A DISCUSSION ON A PROPOSED BRIDGE MANAGEMENT SYSTEM (BMS) FOR TEXAS HIGHWAYS

By

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Reference: PONTIS Executive Summary - A Network Optimization for Bridge Improvements and Maintenance, Prepared for Federal Highway Administration by Kamal Golabi of Optima, Inc., and Paul Thompson of Cambridge Systematics, Inc., December 31, 1991.

OVERVIEW

The Texas state highway network consists of approximately 77,000 miles of roadways and 33,000 bridges, and culverts that may be classified as bridges.

The intensity of road construction during the 1930's through the 1960's resulted in construction of a great number of bridges, so that more than 5000, or about 15 percent of our existing state highway bridges, are more than 50 years old. Many of them even date back to the 1920's and still carry large volumes of traffic. Although few of the interstate bridges are of 1920's vintage, a large number of them are more than 30 years old. The age of the bridges, the fact that many were designed for less traffic, slower speeds and lighter loads, combined with the gradual effects of weather and wear, have caused substantial problems for our state highway system bridges. Unavailability of adequate funds, which has been responsible for many of the decisions to defer maintenance, has added to the problem. Today, approximately 20 percent of the state's highway bridges, by reasons of their conditions or appraisal, are eligible candidates for the Federal Highway Bridge Replacement and Rehabilitation Program. In spite of the allocation of large sums of money through federal and state programs, the gap between bridge replacement, improvements and maintenance needs on one hand, and available funds on the other, has not greatly decreased.

Given the magnitude of the problem and the enormous funds needed, it is obvious that available funds will not permit the immediate remedy of all these candidate deficient bridges. What is needed is a careful and systematic allocation of funds and the formulation of an efficient bridge work policy that derives the maximum benefit from use of the limited funds. Formulation of such a policy requires a networkwide analysis that evaluates the needs of each bridge, and options available to meet those needs, in the context of overall network benefits, budgets and restrictions.

Now, in most agencies that are responsible for highway bridges, bridge work has been typically accomplished over the years through the use of separate programs of work for bridge maintenance, rehabilitation, improvement and replacement. However, there usually was a lack of coordination among those separate programs of work, which often resulted in inefficient use of bridge funds. Certainly each of these separate programs has accomplished an objective, but the objective in terms of overall network considerations has been unclear. While perhaps not always the sole answer, better management of the different work activities should at least partly alleviate the ills of having short funds and huge backlogs of urgently needed bridge work. While there may continue to be a need for separate programs of work, those programs need to be coordinated into a single, overall highway network objective in a cost-effective manner through the use of an overall Bridge Management System.

For several years more effective bridge management has been becoming more of a concern nationwide, and several bridge management systems have been tried with varying degrees of success. With the given that the bridge management system idea was sound, clearly what was needed was a fresh start in developing an overall system for agencies with highway bridge responsibilities, especially state DOT's. Consequently, in August 1989, a federally funded consultant contract was awarded by the California Department of Transportation to develop a comprehensive, rigorous and flexible network optimization and planning system that could be used by a state DOT, such as Texas, to formulate policies, practices and programs for bridge work at network level. The system resulting from this effort is named

Pontis (from the Latin word *pons* for bridge).

The development of Pontis is now complete, and the system is being looked at for implementation by the Texas Department of Transportation. Although the first implementation of the system is in California, the Federal Highway Administration-funded system has been developed with sufficient generality and flexibility to allow customization for other state DOT's. To assure this flexibility, a Technical Advisory Committee comprised of representatives from the Federal Highway Administration, the Transportation Research Board, and six states with divergent environments and needs that included California, Minnesota, North Carolina, Tennessee, Vermont and Washington, oversaw the development of the system. In addition to providing guidance and sharing their considerable experience in bridge management and engineering judgment, the advisory committee was also responsible for defining the list of bridge elements, the possible conditions that each element can be in, and a set of appropriate remedial actions for each condition.

As a further note, the 1991 Federal Surface Transportation Act requires each state to have a Bridge Management System in place by September 30, 1995.

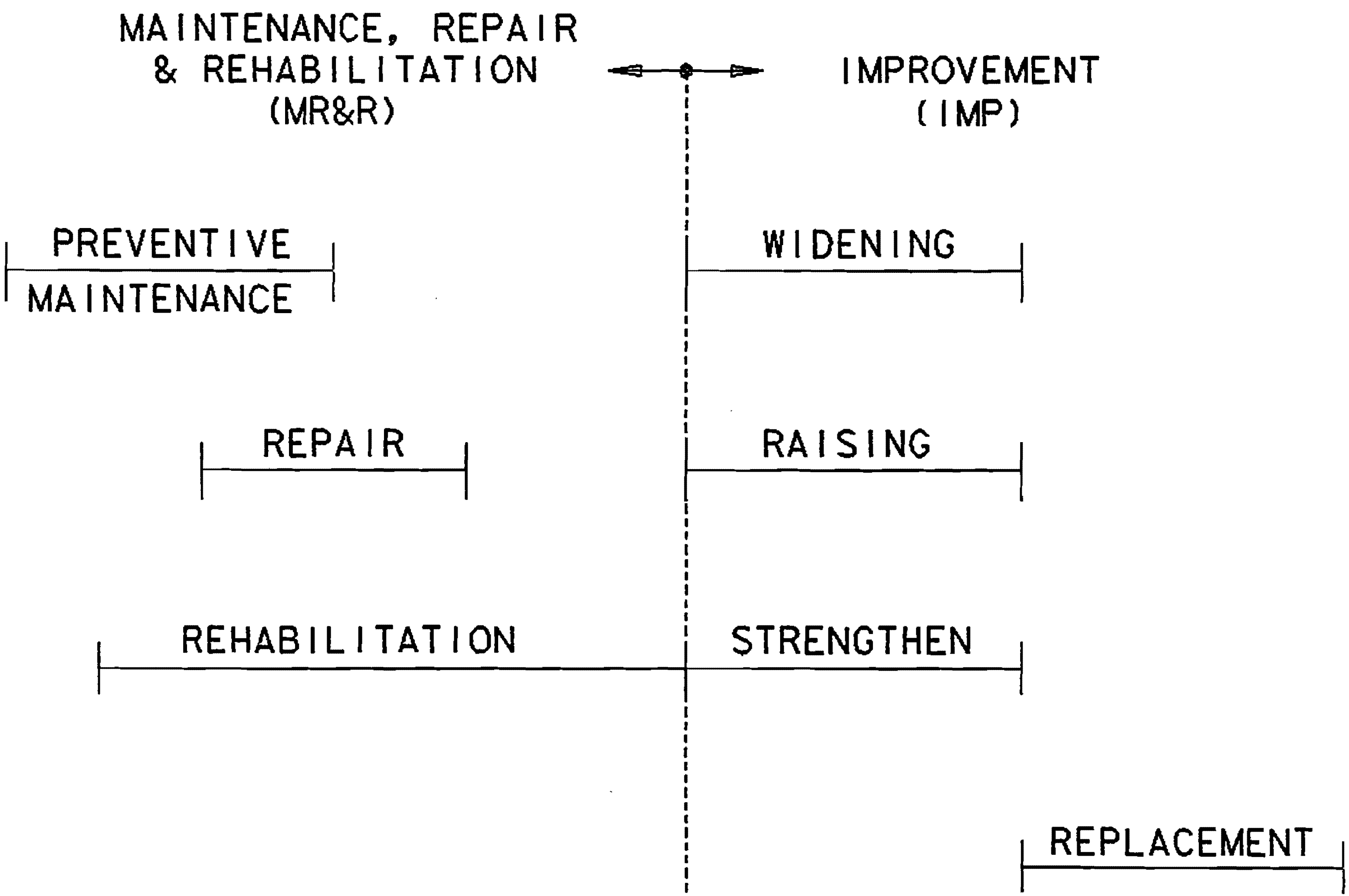
PHILOSOPHY OF PONTIS ON BRIDGE WORK

A spectrum of bridge work may be visualized with preventive maintenance at one end and complete bridge replacement at the other. While in actual practice there may be overlap of activities, two distinct sets of activities are identifiable. These are: maintenance, repair and rehabilitation which we call "MR&R", and improvement work which we call "IMP". The IMP set is considered to include bridge replacement. Identification and use of these two broad groups of activities is proving helpful in better understanding how to go about better managing highway bridge assets.

As we said, the first of the two sets of bridge work activities constitutes maintenance, repair and rehabilitation actions. Such actions, as correcting scour conditions or replacing wearing surfaces, each improve the condition of the bridge, which may deteriorate again with time. On the other hand the improvement set essentially deals with functional aspects, and once performed do not change with time. This set includes actions such as deck widening or bridge raising to gain vertical clearance, and as we said, this set also includes bridge replacement. Recommended improvement actions are usually driven by state or agency-specified level-of-service goals for selected bridge characteristics that are used in assessing bridge adequacy. Those characteristics are usually in the areas of weight, size and volume of traffic loads. Specifically the characteristics are load capacity, clear deck width, vertical overclearance and vertical underclearance.

The set of recommended actions dealing with MR&R work, and their budget requirements, need to be generated through a dynamic model, since the condition is time-dependent and at least for some of the actions, there is a tradeoff between their cost and the time until the next action is necessary. To be specific, if two actions achieve a desirable condition at this

SPECTRUM OF BRIDGE WORK



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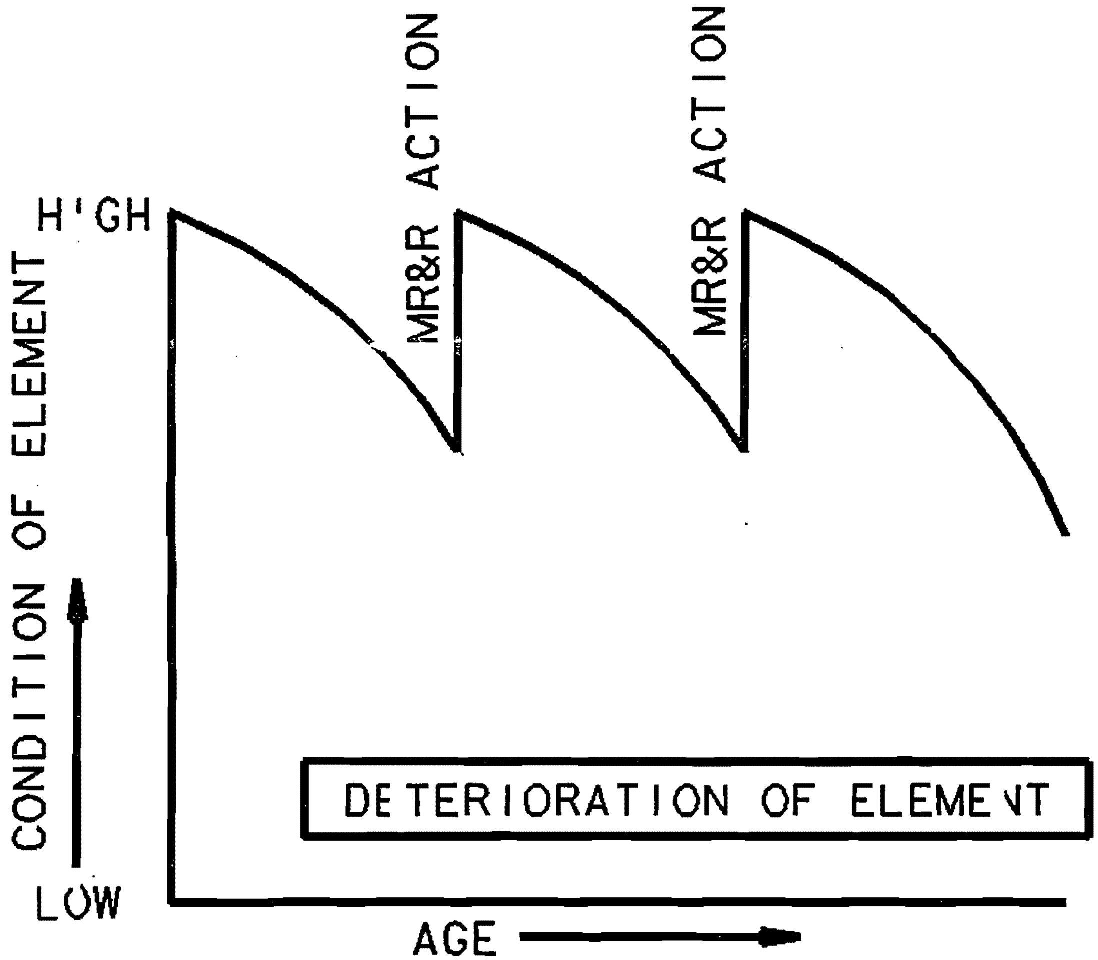
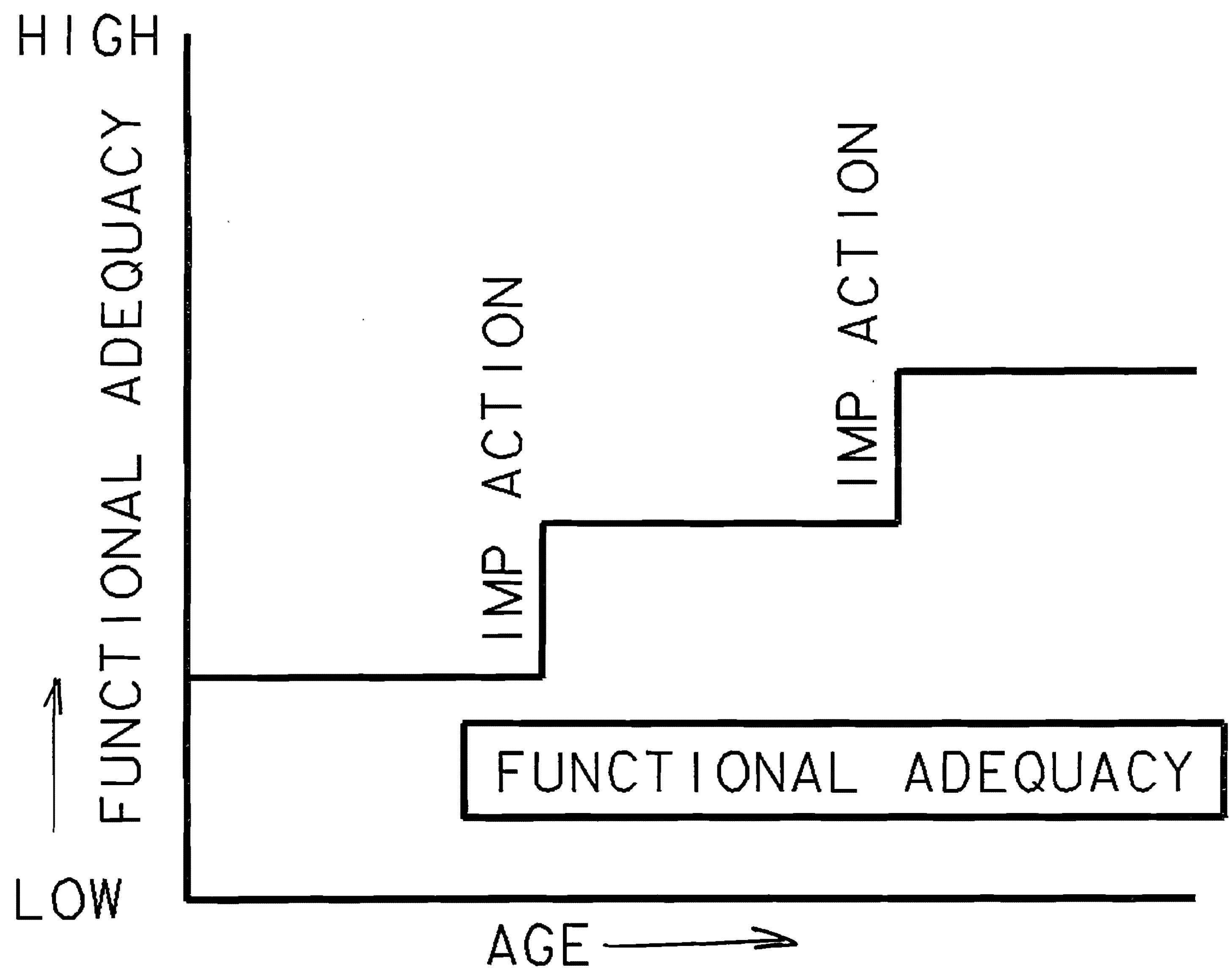
BRIDGE WORK ACTIVITES

- MAINTENANCE, REPAIR AND REHABILITATION (MR&R)
- IMPROVEMENT (IMP)


MR&R ACTION
MR&R ACTION
HIGH
CONDITION OF ELEMENT
LOW
DETERIORATION OF ELEMENT
AGE



VI=16 DISPLAY COMPLETE LEVEL=1, SOLID, WT=5, LC=SOL , PRI CO=3 time, and one is less expensive than the other but has a higher probability of deterioration in the future, the model must be able to address that tradeoff and incorporate it in its calculations. Based on this understanding, it has been concluded that a bridge management system should have two distinct, but interrelated components to address both MR&R and improvement actions.

Although these optimization models may be distinct, there is a substantial interrelationship among the two sets of activities. The interrelationships are not only through budget requirements, but also through coordination issues which may affect the prioritization and sequencing of improvements. For example, the improvement of a bridge needing both improvement and major maintenance or rehabilitation may be accelerated to save cost and satisfy immediate maintenance needs, even if ordinarily the bridge would not have been scheduled for improvement for some time.

OBJECTIVES OF PONTIS

Budgeting for expected expenditures to address current and future needs is related to the desire of decision makers to meet several objectives. An effective planning system must systematically address those objectives and prescribe the actions necessary to achieve and maintain desirable standards with respect to those objectives. In addition to cost and budgetary issues, the main objectives of planners and administrators include the following:

- Meeting and maintaining the highest standards of safety for the traveling public.
- Preserving the considerable investment in structures.
- Correcting deficiencies within reasonable time.
- Equitably allocating resources to the various geographical areas and bridge activities.
- Avoiding costly repairs through appropriate preventive maintenance.
- Efficiently utilizing funding sources.
- Minimizing total expected costs over the long run.

Budget requirements normally are a function of envisioned future needs, and these needs are usually dictated by the present conditions of the structures, future expansion needs to handle increases in traffic, and the uncertainties associated with deterioration, as well as the complex interrelationship between present preventive and future corrective actions. In addition, a budgeting and maintenance planning system must be an iterative tool allowing adjustments dictated by actual conditions over time (instead of an assumed series of actions envisioned now for a long future period). It must also have sufficient flexibility to allow an analysis of the effect of various budgetary policies on future conditions which in turn would dictate future costs. The interrelationships among conditions, MR&R actions, and budget needs necessitate the development of comprehensive, dynamic planning model that would effectively address the above objectives, as well as provide defensible near-term and long-term budget requirements. Furthermore, it should provide the decision makers with the flexibility for predicting and analyzing the effects of budget cuts on future conditions of the structures. The formulation of the Pontis model enables the effective address of the above objectives. Pontis is designed with many specific achievements in mind including:

- Provide a systematic procedure for finding MR&R budget requirements.
- Incorporate level-of-service goals in assessing bridge improvement needs and budget requirements.
- Provide a capability to consider the entire bridge network simultaneously in arriving at optimal policies and recommendations for MR&R.
- Retain the flexibility to address any subset of bridges.
- Provide priority orders and sequencing for bridges in need of MR&R and improvement.
- Coordinate MR&R planning decisions with future improvement decisions.
- Consider the differing inspection and repair needs of the major structural components for bridges as well as the differing needs of the various types of bridges.
- Allow for updating of predictive probabilities as the necessary data become available over time.
- Consider the immediate and future costs and benefits of the various courses of action and their effect on future conditions. In particular, the model would weigh the benefits of preventive maintenance versus costlier (but less frequent) corrective actions.
- Allow sensitivity analyses of the recommended policies in terms of future conditions of the bridge network, and cost requirements.

- Be flexible to accommodate different state-specific improvement, MR&R and fiscal policy issues.
- Provide a basis for short-term and long-term MR&R and improvement budget planning and resource allocation.
- Provide a rigorous procedure and an analytical framework for incorporation of expert engineering judgment in the model.

Pontis addresses the above issues and requirements through the use of several interrelated modules.

MODELING FRAMEWORK

Approach

The objectives previously described may be realized through development of several interrelated submodels that together would address the multi-objective MR&R and improvement problems of a bridge network. Each of these submodels addresses different facets of the problem, and each requires a separate modeling approach. Together they provide a vehicle for comparing preventive versus corrective actions and a systematic procedure for allocation of resources for the improvement and maintenance of bridges in the network.

The approach to modeling the system has been selected with several additional objectives and features in mind:

- Flexibility and generality--choosing the most general formulations to accommodate future adaptation to other condition states, and flexibility in meeting unforeseen future requirements.
- Formulating the problems and finding solution methodologies that would make the system independent of the number of bridges involved. This would free the model from some computational restrictions associated with other approaches to bridge management.
- Separation of MR&R from improvement. Maintenance, repair and rehabilitation management is the pursuit of a most efficient way to keep existing bridges in operation at their current level of service. It asks the question of what the required level of service should be, or even whether the bridge should remain open, assuming that operations must continue and that deterioration must be detected and remedied before operations are affected, at minimal cost. Improvement

management, on the other hand, addresses functional shortcomings, identifies instances where adequate standards are not met, develops strategies to meet them, and prioritizes and sequences such improvements. The modeling approach addresses these functions separately, and then combines and coordinates recommendations for each bridge in the content of overall network requirements.

- Dynamic Optimization of MR&R. The MR&R problem is a dynamic problem in the sense that future conditions are a function of present decisions--to choose current decisions, future consequences of present-day actions and the cost of those consequences should be considered. The MR&R models of Pontis are dynamic models that attempt to address this issue.
- Addressing Uncertainties in Deterioration Patterns. Deterioration of bridges is a probabilistic phenomenon--it is not possible to predict with complete certainty how each element of each bridge will deteriorate over time. Pontis addresses this question through a set of probabilistic deterioration models. As data is collected over years, an updating model "learns" from experience and produces new deterioration probabilities, leading to more accurate results over time.

The Rating Method vs. Information Requirements of Pontis

The Pontis approach to bridge management is fundamentally different from what has been typically suggested and practiced earlier. Previously, condition information gathered from inspections typically has been lumped into one or a few rating numbers. This current FHWA rating method, despite its advantages for descriptive purposes, has severe limitations that would make models based on that data questionable:

- The major components of a bridge (roadway, superstructure, substructure) consist of many elements, materials, possibly different functions for the same element, and different quantities of the same element. Each of these elements behaves differently over time as a function of the load and environment that they are subjected to. While engineers do observe and collect various amounts of information on the components, lumping all that information in one number for an entire bridge component grossly reduces the value of the information gathered.

- Two components with the same rating can have totally different conditions, and totally different actions may be suitable for them. Therefore, just knowing the rating is not sufficient to specify the action required.
- Ratings are ordinal measures in the sense that they can show the relative condition of components but this would not allow investigation of tradeoffs of benefits and costs of various actions.
- No matter how many guidelines are set and no matter how detailed the definitions for the ratings are made, there will be a considerable amount of subjectivity associated with those ratings, especially since there are so few ratings and so many exceptions. Furthermore, in the absence of a more detailed and systematic procedure, the engineer may deviate from the ratings to assert an opinion that an action needs to be taken by opting for a worse rating than what the bridge deserves.

In Pontis, those shortcomings have been largely overcome by dividing each bridge into its constituent elements, by defining the condition of each element by a set of measurable or quantifiable parameters and by presenting the values of those parameters as some "condition states". The optimal MR&R and improvement policy for each bridge is found by combining and coordinating recommendations for its elements, and by systematically considering the interaction among the elements.

BRIDGE COMPONENTS

- ROADWAY
- SUPERSTRUCTURE
- SUBSTRUCTURE
- CHANNEL AND CHANNEL PROTECTION
- APPROACHES

BRIDGE COMPONENTS AND ELEMENTS

COMPONENT	ELEMENTS
• SUPERSTRUCTURE	— MAIN MEMBERS
	— INTERMEDIATE MEMBERS
	— SECONDARY MEMBERS
	— BEARING ASSEMBLIES
	— HINGE ASSEMBLIES
	— OTHER CONNECTIONS

BRIDGE COMPONENTS AND ELEMENTS

COMPONENT	ELEMENTS
• SUBSTRUCTURE	— ABUTMENT CAPS
	— BENT/PIER CAPS
	— ABUTMENT EXTENSIONS
	— BENT/PIER EXTENSIONS
	— ABUTMENT FOUNDATIONS
	— BENT/PIER FOUNDATIONS

ORGANIZATION OF PONTIS

Bridge management consists of a series of activities involving information gathering, interpretation, prediction, cost accounting, decision making, budgeting and planning. Pontis, then, consists of a set of interconnected models that address these functions systematically and effectively. The system is also designed to help managers prepare and evaluate a capital program for bridges. It is a flexible and interactive tool which allows user input in every stage of the process and uses mathematical models to help in generating and evaluating alternatives.

The heart of the system is a set of optimization models which derive their information requirements from predictive, cost and feasible action models. Engineering judgment and managerial considerations are also inputs to the model. The outputs are action plans for improvement and MR&R, along with schedules and budget requirements. An updating model provides a tool to adapt the deterioration probabilities as new data becomes available over the years. Thus, while the Pontis process starts by using engineering judgment as the basis for its predictive model, it subsequently will "learn", as we said, from new data and automatically adjust its predictive equations over time.

MAJOR SYSTEM COMPONENTS

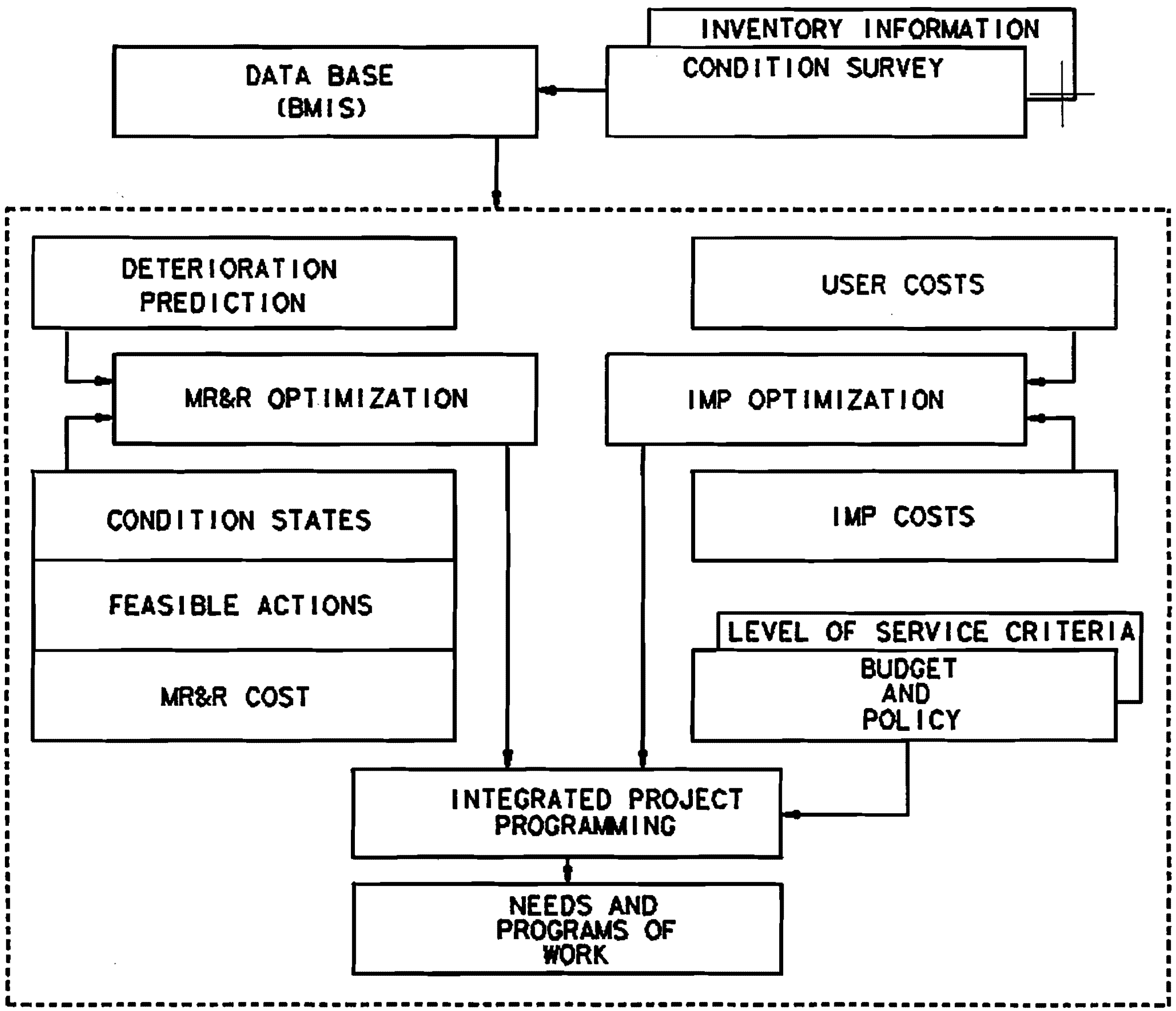
The major components of Pontis are a data base and models.

Pontis Data Base

Every state has a bridge inventory which meets the minimum standard of being able to produce a computer tape for the FHWA's National Bridge Inventory (NBI) which is required by the National Bridge Inspection Standards (NBIS). This inventory in our department is known as the BRINSAP data file, which was designed and has been modified over the years to meet a large number of objectives. Conspicuously absent from these objectives is the kind of detailed network optimization that needs to be accomplished by a BMS. As a result, agency NBI inventories typically contain a large number of data items which are not relevant to Pontis, and conversely Pontis needs a large number of items that are not present in the inventory. Consequently PONTIS needs to be able to draw what data it needs and is available, from the inventory and from other sources. It also needs to be kept updated as more information becomes available over time. It needs to retrieve and store the inventory, the physical characteristics of bridges, condition survey data and other relevant information from the existing data files. It should also store traffic information, load characteristics, and cost information, as well as the main elements of each bridge, the condition states defining the possible conditions of each element, and the set of feasible MR&R actions associated with those conditions. The data base should also organize the results of the individual optimization models to help in coordination of activities for each individual bridge.

PONTIS

MAJOR SYSTEM COMPONENTS



Optimization Models

The main feature of Pontis is its optimization capability. The two optimization models address MR&R and improvement decisions for the bridge network, and derive their information needs from other auxiliary models. The two optimization models feed the Integrated Project Programming Model that prioritizes and schedules the work, estimates backlogs, and predicts network conditions as the result of any budgeting scenario.

MR&R OPTIMIZATION

The objective of the MR&R optimization model is to find the long-term policy, for each element in each environment, which minimizes the long-term maintenance funding requirements while keeping the element out of risk of failure.

Bridge management can be called a "going concern," because the over-riding factor driving MR&R policy is to sustain an optimal policy every year into the far future. In the Pontis MR&R model framework, three important occurrences typically happen every year:

1. Bridge elements deteriorate, making transitions from one condition state to a worse one.
2. Maintenance, repair or rehabilitation actions are taken on specific bridge elements, incurring a cost.
3. The MR&R action taken improves the bridge condition.

The MR&R model, in reality, consists of other interrelated submodels. One model calculates the steady-state network conditions of optimal actions are followed, while another model determines the optimal action for each condition of each element. These two models are dynamic optimization models--in making their current recommendations, they will consider the effect of different actions on future conditions and the expected costs that would arise from those conditions if the optimal policy is followed. The models are also probabilistic as they consider the uncertainties associated with deterioration rates for each condition. These submodels recommend network-wide MR&R policies. Still another component of the MR&R optimization model applies the optimal network policies to individual bridges to specify what action should be taken for each bridge. It then calculates the associated cost and prioritizes the bridges in need of work. Thus for each budget, it can specify the optimal set of bridges that should be selected for MR&R work and their priorities. What is equally important is that the structure of the model is such that the priorities do not change as budgets are changed. Hence the model can work without a budget constraint, and this is in fact the path that it follows so that maximum flexibility is provided to the Integrated Project Programming model to combine improvement and MR&R decisions.

Mathematically, the optimization criteria is maximization of benefits subject to budget constraints. Benefits are defined as the cost savings resulting from performing all MR&R work on a bridge in the current year versus postponing it for one period and then following the optimal action. The cost is the cost to the agency to carry out all specified MR&R work on the bridge. The mathematical structure of the model allows achievement of the optimal selection of bridges for work and prioritization of those bridges by simply calculating a benefit/cost ratio, ranking them according to that ratio, and choosing the bridges that fall within any cut-off budget level.

IMPROVEMENT (IMP) OPTIMIZATION

The objective of the IMP optimization model, is to maximize the benefit gained, in terms of user cost savings, from any given level of investment. The actions considered include widening, raising and a set of optimal user-specified actions which might include seismic retrofit and scour mitigation. Replacement is also an improvement action which is considered in a manner that integrates with other improvement considerations as well as with MR&R considerations.

As discussed earlier, there is a fundamental difference between MR&R and improvement decision models. MR&R activities are geared towards keeping a bridge in the best possible condition but at its current level of service. MR&R activities retard or repair the effects of deterioration but they do not directly change the level of service of the bridge. In improvement activities, however, decisions usually change the level of service, but once an action is taken, the physical characteristics remain the same and no new action needs to be considered until future traffic growth makes an action necessary again. Thus, the optimization model for improvement is a static model, and since all parameters are assumed known, it is deterministic.

The mathematical structure of the model, and the solution method, is similar to the third component of the MR&R optimization model. We are interested in finding the set of bridges that provide the highest benefits within a budget limit leading to the optimality of a ranking procedure by benefit/cost ratio. Benefits are again defined as the difference between savings in user costs if the action is taken now versus later and are provided by the Users Cost model. The results of the improvement model are applicable for any budget constraint and hence can be used with or without such constraint. The model recommends the set of bridges that should be improved for any given budget, and gives the priority rank for each improvement. The original candidate bridges for improvement are chosen based on whether or not they meet current levels of service goals for their respective traffic levels.

INTEGRATED PROJECT PROGRAMMING

Both the MR&R and improvement models generate unconstrained needs and provide the information necessary to prioritize them. The Pontis programming module schedules the projects to conform to budget constraints. It has the ability to recognize eligibility requirements and funding constraints for specific funding programs and separately program eligible projects. It also has the ability to simulate the possibility of future year projects and prioritize them according to their expected benefit/cost ratio to generate rough future schedules.

The Integrated Project Programming model not only combines the results of MR&R and Improvement Optimization models but is a tool for predicting future network conditions, needs and backlogs as a function of budget allocations, traffic growth and changes in the level-of-service goals and standards.

The Integrated Progamming Project model is, by itself, not an optimization model but a device for bringing the results of the optimization models together, and for simulating future events according to the criteria set by other models.

SUMMARY AND CONCLUSION

Pontis is an optimization system to address at network levels the maintenance, repair, rehabilitation, improvement and replacement of bridges. This FHWA-funded bridge management system is intended to have sufficient flexibility for implementation in various agencies, replacing current procedures which are largely based on subjective sufficiency ratings. The system should provide an agency with a decision tool to help in planning for MR&R and improvement of its bridges.

Pontis addresses the dynamic, multi-objective bridge MR&R and improvement problem through a set of interrelated predictive, optimization and economic models. The system integrates the objectives of public safety and risk reduction, user convenience, and preservation of investment, with budgetary and program policies, and it effectively provides a vehicle for comparing preventive versus corrective replacement maintenance policies. It gives a systematic procedure for allocation of resources to the improvement and MR&R of various bridges in a system, and considers the costs and benefits of maintenance policies versus investments in improvements. Furthermore, it specifies minimum funding requirements to remove backlogs and achieve goals, and predicts future network conditions for various budget scenarios.

More simply put, a BMS is to help in better managing bridge work and Pontis should help us do that.

Biographical Data

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1963 Civil Engineering graduate of the University of Texas at Austin.

Over 29 continuous years of service to Texas Department of Transportation (TxDOT).

Currently is Bridge Programs Engineer with the Division of Bridges and Structures, TxDOT. Primarily responsible for development and monitoring of bridge replacement and rehabilitation programs of work.

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