

Integration of Bridge and Pavement Management Systems: A Proposed Strategy for Asset Management

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ABSTRACT

As federal funding programs become more flexible, tools are required to enable upper level decision-makers to assess tradeoff of investments across varying transportation assets. The impact of allocating funds to one asset versus another asset must be considered when making current decisions. Asset management systems currently used by transportation agencies, namely bridge and pavement management systems, do not consider other asset classes when developing programs or needs estimates. One theoretical approach would employ the same predictive and optimization models for all types of assets. This approach may not be necessary and separate bridge and pavement management systems may be maintained, assuming that relational data models are accessible to ensure data compatibility and eliminate data duplication. With existing models, economic measures are used and, again theoretically, the outputs may be synthesized to develop joint programs. However, output compatibility quickly becomes an issue. For instance, benefit-cost ratios for bridge improvements may take precedence over all pavement activity, which may in turn take precedence over all bridge maintenance, repair and rehabilitation. Under constrained scenarios, therefore, a potential situation arises where all funds are allocated to bridge improvements with pavement and bridge MR&R activity deferred. Such a result is unrealistic and does not adequately reflect the network-level needs or the preferences of upper-level decision-makers. Furthermore, this approach limits the considerations deemed important by these decision-makers, such as safety, preservation of investment, the effect on the environment, rideability, user costs, and mobility issues. A framework is developed and proposed to permit the measurement of asset management system outputs as indices reflective of these decision variables. This framework provides the basis for a comprehensive, integrated asset management system approach. Application of the procedure is outlined and discussed.

INTRODUCTION

With a significant proportion of the nation's physical infrastructure deficient and needs increasing given available funding levels, the U.S. Congress mandated the development and implementation of intermodal management systems, including bridge and pavement management systems through the ISTEA legislation. Though this legislative mandate has since been repealed, owning agencies have continued efforts to implement these systems to provide 'state-of-the-art' decision support. In recent years, the need for a more

comprehensive approach providing integrated decision support for diverse transportation assets has been recognized.

Asset management has been described as a “systematic process of maintaining, upgrading and operating physical assets cost-effectively” (AASHTO, 1998). Asset management systems are intended to support the decision-making process, thereby facilitating quality improvements through short-range, long-range and strategic planning. The philosophy is intended to be “more than an engineering tool,” and, theoretically should “provide an opportunity for both horizontal and vertical integration within an agency,” bringing together diverse perspectives from Engineering, Finance, Environment & Planning, Administration, etc.

To examine alternative strategies for integrated asset management, this paper focuses on integration of bridge and pavement management systems. Transportation funding sources for the maintenance, repair, rehabilitation, improvement and replacement of bridge and pavement assets are first examined. A typical decision-making process is outlined and areas for asset management decision support are addressed. Decision-critical variables for long-term and strategic planning and STIP development are identified. Alternative structures for integrated bridge and pavement management are identified, evaluated and discussed.

BRIDGE AND PAVEMENT FUNDING SOURCES

Transportation projects are funded using Federal, State and local budgets. For many agencies, federal monies are the most significant funding source for new construction, preservation actions, replacements and improvements. These funds are disbursed to the States through various funding programs, including the Interstate Maintenance program, the Highway Bridge Repair and Rehabilitation Program (HBRRP), the Surface Transportation Program (STP), etc. Presently, these funding mechanisms are semi-prescriptive, requiring that monies be utilized only for projects that meet defined eligibility requirements.

For bridge needs, the HBRRP is the dominant funding program. Monies are apportioned to the States based on the cumulative deck area of deficient structures with minimum obligations to each State based on tax revenue contributions. The funds may be used for any structure that meets eligibility requirements, which are guided by the sufficiency rating and the type of action required. Sufficiency ratings are calculated for each structure in the inventory based on the condition, functionality and importance. Bridges with a sufficiency rating less than 50 are eligible for replacement funds while structures with sufficiency ratings less than 80 are eligible for repair or rehabilitation funds. Repair and rehabilitation funds may be spent on more substantial actions, such as major repairs, deck replacement, reconditioning efforts, etc. Maintenance activities, such as joint cleaning or spot painting, are typically not eligible. For eligible projects through the Bridge Program, federal funds provide 80% of the total cost with the remaining 20% matched by the State and/or locality.

Pavement funding programs are less prescriptive. Project funds may be obtained through the National Highway System program, the Interstate Maintenance program or the Surface Transportation Program. Each of these programs requires funds to be spent

on roadways with specific functional classifications. Furthermore, the programs provide differing levels of federal fund participation. Available funds are intended for multiple needs, including pavements, capacity improvements, ITS implementation, construction of intermodal facilities, natural habitat mitigation, and a variety of additional, diverse transportation needs depending on the funding program under consideration. Pavement action often must compete with these other needs for limited available monies.

TYPICAL DECISION-MAKING PROCESSES

From the FHWA-sponsored Management System Integration Committee, three generalized levels of decision-making were identified:

- Long-term and strategic planning,
- STIP/TIP development, and
- Project-level planning and programming

The inter-relation of the levels of decision-making is depicted graphically in Figure 1. Long-term decisions are typically made through a strategic planning process. For instance, the FHWA has identified strategic focus areas of mobility, productivity, safety, etc. Specific goals are established, such as the reduction of the number of deficient bridges to a minimum acceptable level over a defined horizon, in support of the strategic focus areas. Management system tools may be used in an iterative fashion to establish realistic, achievable long-term goals within the strategic planning process given projected available budgets.

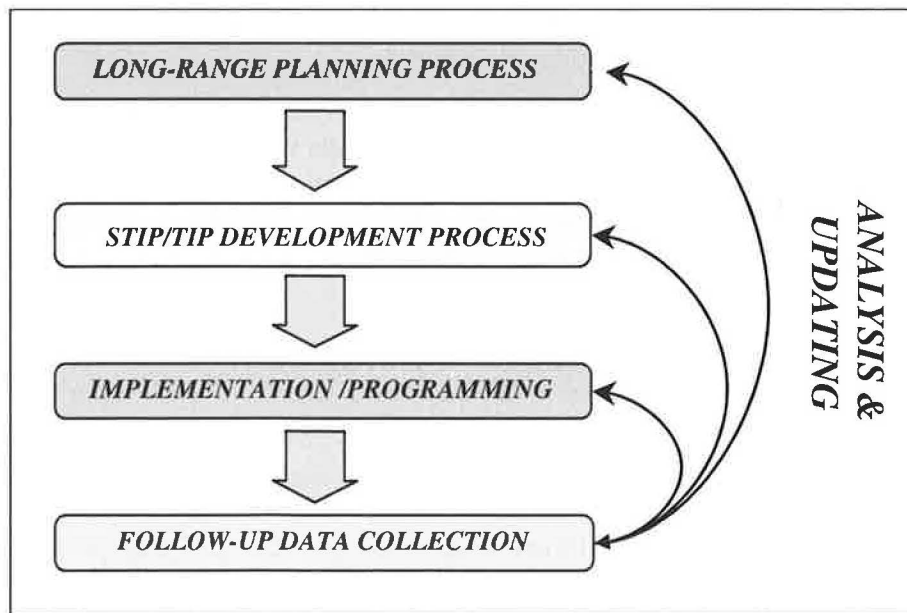


Figure 1: Levels of decision-making.

STIP/TIP (State Transportation Improvement Programs or Transportation Improvement Programs) may be considered as a bridge between long-term planning and project-level programming. Decision-making at this level is typically performed over a moderate time-horizon, such as 5 to 7 years. In a typical organization, State transportation commissions and MPO boards are responsible for STIP or TIP development, which is an integral component of asset and performance management. Consider the typical State budgeting and investment-planning process, which is very similar to the process used by MPO boards, as follows:

- The management system is used to develop needs estimates and optimal strategies over a defined planning horizon, which is typically 5 to 7 years. Outputs are developed independently by personnel responsible for management of each of the asset classes.
- The budget requirements for the maintenance and improvement programs over this horizon are submitted to transportation commissions (TC's) charged with STIP development.
- The TC receives budget requests to cover all transportation needs. Typically, the cumulative sum of all needs will exceed the available funds. Tradeoffs must be made to determine available budgets for each of the transportation asset and performance classes. The STIP typically results in defined budgets, a portion of which is typically targeted to specific projects.

In most situations, the iterative features of asset and performance management systems are *not* used at the TC level; however, support could be provided to the TC members, which would facilitate the application of these capabilities in the STIP development process. Such an approach would effectively enable these critical upper level decision-makers to:

- Perform what-if style analysis, and
- See the impact of varying budget levels on individual transportation system features.

The results of the STIP/TIP development process guide project-level planning and programming. Frequently, resulting STIP/TIP documents will combine budget-levels and project-specific requirements. Given available budgets and project-constraints, the management system is then used to assist the project-level decision-makers in establishing the optimal program for fund expenditure.

THE CASE FOR INTEGRATED ASSET MANAGEMENT

Examination of the levels of decision-making and the typical departmental responsibilities makes it evident that integrated asset management is primarily pertinent for upper-level managerial decision analysis. These decision-makers will require integrated decision support, particularly in the current climate of increased flexibility with respect to the use of available Federal funds. Issues and benefits of employing the systems are discussed.

Current management systems provide decision-makers with the capability to develop programs that optimize expenditures within a single asset class. Personnel may

Thompson, P.D. and Harrison, F.D., *Pontis Version 2.0 User's Manual: A Network Optimization System for Bridge Improvements and Maintenance*. Report FHWA-SA-93-083, Office of Technology Applications, Federal Highway Administration, Washington, DC, December 1993.

Thompson, P.D., Small, E.P., Johnson, M., and Marshall, A., *The AASHTOWare Pontis Bridge Management System*, submitted for review in *Structural Engineering International*, 1998.

philosophy exhibits promise for the development of integrated asset management, significant additional study is required.

Additional research will be performed by first examining the scalability of the benefit-cost ratios between the bridge and pavement management systems discussed. The examination will be performed using random samples of information collected from existing inventories. Following this examination, research will be performed to examine the effects of alternative performance measures on the distributions for the non-dimensional approach. A structure will then be developed and demonstrated again using actual randomly selected data. It is anticipated that this examination will be performed within the next year at the FHWA Turner Fairbank Highway Research Center.

ACKNOWLEDGMENTS

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quantifiable for bridges. Mobility represents inconveniences to the commuters in the traffic stream. Both considerations are dependent upon the availability of a quantitative congestion model relating the bridge geometrics and conditions to the traffic stream. With application to pavements, studies determined that for pavements, their contribution would be quite small compared to the other factors. This assumption is presumed to be valid for bridges and the mobility and environmental variables are not considered. In addition, the "use" factor was not considered since application was deemed more appropriate at the policy level than at the technical analysis level.

Quality is intended to measure the quality of the ride. Arguably, bridge deck condition, which in Pontis is measured by spalling for concrete bridge decks, could be used to reflect the quality of the ride over the structure. For the sake of discussion, at this point, quality is not considered. It is recognized, however, that this variable may be included if the technique is explored for actual implementation.

Many different measures could be used for generation of the non-dimensional indices for bridge needs. Long-term agency costs may be used as a basis for the agency cost distributions. Minimum width standards may be employed for safety distributions. User costs could be developed based on clearance and load-carrying capacity distributions and or costs. With each of these considerations, many questions arise:

- Should the indices be based on user-costs/accident risk costs or benefit-cost ratios?
- Should the index be based on geometric information?

Using these alternative measures may supersede optimal policies generated through the bridge management system. A vertical level of consistency is desired in such an approach and thus additional study is warranted.

SUMMARY AND CONCLUSIONS

The purposes and goals of developing integrated asset management systems have been discussed in the context of typical decision-making processes. It was shown that asset management concepts are pertinent at upper levels of decision-making in support of long-term planning and STIP/TIP development. At these levels, decision-makers are required to assess the impacts of varying levels of investment between alternative transportation assets, the impacts of policies, etc. Establishment of an integrated asset management approach thus will provide significant benefits in support of these processes.

Alternative structures for integrated asset management were outlined and it was shown that an approach combining the results of individual management systems (BMS, PMS, others) would be of benefit. Two alternative techniques are available to accomplish this goal: integration in economic terms using incremental benefit-cost analysis with input from the individual systems or the development of a new, non-parametric approach combining measures of decision-critical variables. Potential difficulties with integration using benefit-cost ratios were discussed and an alternative non-parametric approach was outlined. Development of indices for pavements was shown through example. Issues with development of the indices for bridges were outlined and discussed. While this

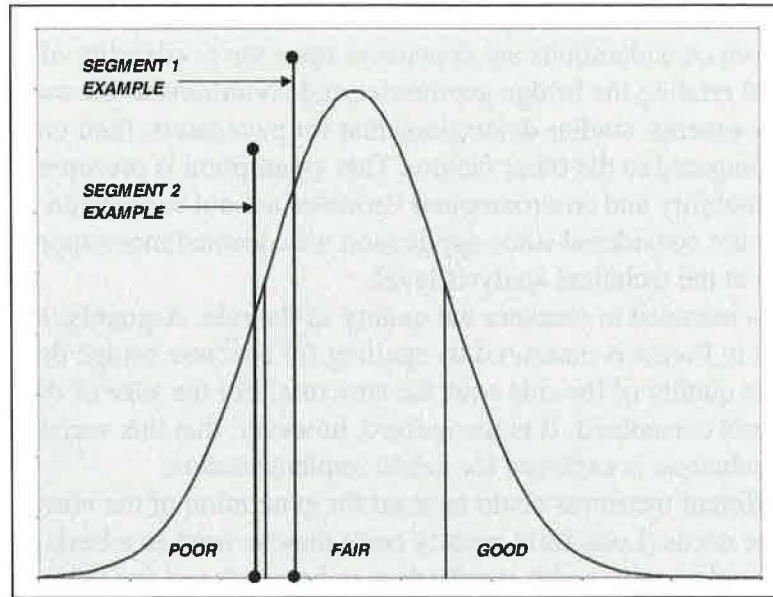


Figure 2: Hypothetical distribution and definition of safety index categories.

The same philosophy may be employed for an overall index, shown as follows:

- Index = Agency cost index (.35) + quality index (.30) + safety index (.25) + user index (.10)
- Index = $75 \times .35 + 50 \times .30 + 65 \times .25 + 65 \times .10 = 64$

With this approach, the overall index would be rated in the fair category, for the sake of discussion.

This approach enables upper level decision-makers to see the impact of fund allocations and program priorities on safety, quality and other decision critical variables for the pavements.

DISCUSSION OF THE APPROACH FOR BRIDGES

Four of the seven possible decision variables were pertinent for pavement analysis and were included in the determination of an overall segment index. These decision variables were the agency cost index, the quality index, the safety index, and the user index. When considering bridge needs, as with pavements, not all of the 7 critical decision variables are pertinent and/or quantifiable. The following are recommended for consideration.

- Agency Costs—Based on the output from the preservation optimization model.
- User Costs—Considered for raising and strengthening deficiencies.
- Safety—Modeled using the deck width deficiencies.

Decision variables not considered include the environment, mobility and quality variables. Environment is intended to reflect air quality impacts which are presently not

For demonstration purposes, the indices are generated using hypothetical relationships. Actual relationships must be developed following further research.

- Converting the IRI score to a quality index: $(240 - 140)/(240 - 40) \times 100 = 50$;
- Converting the rut depth index: $((0.95 - 0.64)/(0.95 - 0.15) \times .5) = 0.194$; and
- For demonstration,

Safety Index = $f(\text{rut index}, \text{MTD}) = f(0.194, 0.20) = 65$.

As mentioned previously, the user index is presently computed in the same way as the safety index in that they both consider only the effect of crashes. Therefore, the user index is 65 also.

This pavement section falls into a pavement family with flexible pavement, moderate truck traffic and hot climate zone. By formula, this section falls into the Condition State C category for cracking. The network optimization run recommends that 100% of segments in this pavement group in CSC receive a 2-inch overlay in year one. After one year, 97% of segments are projected to remain in CSA, and 3% deteriorate to CSB (applying transition probabilities). No action is recommended for CSA or CSB in year 2. This process continues for a 20-year planning horizon. Every recommended action has a cost associated with it. Assuming that these actions would actually occur, those future costs are brought back to present value using a discount rate. That present value is then annualized. That cost is found to be \$12/sy/yr. By a similar process, the annualized costs are computed for CSA and CSE (best and worst conditions).

- CSA = \$9/sy/yr
- CSE = \$21/sy/yr
- The agency cost index is computed as: $(21 - 12)/(21 - 9) \times 100 = 75$

In summary, for this example segment, the indices are as follows:

- Agency cost = 75,
- User Cost = 65,
- Safety = 65, and
- Quality = 50.

The ratings become meaningful when applied within the context of a network. Consider a hypothetical distribution of safety indices with two hypothetical segment ratings as shown in Figure 2. Note that for this example, the categories shown were defined on the basis of an assumed deviation from the mean based on the distribution of ratings. Alternative category definitions may be employed, such as quantitative measures from experimental studies, etc. Ratings for two hypothetical segments are shown with one segment measured in the fair category while the other segment results in a poor category.

Consider the example pavement segment with a safety rating of 65 as being in the fair category. Using a similar process for the other indices, this segment may be found to be in the poor category for quality, the fair category for user costs, and the good category for agency cost.

individual segments on the pavement network. In lieu of usable results from on-going studies, the Remaining Service Life (RSL) analysis may be used to establish this investment need.

All pavement segments in the inventory are categorized into “families” based on like pavement type, truck volume, and environmental zone. Budget constrained network optimization is performed which establishes the recommended actions according to pavement group and cracking condition state. This process is repeated for a 20-year planning horizon. Every recommended action has a cost associated with it. All of these costs are brought to a present value using a discount rate then annualized for a direct comparison. Segments that are in condition state A (CSA) will typically require the least annualized cost, since they are starting out in the best condition. Annualized costs are also reduced on these segments since the required actions are several years removed from the present and future costs are discounted. Conversely, segments in CSE for cracking (the worst condition) will require the highest annualized costs. Segments in CSA will be assigned an agency cost index of 100 while CSE receive a 0. CSB, CSC, and CSD will receive a score based on their annualized costs relative to that of CSA, based on a linear scale between 0 and 100.

User costs may be limited to those costs related to crashes. Other costs, such as increased vehicle wear and tear due to rough riding pavement, may be added at a later date when meaningful information becomes available. As a result, the user cost factor is considered equivalent to the safety factor index for the purposes of demonstration.

The “quality” factor refers to the ride quality (i.e., roughness of pavement) as perceived by the driver. The International Roughness Index (IRI) was established to quantify this perception of roughness. This index is converted to a simple 0 to 100 scale for the “quality” factor index by a straight-line method.

The safety and quality factors could be linked more closely to projected deterioration rates as opposed to more simple static condition state analysis. The advantage of this approach would be to assess performance of the system in terms of projected “need” as opposed to providing a simple “snapshot” of the system condition. For example, using the current method a roughness factor rating of 50 merely indicates that the roadway surface is moderately rough. It does not address how quickly that segment of pavement will deteriorate to such a condition that it requires some action. A pavement segment with a rating of 50 that experiences heavy truck traffic may need resurfacing very soon and thus have an immediate need. Conversely, a segment with very low traffic volume with a rating of 50 may not need any action for many years and has relatively low need. This could be implemented as the RSL analysis process becomes more robust.

To exemplify the procedure, consider an arbitrary 3.4-mile segment located on the National Highway System. A 2-inch overlay was performed in 1993. The following 1998 condition data were available (1/10 mile data aggregated to this logical project length):

- 16% alligator cracking, 20% transverse cracking;
- Mean texture depth (MTD) of 0.20 inches;
- Rut depth of 0.64 inches; and
- International Roughness Index (IRI) of 140.

“The costs [can] be compared to the annualized costs of a given segment of the inventory in the same environment. The farther the segment is out of alignment with the optimization, the poorer the performance. . . . This analysis allows for the inherent value of the infrastructure, allowing for normal maintenance costs without penalizing assessed performance” (MSIC Final Report, p. 91).

- **User costs**—This index reflects the “out of pocket expenditure of citizens and industry as a result of poor performance of that industry” (MSIC Final Report, p. 91). In bridge management, travel time and detour user costs are quantified for vertical clearance and load carrying capacity deficiencies. Accident user costs are used for deck width deficiencies, which are considered under safety.

- **Safety**—The safety index reflects potential injuries and fatalities that are caused by the poor performance of an inventory. As previously discussed, difficulties arise with assignment of economic values to life factors; therefore, this index may be assessed nondimensionally. “Injuries and fatality [risks] may be put on 0 to 100 scale, negating the need to assign esoteric dollar values to human suffering” (MSIC Final Report, p. 91).

- **Environment**—Currently, this factor is intended to reflect air quality impacts, which, initially, would limit consideration to congestion management systems.

- **Mobility**—This factor represents the inconvenience to commuters in the traffic stream. Truck delays are to be addressed through the user cost factor. As with safety, difficulties arise with the assignment of costs to people’s time. These difficulties could be sidestepped by defining a non-dimensional mobility index.

- **Quality**—This factor is intended to measure the quality of ride, which is pertinent in pavement management systems but is not currently explicitly considered in other asset and performance based systems.

- **Use**—This factor is indicative of the number of people that are affected by poor performance of the asset or system. The use factor eliminates the need to set different performance goals for different functional classifications.

Issues with employing a technique considering these variables will be discussed separately for bridges and pavements. Issues with integration will then be identified.

DEVELOPMENT OF THE METHOD FOR PAVEMENTS

In applying the technique for pavement management purposes, only the agency costs, user costs, safety, and ride quality variables are considered. The mobility and environmental factors could arguably be included; however, studies determined that for pavements, their contribution would be quite small compared to the other factors. The “use” factor as presented in the above formulation is more appropriately applied at the policy level and thus is not considered in this demonstration.

The “agency cost” factor may be referred to as an “infrastructure preservation” factor. The primary concern within the pavement inventory, for this factor, is cracking. Acting alone, cracking does not create a safety or ride quality problem but it does cause a substantial investment need for the agency. Studies have been and continue to be performed to quantify the cost impact of cracking conditions for

benefit-cost ratios. Combining gives precedence to improvement actions when developing bridge programs.

Similar inconsistencies in benefit definitions are expected to result across different asset classes. The benefits of pavements may exceed benefits of bridge preservation but may be less than those of bridge improvement. Under a constrained budget situation in a competitive environment, where combination of needs is performed using an economic technique, such as B/C prioritization or incremental benefit-cost analysis, all bridge improvements would be performed prior to pavement maintenance. These resulting differences are definitional in nature. Not all of the same considerations may be included in the assessment of benefits (i.e., quality of ride issues are considered in pavement decisions but are not considered in bridge management decision-making; while quality of ride could be assessed for bridge, i.e., the 'bump at the end of the bridge,' it is not presently quantified). Combining based on benefit/cost ratios is also limited by controversial issues, such as the cost of human life, which would be required where the decision is assessed through purely economic measures. "Realistically, decision-makers will not accept analysis which puts a dollar value on these quality of life factors, preferring instead to make their own value judgements reflective of their constituents" (MSIC Final Report, p. 88).

PROPOSED FRAMEWORK FOR INTEGRATION

A framework for integration has been proposed based on the following seven significant objective factors determined to be important to transportation decision-makers:

- Agency costs,
- User costs,
- Safety,
- Mobility,
- Environment,
- Quality of ride, and
- Relative use of the system.

The integration is performed for project selection and to provide a mechanism for the assessment of network performance. A non-dimensional index is developed for each of the objective variables and an overall score is developed using a weighted summation, shown as follows:

$$Score = \sum_i (factor_i \text{ weight})(factor_i \text{ index})$$

where $i = 1$ to 7 indicating that the summation is performed over all objective factors

The indices are developed using a 0 (worst) to 100 (best) scale. There are several techniques that can be used as a basis for the calculation of an index or score including additive and multiplicative techniques, utility based procedures, etc. Non-dimensional measurements may be developed for each of the critical decision variables as follows:

- **Agency costs**—Optimal strategies are developed through the preservation components of the management systems. The optimized strategy over a given planning horizon for a constrained budget may be determined and the annualized costs quantified.

information are compiled by collecting actual field data combined with actual construction costs obtained from cost management and accounting systems. Maintenance data and costs are obtained from the Maintenance Management System on a monthly basis. AADT and ESAL data obtained from traffic counts is used in conjunction with environmental condition and pavement type to assign each tenth mile section to a specific pavement family.

Dynamic segmentation is used to aggregate the data into project segments. The project history information described is maintained for each segment. Deterioration models for each of the four indices are produced for tenth mile segments, each project segment, and each pavement family. The deterioration models are utilized by the system to calculate Remaining Service Life (RSL) using the Ballady method for the current year by segment. The RSL information is provided to the regions for project level pavement design and to prepare a report to the Transportation Commission and other decision-makers on the Good/Fair/Poor conditions of the network.

Network level optimization builds upon the project-based segmentation. Trigger points and reset values, based on expert opinion for each pavement group and functional classification, are used to optimize each project based segment for RSL using an incremental benefit-cost analysis method. The sum total of recommended actions resulting from the project based benefit-cost analysis is optimized at the network-level to ensure an effective use of dollars at the network-level. An aggregated list of recommended projects for the coming year is then generated using the optimized activities from the current project set.

LIMITATION OF INCREMENTAL B/C FOR INTEGRATED DECISION-MAKING

The bridge and pavement management systems outputs, as described, are in terms of benefits and costs. Network and project-level programs are developed using incremental benefit-cost approaches. Initially, it appears that the needs and programs developed through the BMS and PMS are compatible. Given multiple lists in terms of benefit-cost ratios, straightforward techniques may be theoretically used to develop combined programs. However, there is a strong possibility that the definitions of benefits between varying asset classes are incompatible due to differences in the way that benefits are defined. A similar issue is generally considered to exist in bridge management systems; therefore, scalability of bridge preservation and improvement benefits are first examined.

Benefits for preservation needs are incremental, defined as the differential between taking an action today and postponing the action for one planning/programming cycle. The costs of taking the action or taking the do-nothing action are the long-term discounted costs and the magnitude of the differential is thus often less than the total cost of taking an action. Therefore, fractional incremental benefits result.

Improvement benefits are defined using user cost models for accident risks and detours. These may be looked at as incremental benefits, defined as the difference between taking the action and not taking the action. However, the costs act as first costs, not long-term discounted costs. The magnitude of the improvement benefits frequently exceeds the cost of taking the action and thus results in more favorable incremental

policies are then translated to individual structures and aggregated to develop bridge level strategies. The improvement model identifies level of service deficiencies and prioritizes actions to remove these deficiencies. Policy matrices are defined with acceptable and desirable conditions that are used for isolating the deficiency and estimating the cost of correction.

Benefits are defined for preservation actions and for improvement alternatives. For preservation, a type of incremental benefit is employed, which is defined as the agency cost savings resulting from taking the optimal or recommended action. The optimal action, by definition, will always be the minimum long-term cost alternative. These 'incremental' benefits are therefore quantified through comparison of the long-term cost of taking the action versus the long-term costs of the 'do-nothing' alternative. Improvement benefits are defined as user cost savings. Where deficiencies exist, user cost savings are incurred. Narrow deck widths increase the risk of accidents. Vertical clearance and load carrying capacity deficiencies cause percentages of the traffic stream to be detoured. Travel time and operating costs are incurred. Removal of the deficiency alleviates the detour or reduces the accident risk, thereby eliminating the user costs.

Integrated programs are developed using an incremental benefit-cost analysis with the optimization effectively maximizing the total benefits within the budget constraints. For each bridge, this procedure considers taking the preservation actions, taking the improvement actions, performing both maintenance and improvement, and bridge replacement.

PAVEMENT MANAGEMENT SYSTEMS

There are many different approaches available for pavement management. One such approach follows a procedure similar to Pontis, using a Markovian decision process to optimize network-level preservation needs. A second approach begins at the project level and uses incremental benefit cost analysis to build project-level needs into network-level strategies. To enable consideration of integration issues, a project-level system developed by Deighton is examined. The Deighton PMS software products are currently employed by 16 State agencies and thus may be considered as one of the predominant systems.

Roadway surface condition data, project history information and traffic data are aggregated into logical project segments. Deterioration models for each of these segments and for their respective pavement families are developed to determine Remaining Service Life. These models are combined with expert opinion based trigger points and strategies for network-level optimization using incremental benefit-cost analysis. A brief overview of the data elements and optimization procedure is presented and discussed. Though the system provides an off-the-shelf software tool, it is flexible enough to be customized by the end user.

Roadway surface condition data may be collected annually for the entire network on a tenth mile basis using an Automated Road Analysis (ARAN) vehicle or other commercially available data collection techniques, including ROSAN developed by the FHWA. This condition data is expressed as four indices indicating Ride, Rut, and Crack and a combined measure of these three factors, which is termed as the Overall Pavement Index (OPI) rated on a 0 to 100 scale. Roadway surface treatment details and project cost

1. The development of an overall asset management system optimizing for preservation and improvements of multiple assets concurrently under the constraints of multiple, diverse funding programs.

2. The development of an overall asset management system based on optimal results obtained through individual management systems (i.e., the results of separate BMS, PMS and other asset management systems provide input to the overall planning and programming system). Following this approach, there are two viable techniques:

- A. Utilize economic measure of elements and/or projects, such as the benefit-cost ratios, as input to a prioritization or incremental benefit-cost optimization.

- B. Employ an alternative, non-economic technique for integration of the optimal element-level or project-level outputs.

Much of the activity and discussion revolving around asset management systems has focused on the first approach. Through this philosophy, generic preservation and improvement models would receive input on generic assets. Pavements, bridges, signs, and other asset databases would provide input to the systems and optimization would be performed concurrently to develop joint-programs. This would provide benefit to upper-level and middle-management; however, limitations would be introduced with use of the systems for project-level programming. These limitations primarily result from differences in the level of detail required. For instance, in long-range and STIP development functions, decision-makers are concerned with gross measures, such as the impact of various budgets on the overall conditions (in terms of excellent/adequate or good/fair/poor). These decision-makers typically are not concerned with engineering details, which are more of a focus at the project-level.

It is beneficial to maintain and operate independent bridge, pavement, and other asset management systems within the existing organizational environment. An alternative approach that retains individual systems and integrates either the network or project-level results may be employed. The bridge and pavement management systems employed by the Colorado DOT are first discussed followed by a discussion of alternative strategies for integration using the existing systems.

BRIDGE MANAGEMENT SYSTEMS

For examination of the issues involved with integration of systems, the Pontis bridge management system is considered as the system has emerged as the predominant BMS in the United States. The system was developed as an outgrowth of the FHWA Demonstration Project 71. Details are described in the technical documentation, user manuals, and in various journal papers. The system consists of two primary optimization models: a preservation model and an improvement model. The preservation model seeks to keep the inventory in an optimal condition at a minimum cost over a long-term planning horizon. Optimal policies are generated from the element-level using a Markov decision process. For each condition state of each element in each environment, the system considers the long-term cost of taking an action. The set of optimal actions across the condition states form the optimal policy for a given element. The optimal

determine need requirements over a defined planning horizon, justify budget requirements, develop cost effective programs, quantify the effect of varying budget levels on future conditions, etc. In a more flexible environment, such decision support tools must additionally enable personnel to assess tradeoffs between asset classes. For instance, a system must be provided to enable the decision-maker to assess the impact of investment within pavement rehabilitation versus intelligent transportation systems, investment in bridge improvements versus roadway resurfacing, etc. Current management systems are intended for use by personnel responsible for programming needs in a single asset class and do not necessarily address the needs of upper-level decision-makers responsible for budgeting across multiple transportation needs.

Though the individual systems provide significant analysis and essential decision support, limitations persist, particularly in the long-term planning and STIP/TIP development processes. These decision-makers require capabilities to facilitate value tradeoffs in the budgeting process. Integration is currently performed at the project-level in a semi-manual fashion. Typically, personnel with the responsibility for construction or pre-construction management will examine programmed needs for multiple assets over a short to moderate time horizon (3 to 5 years) to manually coordinate activities. Integrated decision support would naturally facilitate better coordination, thereby increasing safety and reliability while minimizing traffic disruption and life-cycle costs of the joint assets. Some additional benefits of integrated asset management include the following:

- Enable identification of budget levels to maximize achievement of strategic focus areas, such as overall mobility, productivity, etc.
- Facilitate the definition and determination of appropriate goals and performance measures utilizing quantitative information on individual asset classes combined with impacts and inter-relationships between asset and performance characteristics.
 - Improve identification of important areas for upper management consideration.
 - Facilitate the development of joint-programs and corridor planning/programming.
 - Permit optimization of expenditures to multiple-assets through multiple budget sources.
- Reduce life-cycle costs and increased safety to the traveling public.
- Reduce agency costs through identification of decision critical variables, elimination of data duplication, etc.

The need for more effective decision support systems that address multiple, and perhaps diverse, transportation inventories has been established. Government and industry have been actively involved in examining the issues associated with development of systems to provide such decision support.

ALTERNATIVE STRATEGIES FOR ASSET MANAGEMENT SYSTEM DEVELOPMENT

As may be recognized, integrated asset management is intended for long-range planning and STIP/TIP development processes within current organization structures. It may be considered that there are two viable approaches for integrated asset management: