is that this analysis cannot control various changes when addressing benefits of PMS implementation. Despite the disadvantages, this may help to address the reason why unexpected results occur in the following analyses.

Regression Analysis

After agency’s performance is addressed by the descriptive analysis, regression analysis will be performed to complement the weakness of before and after analysis, not being able to consider various changes simultaneously. This analysis is intended to articulate answers to the second research question by observing the degree of independent variables’ influences on dependent variable expressed by the coefficients.

There are three tasks in the analysis. One is to find an appropriate dependent variable representing productivity. We can assume productivity is as increase of PCI, increase of pavement life, reduction of M&R costs, and so on. Otherwise, TFP representing productivity per se can be employed. It is necessary to explore various indicators and determine an appropriate one. Another is to look for independent variables which are statistically significant. For example, we can identify significant variables using t-values. The other is to determine a type of regression model. Among many types such as linear, polynomial, log linear, and so on, we should determine the best type by measure of fit (i.e., R-square).

Benefit-Cost Analysis

Finally, benefit-cost analysis will be employed to answer the first question, and also, where possible the third question, because benefit-cost analysis allows calculating user and external costs. The qualitative
benefits and costs (e.g., communication, satisfaction, external costs: air pollution, noise, and annoyance) will not be taken into account in this research in order to simplify the analysis. However, this framework is applicable to the qualitative benefits and costs in future research to obtain more complete results.

We will conduct retrospective analysis for an agency which has already implemented PMS and prospective analysis for agencies where there is no PMS. FIGURE 3 depicts the concept of benefit-cost analysis. Benefits consist of savings in agency costs and savings in user costs. Agency costs and user costs consider M&R cost and costs for travel time, vehicle operation, and safety, respectively. The savings in agency costs and user costs are expressed as follows:

\[
\text{Savings in Agency Cost} = \text{M&R Cost without PMS} - \text{M&R Cost with PMS}
\]
\[
\text{Savings in User Costs} = \text{User Cost without PMS} - \text{User Cost with PMS}
\]

The total for the two benefits is the benefits of PMS implementation. For the retrospective analysis, we will use data of historical M&R executed based on PMS’ decision and user costs with PMS and simulated data of M&R based on decision without PMS such as a worst first strategy and user costs without PMS over analysis period between after PMS implementation and present. On the other hand, in the prospective analysis, we will use data simulated by PMS for M&R and user costs with PMS and data simulated by the current M&R strategy (e.g., worst first) for M&R and user costs without PMS over analysis period. Costs include PMS development, operation, training costs, and survey equipment costs and are common to both the retrospective analysis and prospective analysis. However, the prospective analysis should refer to other agencies’ costs since there is no actual record.

Retrospective analysis will answer whether benefits of implementing PMS exceed PMS costs while taking into account the effect of PMS and the degree of conformity of agency’s business to M&R program made by PMS. Because an agency may not fully follow the program due to lack of budget, policy change, etc., the historical M&R data don’t reflect the effect of PMS completely. If needed to divide impacts into the effect of PMS and the degree of conformity, we should have data on the original M&R program recommended by PMS and compare with M&R and user costs without PMS. The difference between the M&R and user costs without PMS and those with PMS derived from the original M&R represents the effect of PMS.

Prospective analysis will address the effect of PMS only since there is no issue of conformity. However, it is noted that the result will be different from what an agency will experience in the future because the savings are calculated by both the costs for M&R and user without PMS and those with PMS, which are based on assumptions (e.g., traffic volume and budget) and cannot consider uncertainties such as policy change in the future.

The results of the analyses show us when benefits of PMS pay off the costs for PMS implementation, and current net benefit and benefit-cost ratio. If analysis period in the retrospective analysis is insufficient to pay off the PMS implementation costs, then the analysis has to shift to the prospective analysis in order to predict future benefit of PMS.

Issues

Based on the framework to quantify benefits of implementing PMS, there are five issues to be dealt with as follows:

Data Availability

If a simple method such as before and after analysis is employed, it is not needed to collect a number of explanatory variables for this research. Otherwise, it is necessary to collect large quantities of data recognizing data availability. If focusing on a specific agency, we should be aware of data availability related to pavement, funds, history, etc. In particular, it is important to have data for many years since the benefits accrue over the years and may not be observed for several years.
The method is not for a specific agency. The method should be transferable and we must consider using data commonly collected in any agency. In addition, it is required to think of data availability in terms of access, format and quality, such as whether the data is open source, not confidential, and not in a proprietary format.

Data Quality

Quality of data is critical because it affects the result of analyses. It is important to ascertain whether data are collected in a consistent and quality assurance manner; whether data sources are reliable; and whether there are outliers in the data set and why. This process makes the result of analyses closer to the real result of PMS implementation.

Valuation Method for User Costs

User costs include travel time cost, vehicle operating cost, and safety cost. The problem is that there are various valuation methods. Researchers use different methods to calculate the costs, and thus leading different results. We should determine what method is the most appropriate among the methods currently used. Also, we should be aware of what kinds of data are needed by the method.

Simulation

Both retrospective analysis and prospective analysis in benefit-cost analysis need to simulate M&R and user costs in order to obtain benefits of PMS implementation including savings in agency and user costs. It is required to construct simulation models to estimate the costs without PMS for retrospective analysis; and those without PMS and with PMS for prospective analysis. Also, M&R strategy which will be simulated by the models is needed to derive from an agency.

In addition, the simulation requires budget constraints for M&R expenditure over the analysis period. Although the retrospective analysis can refer to the M&R expenditure record, the prospective analysis does not have one. Hence, it has to predict future expenditure based on the historical record.

Analysis Result

The framework addressed a direction for building a generic method for quantifying and evaluating benefits of PMS implementation. From the analysis result, we assume that agencies can recognize the effect of PMS and are motivated to disseminate and implement AMS. Depending on the delivery of the result, however, agencies may not pay attention to the result. It is important to think of what kind of result is useful for agencies.

SUMMARY AND CONCLUSIONS

It is expected that AM provides various benefits to representatives, agencies, and public, throughout its usage in agencies’ transportation business. Although agencies recognized the benefits of implementing AMS, there are several barriers for the implementation. In order to disseminate and implement AMS in agencies, it is imperative to quantify the benefits of AMS implementation and demonstrate that the benefits exceed the implementation and operating costs.

This research addressed a direction to quantify the benefits of AMS implementation to respond to three research questions: Do the benefits of implementing AMS exceed implementation and operating costs? Does an agency increase productivity and decrease costs with AMS? Do the public realize user and external cost reductions due to AMS implementation? The research formed a framework for developing a quantifying method using before and after analysis, regression analysis, and benefit-cost analysis, derived from literature review. The framework triangulates the three analyses to obtain richer insight into PMS
implementation as a preliminary experiment.

Although the framework focused on PMS, one of AMS applications, it is required to apply the framework to other AMS applications after conducting the PMS preliminary experiment because agencies want to know benefits of implementing various AMS. Therefore, we will start the preliminary experiment using the quantifying method in fall 2005, and then discuss the feasibility of utilizing the method for other assets.

ACKNOWLEDGEMENTS

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**TABLE 1 Benefits of AMS Implementation**

<table>
<thead>
<tr>
<th>Category</th>
<th>Elected Representatives (Strategic Level)</th>
<th>Top Management (Tactical Level)</th>
<th>Technical Level People (Operational Level)</th>
<th>Public (User &amp; Non-user Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget allocation process</td>
<td>• Assurance of best expenditure of funds</td>
<td>• Improved allocation process within a program area</td>
<td>• Ability to build more accurate information</td>
<td>• Satisfaction of using improved assets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Assurance of best use of available budget</td>
<td>• Ability to track the performance of treatment strategies</td>
<td>• Improved road serviceability</td>
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<tr>
<td></td>
<td></td>
<td>• Providing a basis for allocating funds among different districts or agencies</td>
<td>• Ability of a wide range of staff to query database</td>
<td>• Savings in user costs (travel time, vehicle operation, and safety)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Justifying capital spending and maintenance programs to the elected council or legislature</td>
<td>• Integrated harmonized database (consistent data)</td>
<td>• Reduction of environmental impacts (air, noise, and annoyance)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Use of standard accounting concepts and terms to provide understandable information to the decision makers</td>
<td>• Provision of up-to-date accurate information on the condition</td>
<td></td>
</tr>
<tr>
<td>Asset Inventory</td>
<td>• Defining the “management fee” as a percentage of the spending on capital and maintenance work</td>
<td></td>
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<tr>
<td>Road performance</td>
<td>• Improved road performance</td>
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<td></td>
<td></td>
<td>• Savings in agency costs (construction and M&amp;R)</td>
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### TABLE 1 Benefits of AMS Implementation (Cont’d)

<table>
<thead>
<tr>
<th>Category</th>
<th>Elected Representatives (Strategic Level)</th>
<th>Top Management (Tactical Level)</th>
<th>Technical Level People (Operational Level)</th>
<th>Public (User &amp; Non-user Level)</th>
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</thead>
<tbody>
<tr>
<td>Management tools</td>
<td>• Realization of the magnitude of the investment that the agency has a better chance of making correct decisions on spending funds</td>
<td>• Common definitions and standards for maintenance and rehabilitation</td>
<td>• Satisfaction of providing best value for available funds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Actual operation of the system being able to defend/justify programs of maintenance and rehabilitation</td>
<td>• Economic modeling</td>
<td>• Capability of assessing the implications of:</td>
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<tr>
<td></td>
<td>• Reduction of pressure (from constituents) to make arbitrary program modifications</td>
<td>• Provision of an estimate of the economic effect of spending scenarios (scenario analysis)</td>
<td>− less funds, lower standards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Objective answers to the implications of:</td>
<td>• Ability to manage assets on an economic basis (cost-benefit, engineering economics)</td>
<td>• Capability of making the case for higher standards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>− lower levels of funding</td>
<td>• Prioritization of maintenance needs on the basis of future costs rather than current condition (life cycle cost)</td>
<td>• Capability of quantifying the assessment of the condition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>− lower standards</td>
<td>• Selection of the best maintenance and rehabilitation measures or strategies</td>
<td>• Improved credibility of decision-making process when dealing with top management</td>
<td></td>
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<tr>
<td></td>
<td>• Comprehensive, comparative assessment of:</td>
<td>• Objectively based answers to:</td>
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<td></td>
<td>− current status of the network</td>
<td>− what level of funding is required to keep the current status</td>
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<td></td>
<td>− expected future status</td>
<td>− the implications of greater or lesser budgets</td>
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<td>• Objective answers to:</td>
<td>− the implications of deferred work</td>
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<td>− lower standards</td>
<td>− the implications of lower standards</td>
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<th>Top Management (Tactical Level)</th>
<th>Technical Level People (Operational Level)</th>
<th>Public (User &amp; Non-user Level)</th>
</tr>
</thead>
</table>
| Staff development      | • Improved knowledge of pavement conditions and needs | • Improved knowledge of pavement conditions and needs | • Improved recognition of various administrative and operating elements of the organization  
  – Broad multi-disciplinary knowledge  
  – Provision of access to accurate data, state-of-art IT, and analysis tools needed for cost-effective management  
  • Improved knowledge of pavement conditions and needs  
  • Upgrade skills | • Understanding of agencies business via performance monitoring reports |
| Communication          | • Improved communication  
  – Common benchmarks  
  – Improved internal and external communications  
  • Adoption of accounting practices  
  • Ability to defer lobbying pressures from special interest groups | • Improved communication with design, construction, maintenance, planning, and research  
  • Enabling front line staff to become more involved in the decision making process | • Increased awareness of available technology and how to use it  
  • Better utilization of manpower  
  – Time saving in evaluating development alternatives | |
| Application of technology |                                           |                                 |                                           |                               |
TABLE 2 Costs of AMS Implementation

<table>
<thead>
<tr>
<th>Category</th>
<th>Elected Representatives (Strategic Level)</th>
<th>Top Management (Tactical Level)</th>
<th>Technical Level People (Operational Level)</th>
<th>Public (User &amp; Non-user Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data acquisition</td>
<td></td>
<td>• Data collection</td>
<td>• Data collection, processing, storage and analysis</td>
<td></td>
</tr>
</tbody>
</table>
| Management system      |                                          | • Software development/acquisition and installing the system  
• Computer hardware, staff  
• Operating costs of the system |                                |                              |
| Others                 |                                          | • Organizational changes  
• Staffing                | • Making changes in procedures  
• Extra time and effort to upgrade skills and learn new procedures  
• Training and education costs | • Increase of user costs and environmental impacts due to:  
-- Frequent preventive M&R works  
-- Increase of driving speed  
-- Inducing additional traffic produced by high quality road |
### TABLE 3 Pros and Cons of Benefit Quantifying Methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before and After</td>
<td>• Can use a common measurement to discuss benefit of PMS implementation such as increase of PCI.</td>
<td>• Cannot consider changes (e.g., traffic, budget, network length, etc.), when addressing benefits (e.g., increase of PCI) simultaneously. It is difficult to specify how much PMS contributes to the increase of PCI without controlling those variables.</td>
</tr>
<tr>
<td></td>
<td>• Require minimal data because it focuses on one performance dimension.</td>
<td>• When using PCI, researchers tried to show the benefits (i.e., increase of PCI) using monetary value. However, calculating monetary value is not straightforward because each PCI has different monetary value. For example, lower PCI has larger monetary value; higher PCI has smaller monetary value.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In order to calculate monetary value from PCI or pavement life, researchers used those average values for entire network. The value, however, may cause aggregation bias. Using condition index expressed by small range scale (e.g., 0-10), the bias produces significant difference in the result of monetary value.</td>
</tr>
<tr>
<td>Regression</td>
<td>• Specify what kind of and how much independent variables significantly influence dependent variable. If use a dummy variable indicating that PMS is used, it can address the degree of PMS effect on dependent variable.</td>
<td>• Requires a number of variables to show the pattern of relationship existing between variables.</td>
</tr>
<tr>
<td></td>
<td>• Can consider various changes which cannot be incorporated into before and after analysis.</td>
<td>• Need to determine appropriate dependent variable as an indicator of benefits of PMS implementation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Difficult to conclude that there is the cause and effect relationship between the two because the coefficients are derived from the pattern of relationship, although coefficients of independent variables show significant relationship with dependent variable. Hence, it is required to interpret the relationship based on subjective interpretation or refer other research addressing the relationship.</td>
</tr>
<tr>
<td>Benefit-Cost</td>
<td>• Show analysis result using monetary value, thus being able to understand benefits easily.</td>
<td>• No consistent manner to calculate benefits and costs. The definition of benefits and costs and those calculation methods are different from each other.</td>
</tr>
<tr>
<td></td>
<td>• Address how much benefits exceed costs with net benefit.</td>
<td>• Cannot control change of traffic, budget, network length, and so on.</td>
</tr>
<tr>
<td></td>
<td>• Consider benefits and costs in terms of various standings such as agency, user, and non-user.</td>
<td>• Need to decide appropriate analysis time horizon, since it is assumed that benefits and costs accrue over years.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cannot count all benefits and costs using monetary value. The result of this method may reflect only a part of them.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Difficult to quantify qualitative benefits. Although there is contingency valuation method to quantify them, it is cumbersome and difficult to reflect people’s real value.</td>
</tr>
</tbody>
</table>
FIGURE 1 Researches based on Benefits Quantification Methodology

Before and After Analysis

Benefit-Cost Analysis

Regression Analysis

Smadi (4)

Cowe Falls and Tighe (5)

Hudson et al. (9)

Ran et al. (12)

Gillen et al. (11)

Weinberger (10)

*The numbers in parentheses correspond to the numbers of references.

FIGURE 1 Researches based on Benefits Quantification Methodology
FIGURE 2 Concept of Benefit Quantifying Methodology
A. Retrospective Analysis

Prospective Analysis

B. Prospective Analysis

FIGURE 3 Concepts of Benefit-Cost Analysis