BRIDGE MAINTENANCE MANAGEMENT SYSTEMS

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AN IMPORTANT NOTE FOR THE READER

CONTENTS

EXECUTIVE SUMMARY

1. Objectives

The primary objective of Stage I of this bridge maintenance project (undertaken in 1992/93) was to identify and review existing bridge inspection and maintenance management systems used in New Zealand and overseas. The secondary objective was to determine perceived needs for improving inspection, maintenance and management operations within New Zealand.

A literature review was carried out, and discussions were held with roading authorities in New Zealand and overseas. Information on the required capabilities of a comprehensive management system for use in New Zealand was obtained by a mail survey of New Zealand's main roading authorities.

2. Systems used in New Zealand

The bridge inspection and recording systems at present in use (1990s) in New Zealand are deficient in a number of respects. The computer-based systems in use are essentially asset registers that are used to record historical inspection information. They do not contain rational procedures for classifying bridges and ranking maintenance, replacement or rehabilitation priorities. The inspection information collected is not detailed enough to be of more than short-term value and does not provide the data required to set maintenance priorities using a rational procedure.

3. Systems used in other countries

Comprehensive bridge management systems have been implemented, or are in the process of development, in at least 20 states in the United States of America (USA), and in several provinces in Canada. Systems are also being implemented in at least four European countries and in several states in Australia. Although the theory and facilities to develop comprehensive management systems were well advanced, clearly data collection and software writing are a major task. It is best to use a modular approach based on utilising existing computer-based inventories and to stage the development work.

Initially most large overseas agencies developed their own systems making use of existing databases, electronic data processing equipment and software. More recently the system known as Pontis was developed under contract to the US Federal Highway Administration. This system has been successfully trialed in 14 USA states and in Australia.

4. Conclusions

Considerable benefits are to be gained by adopting an advanced comprehensive bridge management system for application in even relatively small countries or regions. However, the degree of sophistication of the system needs to be tailored to local needs and conditions. Because of the very large investment in time and cost required to develop a comprehensive bridge management system, trial evaluations should be carried out of systems already developed overseas. Even if considerable modification is required to adapt available programs to meet local conditions, this is likely to be a more efficient approach than the development of a new system.

5. Recommendations

As the initial step in setting-up a bridge maintenance management system in New Zealand, it is recommended that Transit New Zealand pilot the Pontis program using the existing descriptive bridge inventory to provide the essential information from which the more comprehensive inspection procedures can be developed.

ABSTRACT

Bridge inspection and maintenance management systems used in New Zealand and overseas have been identified and reviewed. The research was undertaken in 1992/93. Comprehensive bridge management systems have been implemented, or are in the process of development, in many overseas countries. These are considerably more advanced in capability than the inventory and maintenance recording systems used at present (1990s) in New Zealand.

Considerable benefits are to be gained by adopting an advanced comprehensive bridge management system for application in even relatively small countries or regions. The main benefit is that rational procedures for classifying bridges and ranking maintenance, replacement or rehabilitation priorities on a nationwide basis can be implemented.

Evaluation of extant systems shows the Pontis system, developed for the United States Federal Highway Administration, as being that most appropriate to New Zealand requirements.

1. INTRODUCTION

The New Zealand road network includes some 3,300 state highway bridges and approximately 12,000 local authority bridges that have cumulative lengths of 129,800 m and 208,500 m respectively. About 43% of the bridges were constructed before 1960.

The total replacement value of the bridge stock is estimated to be approximately $3,000 million. Over recent years the annual cost of bridge replacement work has been about $25 million and of bridge maintenance work about $15 million. As the capital investment in the bridge stock and expenditure on replacement and maintenance is so very large, this asset needs to be managed properly to minimise the total costs of the roading network.

Recent studies have shown that significant economic advantages are gained from carrying out preventive maintenance on bridges. For example, in United States of America (USA) in New York City, the annual total cost of a complete preventive maintenance programme together with replacement costs was estimated to be US$152 million. This cost increased to US$600 million if maintenance work was not carried out (Stukhart et al. 1991).

There is scope to improve the efficiency and effectiveness of the present inspection and maintenance programmes and to apply a more uniform standard throughout New Zealand. One way of achieving this improvement would be to develop or adopt a new bridge management system (BMS) which can be incorporated into Transit New Zealand's procedures for state highways and into local authority procedures for local roads.

The primary objectives of this system should be to maintain an appropriate level of safety to the travelling public, to protect the substantial investment in bridge structures, and to provide an efficient management tool for all aspects of the decision making and project implementation required for bridges on the highway network. The management of the bridge investment requires optimising life-cycle costs for the bridge network, optimising expenditure for limited budgets and forecasting future budget requirements.

No widely accepted definition of what constitutes a management system for bridges is available but clearly a very wide range of possible capabilities for a system exists. For this report, the following definitions of management systems have been adopted.

- **Bridge Management System** (BMS): a comprehensive computerised system which evaluates, ranks, and optimises maintenance, repair, rehabilitation and replacement actions for a network of bridges.

- **Bridge Maintenance Management System** (BMMS): a computerised system for organising inspection and routine maintenance actions for a network of bridges. A BMMS is often used as one module of a BMS.

Clearly a wide difference exists in capability between a full BMS and a simple BMMS. The emphasis in the present study undertaken in 1992/93 has been directed to BMS capabilities as it was considered that a relatively high level of sophistication would be appropriate for the management, on a national basis, of the New Zealand highway bridge network.

2. PROJECT OBJECTIVES

The objectives of this Stage I of the project were to:

- identify and review existing BMSs and BMMSs used in New Zealand and overseas
- determine perceived needs for improving inspection, maintenance and management operations within New Zealand.

3. LITERATURE REVIEW

Library databases were searched for literature on the topics of bridge inspection, maintenance, maintenance management and bridge management systems. Over 30 useful publications were found. Details of these are given in the References (Section 12) and Bibliography (Section 13) of this report. These references have been reviewed and abstracts from some of the more relevant publications are given in the Appendix. Many of the references referred to further publications and earlier work on the topics of interest, and not all have been reviewed. However, the literature reviewed was considered a good representation of the relevant publications on the study topic.

The main findings from the literature review were:

1. Comprehensive bridge management systems have been implemented, or are in the process of development, in at least 20 states in USA and in several provinces in Canada. Systems are also being implemented in at least four European countries and in several states in Australia.

2. The theory and facilities to develop comprehensive management systems are well advanced but data collection and software development are a major task. It is clearly best to use a modular approach based on utilising existing computer-based inventories and to stage the development work.

3. Initially most large agencies developed their own systems making use of existing databases, electronic data processing equipment and software. More recently the system known as Pontis was developed under contract to the US Federal Highway Administration. This system has been successfully trialed in 14 states and in Australia. It appears to be the best available package and, with some minor modifications, would be suitable for implementation in New Zealand.

4. Considerable benefits are to be gained by adopting an advanced comprehensive bridge management system for even relatively small countries or regions. The degree of sophistication of the system needs to be tailored to local needs and conditions.

5. The bridge inspection and recording systems at present in use in New Zealand are deficient in a number of respects. The computer-based systems are essentially BMMSs that do not contain rational procedures for classifying bridges and ranking maintenance, replacement or rehabilitation priorities. The inspection information collected is not detailed enough to be of more than short-term value and does not provide the data required to set maintenance priorities using a rational procedure.

4. BRIDGE MANAGEMENT SYSTEM REQUIREMENTS

Any advanced management system, whether for bridges, roads, or plant and equipment has a number of common components. In terms of the requirements for bridges, these components broadly identified by Clouston (1987) are:

1. A descriptive inventory of the bridges, including information on posting limits and overweight capacities, to be managed.
2. A system of identifying bridge condition and deficiencies, including a method of ranking based on the adequacy of the bridge to meet strength, safety and operational requirements, and on the importance of the bridge to public use.
3. A system for inspection and for recording inspection results.
4. A system to translate inspection results into bridge condition information and to set priorities for maintenance and remedial works based on cost and budget constraints.
5. A system of recording maintenance work done on each bridge including a method of comparing achievements with cost and other performance targets.
6. A system for optimising the various maintenance, rehabilitation and replacement options for the bridge inventory, on a national basis.

5. US FEDERAL HIGHWAY ADMINISTRATION RECOMMENDATIONS ON BRIDGE MAINTENANCE

Based on interviews, literature reviews and assessment of the practice and experience, a USA nation-wide bridge maintenance study (Kruegler et al. 1986) carried out in 1986 by the US Federal Highway Administration (FHWA) recommended adopting the following procedure for managing bridge maintenance:

1. Develop a bridge inventory database which identifies each bridge in the system and the major elements of the bridge.

2. Develop and implement a comprehensive bridge maintenance inspection programme which will identify the condition of each bridge and the condition of major elements of each bridge.

3. Develop and adopt achievable and measurable bridge maintenance programme objectives which are consistent with the agency goals.

4. Develop and adopt general bridge maintenance strategies which reflect the varying degrees of level-of-service.

5. Obtain a policy decision on the percentage of the annual budget to be targeted for each general maintenance strategy, to ensure a reasonable and fair distribution of maintenance funds. This is particularly important in the case of preventive maintenance.

6. Identify specific maintenance activities which are being performed or that should be performed. Determine relative cost-effectiveness.

7. Categorise the specific maintenance activities under each of the maintenance strategies.

8. Identify the bridge maintenance requirements for each bridge, using results of maintenance inspections.

9. Match the maintenance requirements to the maintenance activities.

10. Develop unit costs for each of the maintenance activities based on historical data, if available; otherwise estimate unit costs. Establish a procedure to capture appropriate cost data.

11. Develop added service-life data related to specific maintenance activities. Use historical data if available. Otherwise use expert opinion. Develop a procedure to capture service-life data.

12. Prioritise the maintenance requirement/activities on each bridge based on the needs for each bridge. Prioritise the bridges on the system, one against each other.

13. Develop a bridge maintenance programme using cost estimates for each maintenance activity, the priority list developed, and the funding allocated.

14. Refine the annual programme by checking work schedules and defining costs in more detail.

6. BRIDGE MANAGEMENT SYSTEMS USED IN NEW ZEALAND

6.1 Present Systems

The present Transit New Zealand bridge inspection policy (Transit New Zealand 1991) requires inspection of all the state highway bridges to specified levels at regular intervals. Based on these inspections, a programme of routine maintenance is developed and implemented. Priorities for maintenance work are set on a regional basis and the ranking procedure is generally based on technical considerations rather than on economics.

The regular inspections also identify structural problems which are then the subject of more detailed investigation and evaluation. Generally this more detailed work includes an economic analysis. Remedial works then compete for funding on their benefit/cost ratio (KB Wright pers.comm. 1993).

A list of bridges, in priority order, requiring major rehabilitation or replacement is prepared in each region on an annual basis. This list covers a 15 year period of work.

Most bridging authorities in New Zealand set maintenance and bridge rehabilitation and replacement priority programmes by a manual process without detailed analysis or optimisation. However, the survey of bridging authorities, described in Section 9.2, identified that at least eight authorities use computer-based systems for some parts of the inspection, maintenance and management operation.

The management systems available in New Zealand address only a limited number of the six component areas, identified in Section 4, that are required to form the basis of an advanced management system. The computerised BRIMMS system (BRIdge Maintenance and Management System) operated by WORKS Consultancy Services Ltd (WORKS 1992) addresses, at least in part, the requirements for the components 1, 3 and 5 described in Section 4. It does not provide the information required to satisfy the management needs identified by components 2, 4 and 6.

6.2 BRIMMS System

• Descriptive Bridge Inventory

BRIMMS uses a comprehensive computerised descriptive bridge inventory that was first developed in the 1970s. This same inventory may be suitable for further development and incorporation in an improved management system. Further items will need to be added to the inventory but it is reasonably comprehensive in its present form. One obvious deficiency is that the inventory does not identify the sources and location of design and rehabilitation documentation.

Apart from deterioration expected from traffic and weathering, major causes of bridge failure and damage in New Zealand are river scour and earthquakes. The present descriptive inventory needs to be improved to provide information that would help assess the risks from both scour and earthquakes.

A structural inventory exists for the purpose of checking applications for Overweight Permits. This inventory needs to be improved so that it is consistent with the descriptive inventory. Both inventories need to be integrated or made accessible from the same software system.

• Ranking Bridge Condition

BRIMMS contains no system for ranking bridge condition or performance. Ranking is often based on strength, safety and operational requirements and the importance of the bridge to public use.

It could be improved with a suitable ranking module. This would be a straightforward task as most of the basic information required for ranking is contained in the descriptive and structural inventories.

- **Bridge Inspection**

Reports and forms The BRIMMS system produces blank inspection reports and a schedule for inspections. The present inspection system is particularly weak in terms of the information reported as the report forms are quite general and therefore include information that is not relevant to many bridges. A better approach is to have the management system generate a range of forms that are tailored to the information required for each particular class of bridge.

In an ideal system, a different form should be automatically generated for each bridge complete with the descriptive information so that the inspector is only required to add the inspection results. This would make the inspection quicker to carry out and would allow a greater amount of information to be collected without increasing the apparent complexity of the inspection procedure. It would also allow the current descriptive information on the bridge to be independently checked.

Recording defects In the present inspection procedure, the defect is recorded and a marking given that defines the time within which the defect should be attended to. No information is necessarily collected on location, extent and severity of the defect and the required remedial activity, although some of this information might be extracted from comment notes.

Information would be best collected in a systematic and complete manner so that the necessary work on identified defects can be cost-estimated and programmed. More complete information is also required to enable decisions to be made on whether rehabilitation or replacement of the bridge would be a preferred option rather than continued maintenance.

On the present inspection form, the bridge appearance is addressed with one single record of information. Presumably this item is intended to identify the adequacy of the routine maintenance work as this is not addressed elsewhere. More detailed consideration should be given to the adequacy of routine maintenance.

Inspection interval Under present Transit New Zealand inspection policy, general and detailed inspections are mandatory at intervals not exceeding two and six years respectively. In addition, superficial inspections are carried out at more frequent intervals. For new bridges and structures known to be in sound condition, this level of inspection may not be necessary. Instead a detailed inspection, or even a general inspection, at six year intervals together with regular superficial inspections may suffice, providing a comprehensive management system is used to identify and record the bridges that require less inspection effort.

Such a relaxation of inspection requirements would not affect bridge safety provided that the required superficial inspection standards were maintained on all bridges and details of these inspections are recorded. The superficial inspections are required to include visual checks on the deck hardware and waterways and should identify any important changes in condition or operational safety since the last general or detailed inspection.

A comprehensive management system could therefore help lead to savings in inspection work or free resources to concentrate on implementing other important maintenance needs.

• Actioning Inspection Results

Under the BRIMMS system, the process of actioning the results of inspections, such as assigning priorities, making cost estimates and providing instructions for the work to be undertaken, is all done manually. Proper co-ordination of priorities and rational distribution of funds between regions does not necessarily occur. Overall the manual system leads to the possibility of overlooking essential parts of the proper management procedures. In particular, recommended work may not be programmed or programmed work may not carried out because of pressure of other activities. Without overall priorities set on some uniform and rational basis, it is unlikely that the maintenance programme will make the best use of a limited budget.

• Recording System

In the BRIMMS system, the date, total cost and effectiveness of each repair is recorded. No information is given on method, materials or unit rates.

The information needs to be recorded in more detail so that the long-term effectiveness of repair methods can be assessed and the historical costs can be of value for future cost estimating work and optimising life-cycle costs.

• Optimising Options

The BRIMMS system does not have any capability for optimising maintenance strategies. Under the present system, bridges are either maintained to a standard that is poorly defined, or replaced. The option of major rehabilitation is seldom considered, probably because no database of information exists that can be used to determine whether this option has economic benefits.

If a more advanced management system were available it would be possible with time to optimise the level of maintenance and to more clearly identify the benefits of bridge rehabilitation and replacement decisions. In addition the effectiveness and costs of various repair methods would be obtained.

7. BRIDGE MANAGEMENT SYSTEMS USED IN UNITED STATES OF AMERICA

7.1 Overview

While all states in the USA practise some form of bridge inspection and maintenance management, not many have fully implemented a comprehensive systematic approach to the problem. Many states prioritise their bridge needs based on the FHWA sufficiency rating or other similar ranking system. The sufficiency rating procedure involves three major factors: structural adequacy and safety; serviceability and functional obsolescence; and essentiality for public use.

Several parallel efforts have recently been undertaken to implement comprehensive maintenance systems following pilot studies and the operation of partial management systems that have demonstrated the benefits of the more sophisticated BMSs. Some of the more advanced management systems that are at present under development or have been recently implemented by USA authorities are described in the following Sections 7.2 - 7.7.

7.2 System used in Pennsylvania

The Pennsylvania Department of Transportation developed and implemented a BMS in March 1987 (McClure and Hoffman 1990; Stukhart et al. 1991). The system uses a ranking scheme to systematically prioritise bridge maintenance, rehabilitation and replacement activities at regional and state-wide levels, based upon the structural and functional needs for highway classification. The system is also capable of predicting present and future needs for all bridges using various scenarios for level-of-service.

The inventory system contains 425 data items for each bridge. This includes a total of 76 items related to bridge maintenance activities. In contrast, the New Zealand BRIMMS contains only 38 general data items and 33 items related to bridge inspection activity, a total of only 71 items for each bridge.

The prioritisation of bridges for rehabilitation and replacement is based on the degree to which a bridge is deficient. The deficiencies are evaluated in three general categories: level-of-service; bridge condition; other related characteristics. The level-of-service deficiencies are based on four characteristics: load capacity, clear deck width, vertical clearance for traffic carried by the bridge, and vertical clearance for traffic passing under the bridge.

The acceptability criteria for the deficiencies are primarily dependent upon the functional classification of the highway with some dependence on average daily traffic flow. The deficiencies are combined to yield a total deficiency rating on a scale from 0 to 100.

All bridges on the highway system are ranked in decreasing order of rating. In addition to the ranking, other factors are used to make a comparative evaluation of the bridges as well as evaluation between replacement and rehabilitation options. These factors include cost of replacement, cost of rehabilitation, and average daily traffic. Absent from the evaluation are consideration of life-cycle costing, estimates of economic benefits, and benefit/cost ratio or optimisation procedures.

An additional module in the system uses standardised bridge maintenance activities and costs, as well as stored bridge activity needs, to rank and prioritise maintenance work. In addition maintenance work is programmed and the costs of the completed work are stored.

The Pennsylvania Department of Transportation BMS has a very complete inventory for the bridge description, maintenance and cost data. However, in its initial stage of development it relied on a ranking procedure to prioritise replacement rehabilitation and maintenance rather than on the use of optimisation techniques. Life-cycle costing and optimisation capabilities were to be added at a later stage.

7.3 System used in North Carolina

7.3.1 Level-of-service Criteria

The North Carolina BMS considers the user costs generated by level-of-service deficiencies as well as costs associated with bridge improvement alternatives including maintenance, rehabilitation and replacement (Stukhart et al. 1991). The user costs include those related to deficiencies in load capacity, clear deck width, approach roadway alignment and vertical clearance deficiencies. Determination of user costs includes vehicle operating costs, detour length and accident rates.

Two different level-of-service criteria were established within the BMS: minimum acceptable and ideal desirable. The *minimum acceptable level-of-service* for a bridge was defined as that which provides a safe and functional level for most vehicles expected on the route. The *ideal desirable level-of-service* for a bridge was defined as that which at least accommodates all vehicles which meet current legal limits.

7.3.2 Maintenance Needs

Maintenance costs of a bridge over its service-life were determined by estimating the maintenance needs of the bridge elements at various times during the service life. Several approaches to bridge deterioration rates were used including regression, average of bridge versus element condition rating and expert opinion surveys.

The maintenance needs were established by comparing element condition to maintenance level-of-service thresholds. They were measured by the quantity needed per unit deck area and maintenance costs calculated from quantities and associated unit costs. Annual maintenance costs were then estimated by considering the deterioration rates for the bridges.

7.3.3 Analysis

An analysis model based on equivalent annual cost was used to predict improvement actions and to specify a time at which these actions should be completed. Future funding needs were predicted based on alternatives selected for each bridge that reflected both maintenance condition level-of-service and user level-of-service.

An optimisation option that uses an integer-linear programming formulation to optimise decisions for every year in the analysis horizon is included in the BMS. Inputs include the analysis horizon, minimum performance requirements, policies, granted budget, minimum allowable budget, or unlimited budget for each year in the horizon.

7.4 National Cooperative Highway Research Program 300 System

7.4.1 Developing the Model BMS

The main goal of National Cooperative Highway Research Program (NCHRP) Project 12-28(2) was to develop a model BMS for small sized states within USA and for local transportation agencies, capable of operation on both network and project levels. The first phase of the project presented in NCHRP Report 300 (Hudson et al.1987) defined six basic modules considered necessary to form an effective bridge management system:

1. **Database module** - provides information through collection and storage of bridge inventory, condition and MR&R data.

2. **Major maintenance, rehabilitation and replacement (MR&R) selection module** - is the analytical module at network level. Tasks carried out in this module include ranking of bridges or required MR&R activities, selection of specific MR&R activity, life-cycle costing and optimisation.

3. **Maintenance module** - estimates minor maintenance needs for bridges which are not selected for major MR&R actions.

4. **Historical data analysis module** - uses historical information to estimate parameters such as MR&R costs, MR&R action effectiveness, region to region expenditure and life-cycle activity profiles.

5. **Interface module** - for project level applications, such as bridge structural analysis, provides a medium for interchange of information between the database and the application.

6. **Reporting module** - produces the necessary output reports such as data lists, summary reports, graphs, charts and maps.

7.4.2 MR&R Selection Submodules

MR&R projects can be selected for the network at one of four levels. These four levels are accomplished in four submodules of the MR&R selection module. Each submodule builds on the previous one, thus adding capability to make better selections. The lowest level can be used independently, but higher levels require the lower levels to support them.

1. **Ranking submodule** - uses a sufficiency index (SI) and general categories of maintenance as a simple basis for ranking projects and screening the network to identify general MR&R needs. Rehabilitation and replacement options can be indicated by threshold values of SI. This type of general MR&R category assignment will produce only a rough estimate of needs and normally a "worst first" solution. MR&R costs may be roughly estimated by the size of the bridge and associated unit costs for the general type of work and bridge type.

2. **Specific MR&R action selection submodule** - provides better project selections than the ranking level because use is made of decision trees to choose the MR&R actions. Better estimates of costs and effectiveness are available because each action is better defined than just the broad categories of maintenance rehabilitation and replacement. The decision criteria are bridge condition variables and load capacity. Detailed decision trees allow more accurate assignments of MR&R projects and costs.

3. **Life-cycle costing submodule** - builds on the network MR&R selection level by adding more capabilities and better economic criteria for choosing MR&R strategies. The decision tree is expanded by providing life-cycle activity profiles for selection as MR&R strategies.

This approach accounts for the effects of current actions on future costs and life of a bridge. For example, in choosing which life-cycle activity profile to put at the end of the decision path, one option may be to provide a high level maintenance for a period of time and then to replace the bridge. A second option may be to rehabilitate the bridge immediately followed by a programme of low level routine maintenance. Analysing the life-cycle costs for each option would provide a better basis for choosing the most cost-effective solution.

4. **Optimisation submodule** - is the highest level available for making decisions regarding MR&R strategies to be used on the network. In the optimisation level, the decision tree is expanded allowing multiple life-cycle activity profiles to be chosen for each bridge. Besides the total life-cycle costs, a measure of the effectiveness of total benefits is also available for each life-cycle activity profile. An optimisation routine is used to compare all possible life cycle activity profiles for all bridges in the network and optimise the choices based on budget constraints to obtain maximum effectiveness or benefits over the network.

7.5 System used in Indiana

7.5.1 BMS Modules

The Indiana BMS is similar to the comprehensive system reported in NCHRP 300 but instead of six major modules, eight are used (Sinha et al. 1991; Stukhart et al. 1991). The modules and their main functions are:

1. **Database Module** - contains all the inventory information necessary for the other modules to perform tasks on a network of state-owned bridges.

2. **Condition Rating Assistance Module** - filters out inconsistencies in ratings, to assist bridge inspectors, to train new inspectors, and to predict the condition rating after certain improvements.

3. **Bridge Traffic Safety Evaluation Module** - computes a bridge safety index using fuzzy set theory applied to a bridge inspector's subjective ratings of traffic safety on various bridge components.

4. **Improvement Activity Identification Module** - provides information on the types of improvement activities that may be recommended at certain condition ratings.

5. **Impact Identification Module** - is designed to identify costs and consequences of structurally deficient and/or functionally obsolete bridges on the highway agency, the user and the surrounding community.

6. **Project Selection Module** - is a set of decision-making tools that can be used to select and programme the most economical options for bridge improvement projects. The three submodules are: Life-cycle Cost, Ranking, and Optimisation.

7. **Activity Recording and Monitoring Module** - records maintenance, rehabilitation and replacement of bridges in the network, in addition to accumulating historical data on cost, timing and sequence of bridge-related activities.

8. **Reporting Module** - produces summary reports on bridge condition and characteristics, maintenance needs, improvement activity, network level impact life-cycle cost analysis, priority ranking, optimal activity programming and budget.

7.5.2 Explanation of Modules

If the project selection module uses the life-cycle activity profile, unit costs and timing of activities must be estimated.

The ranking submodule is recognised as not being optimum but is useful for comparing projects on the basis of objectives and economic desirability. It also provides the bridge manager with the opportunity to use some expert judgement to select or eliminate certain alternatives.

The optimisation method uses a combination of integer and dynamic programming to select rehabilitation and replacement projects. Integer programming selects alternatives in a single period planning horizon and dynamic programming selects an optimal policy over a given planning horizon. A deterioration model is used to compute the effectiveness of improvement alternatives in the optimisation and to weight the objective function such that improvement is selected when the deterioration rate is steepest.

The Indiana BMS represents one of the most sophisticated analytical tools developed and published to date on the subject.

7.6 FHWA's Bridge Needs Improvement Process

7.6.1 Levels of Analysis

FHWA's Bridge Needs Improvement Process (BNIP) is designed to carry out two levels of analysis: a needs assessment for the nation's bridges, and an investment analysis of the effects of various budget levels on the condition of the bridges (Stukhart et al. 1991).

7.6.2 Needs Assessment

The BNIP uses National Bridge Inventory data furnished by the states as the basic input data. It identifies current bridge deficiencies in three categories; structural deficiency, functional deficiency, and functionally adequate but with some condition falling below one or more tolerable condition parameters. The minimum tolerable conditions cover the deck condition, superstructure condition, and the substructure condition (including culverts and retaining walls).

If a deficiency is identified for a bridge, a set of criteria is used to select an improvement measure to correct the deficiency. A check is also made to see if other deficiencies will occur within a given time period so that the selected improvement will satisfy current as well as future deficiencies. The cost of the improvement is also estimated.

In the needs assessment, the improvements are simulated by appropriate changes to the bridge data and then the analysis cycles forward over the analysis period simulating bridge deterioration, identifying deficiencies and simulating improvements.

7.6.3 Investment Analysis

The investment analysis uses the needs assessment but checks a funding level before improvements are simulated. If insufficient funds are available to correct all the deficiencies, the analysis uses a priority system to determine which bridges are to be improved. Deficient bridges that are not improved are carried into the next funding period and the analysis is continued. Up to four funding periods may be used in a twenty year analysis period. The summary output gives the aggregated condition of the bridges so that the effects of the budget constraints can be assessed and compared to the current conditions.

7.6.4 Design of Process

The BNIP process is designed as a type of expert system in terms of the criteria for defining deficiencies and selecting improvements. The decision process defines the appropriate improvement alternative for a given set of conditions. These criteria can be adjusted to changing expert opinion.

The BNIP process does not consider maintenance strategies. The improvement types that are considered include combinations of replacement and rehabilitation but not the effects of maintenance in delaying a major rehabilitation or replacement. It also lacks any optimisation process to select the best options for a given period or multiple funding periods.

It is regarded as a useful tool for performing the needs assessment part of a comprehensive BMS. To make it a comprehensive system would require the addition of maintenance strategies, multiple improvement alternatives and an optimisation procedure to select alternatives and their timing.

7.7 Pontis

7.7.1 Overview

In August 1989, the USA FHWA awarded a contract to Optima Inc. and Cambridge Systematics Inc. to develop a comprehensive and flexible network optimisation and planning program for application to bridge maintenance and improvement operations (Cambridge Systematics Inc. et al. 1991a,b,c). The program developed in that contract is known as Pontis.

To ensure flexibility of the program, the work was carried out under the direction of a technical advisory committee comprising representatives of the FHWA, Transport Research Board, and six states with divergent environmental conditions and bridge needs. In addition to providing guidance and experience for the development, the Technical Advisory Committee was responsible for defining the list of bridge elements to be used, the possible conditions that each element can exist in and a set of appropriate remedial actions for each condition.

7.7.2 Objectives for Pontis

The following specific objectives were stated for Pontis (Cambridge Systematics Inc. et al 1991):

1. Provide a systematic procedure for evaluating current maintenance budget requirements.

2. Incorporate level-of-service goals in assessing bridge improvement needs and budget requirements.

3. Find optimal maintenance policies for each element and each condition.

4. Provide a capability to consider the entire bridge inventory simultaneously when deriving optimal policies and recommendations for maintenance and improvements.

5. Retain the flexibility to address a subset of bridges.

6. Provide priority lists and sequencing for bridges in need of maintenance and improvement.

7. Co-ordinate maintenance planning decisions with future planning decisions.

8. Consider the differing inspection and repair needs of the major structural components for bridges as well as the differing needs of the different types of bridges.

9. Allow for updating of predictive probabilities as necessary data become available over time.

10. Consider the immediate and future costs and benefits of the various courses of action and their effects on future conditions. In particular the model should consider the benefits of preventive maintenance versus costlier but less frequent corrective actions.

11. Allow sensitivity analyses in terms of future conditions of the bridge network, and cost requirements.

12. Provide flexibility to accommodate different state-specific, maintenance and fiscal policy issues.

13. Provide a basis for short-term and long-term maintenance and improvement of budget planning and resource allocation.

14. Provide a rigorous procedure and an analytical framework for incorporation of expert engineering judgement in the model.

15. Require a reasonable and realistic amount of data for model input, provide procedures for data collection and checking the reliability of the collected data, assess the relative importance of the data items, and allow for incorporation of engineering judgement with objective data whenever necessary.

16. Be easy to use by maintenance planners and engineers.

17. Centralise the maintenance decision process and reduce uncertainty about the relative condition of similar bridges within the network.

7.7.3 Development of Pontis

The basic approach to the development of Pontis was to build on the following simple ideas (Cambridge Systematics Inc. et al. 1991):

1. Separate maintenance decisions from improvement decisions.

2. Divide each bridge in the network of bridges into a reasonable number of elements, the sum of which would describe all bridges in the network.

3. For each element define a homogeneous unit and specify a set of possible condition states.

4. For each condition state, define an appropriate set of feasible actions.

5. Define "environments" in such a way that interactions between elements can be addressed.

6. Specify for each bridge the percentage of each element in each condition state.

7. Find optimal maintenance policies for each unit, and then bring the policies together to find optimal maintenance actions for each bridge.

8. Use a separate optimisation procedure to find the optimal set of bridges that should be chosen for each maintenance budget and their priority order.

9. Use functional deficiencies, or failure to meet level-of-service standards, to find candidate bridges for improvement actions.

10. Use reduction of user costs as a basis to determine the benefits of carrying out improvements for each candidate bridge.

11. Use an optimisation procedure to find the optimal set of bridges that should be improved for each improvement budget, and their priority order.

12. Bring all the actions specified for maintenance and improvement for a bridge together, calculate the total benefit of recommended actions on the bridge, and find its priority order.

13. Integrate all actions and budget requirements to specify the current work plan.

14. Simulate traffic growth and deterioration of components to estimate budget needs in the future, and for every budget scenario find the future backlog and network conditions.

7.7.4 Modules used in Pontis

The major modules contained in Pontis are as follows:

- **Database**

Pontis maintains its own standardised database and draws the basic data from existing bridge inventories and other sources. It also stores traffic information, load capacities and cost information as well as the main elements of each bridge, the condition states that define the possible conditions of each element, and the set of feasible maintenance actions associated with the conditions. The database also organises the results of the individual optimisation models.

- **Maintenance optimisation**

A main feature of Pontis is its optimisation capability. The objective of the maintenance optimisation model is to find, for each bridge element in each environment, the long-term policy which minimises the maintenance cost while keeping the element from risk of failure. In the maintenance model three important things happen every year:

1. Bridge elements deteriorate, making transitions to a worse condition state.
2. Actions are taken on specific bridge elements and incur a cost.
3. Actions taken cause an improvement in condition.

For any given state, the maintenance optimisation will recommend the best long-term policy and will also quantify the added cost of delaying the recommended policy.

- **Improvement optimisation**

The objective of the improvement optimisation model is to maximise the benefit gained in terms of user cost savings from any given level of investment in bridge improvements.

The actions considered include widening, raising the bridge, and a set of user-specified actions which might include seismic retrofit and scour mitigation. Replacement is also an improvement action that integrates both improvement and maintenance considerations.

Maintenance activities are directed towards keeping a bridge in the best possible condition but at its current level-of-service. However, improvements 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 (or other loading condition) makes an action necessary again.

The optimisation model finds the set of bridges that provide the highest benefits within a budget limit leading to a ranking by benefit/cost ratio. The model recommends the set of bridges that should be improved for any given budget.

- **Integrated project programming**

The Integrated Project Programming model combines the results of the Maintenance and Improvement Optimisation models and also predicts future network conditions, needs and backlogs as a function of budget allocations, traffic growth and changes in level-of-service goals and standards.

- **Condition state and physical action model**

Bridge elements make a transition between condition states as a result of deterioration and maintenance. The definitions of elements and their units, condition states, and the set of feasible actions for each condition constitute this model.

- **User cost model**

Pontis determines if an improvement is warranted partly by estimating the benefits that would result from reducing or eliminating clearance and weight restrictions or limitations. Annual benefits are measured as the annual savings in user costs that result from undertaking an improvement versus maintaining the existing bridge. Benefits are calculated as the sum of the savings in accident, vehicle operating and travel time costs.

- **Prediction model**

The prediction model of Pontis consists of two separate models.
The first or **Prior Model** quantifies the likelihood that a unit of a particular element would make a transition from one condition state to an inferior one within a period of time. The probabilities are derived from a series of questions asked of experienced engineers. The transition probabilities generated by this method are the primary data source during the first two years.

In the second or **Posterior Model**, the transition probabilities are updated as inspection data becomes available. After each inspection, the model analyses the collected data, weighs them against the prior transition probabilities and then generates a new set of transition probabilities that consider the prior information as well as the new data.

The automatic updating feature makes implementation of Pontis possible even when little information is available on how the various elements behave over time.

7.7.5 Implementing Pontis

Pontis has been developed as a modular software system that is designed for personal computers but can also be used on mainframes, work stations and other systems. For most agencies the four following steps are required to implement the program:

1. **Customising the model** All the cost models, user cost formulae, deterioration probabilities, page/screen layouts, as well as many other parts are treated as data and can therefore be easily adapted to specific agency requirements.

2. **Customising the software**. Most agencies will need to perform some minor customisation of the software, such as adding database items, adjusting the element condition descriptions and feasible actions, and determining how bridge identifiers are expressed. The software is intended to be easy to modify.

3. **Learning the Condition Rating system**. Pontis includes a new condition rating system which involves inspection procedures that are different from most current practice. However, the procedures are no more difficult than many in present use.

4. **Learning the software**. The PC-based system is relatively simple to learn. Bridge selections, sort orders, page/screen layouts and models are easily combined in various ways to conduct routine and ad hoc tasks including database updating, cost modelling, optimisation and reporting.

7.7.6 Evaluation of Pontis

Discussions held with managers in bridging authorities within USA and Australia indicated that Pontis is likely to gain wide acceptance in both these countries. Although further developments will occur, the system should be in a suitable form for general implementation at the present time. It is "Public Domain" software that can be customised and initially set-up at relatively low cost for use on PCs.

Pontis would clearly be worthwhile evaluating in more detail by carrying out pilot trials using a New Zealand database. Trials would be helpful in demonstrating the capabilities of a comprehensive BMS and would assist with the important decision on whether it is necessary to develop a special purpose system for local conditions. Even if a decision were made to develop a local system, experience with Pontis would serve as a good starting point.

Of the BMSs reviewed, Pontis appears to be the most suitable for trial evaluation for the following reasons:

1. It is one of the most recently developed BMSs and incorporates the experience gained during the development of a number of its predecessors.

2. The program was developed under the direction of a FHWA technical advisory committee including representatives of six states.

3. The program is available for use by any agency and can be set-up on a trial basis at relatively low cost.

4. The program developers are available to demonstrate the program and to carry out modifications if required.

5. Present indications are that Pontis will be widely used in both USA and Australia. This will ensure the continued development and maintenance of the program.

8. BRIDGE MANAGEMENT SYSTEMS USED BY OTHER AUTHORITIES

8.1 System used by Australian Capital Territory Government

The Bridge Information and Management System (BIMS) developed by the Australian Capital Territory Government (ACTG) is of interest because it has been developed for the management of only 730 bridges. This is a relatively small number in comparison to the number administered by most North American agencies (Hosseen and Stanilewicz 1990).

The principals stated for the ACTG development of BIMS is that a knowledge of the location, characteristics, maintenance history and condition of bridges, combined with a systematic approach to inspections and maintenance, allows the responsible agency to effectively manage the condition and capacity of the bridges and therefore the capacity/capability of the road network to deal with changing traffic loads.

The system functions by regular database updates and inspections, the frequencies of which vary with road and bridge type and conditions, followed by action on maintenance recommendations or, where the identified problem is more complex, detailed inspections preceding corrective action. The tracking nature of BIMS also allows the management of the resources used for the inspections, monitoring and maintenance, thus ensuring that available funds are used effectively. Facilities are provided for information to be retrieved from the databases in the form of standard reports, special reports and ad hoc queries. BIMS automatically schedules cyclic maintenance, general maintenance and inspection cycles.

BIMS is a more advanced system than the BRIMMS used by WORKS Consultancy Services Ltd in New Zealand. BRIMMS is, strictly speaking, little more than an asset register that reports the bridge inventory and maintenance history details. In contrast, BIMS contains a maintenance condition rating module that defines common bridge maintenance activities, their importance and estimated resource requirements. When recommendations from the inspection reports are entered, an appropriate activity code must also be included as part of the data. This code is used to retrieve the standard resource and cost information for that activity. The information is used as the basis for cost estimates of maintenance work. Such a facility provides consistent cost estimates, and avoids differences that might occur if these are made by more than one inspector.

Although BIMS is not a comprehensive maintenance management system it has been reported to be extremely successful in meeting the demands and expectations of the ACTG. Future developments of the system are planned to make it more effective for maintenance management.

8.2 System used by Alberta Transportation and Utilities

In 1985, the province of Alberta, Canada undertook a detailed review of its bridge management practice and concluded that several areas could be improved significantly (Ramotar and Quinton 1988). A comprehensive computerised bridge inspection and maintenance system was investigated that had, as its primary objectives, to ensure an appropriate level of safety to the public, protect the investment in bridge structures which had an estimated replacement cost of $1.4 billion, and to provide an improved management system at all levels.

After reviewing the state-of-the art of management systems, the conclusion was that a BMS system could be developed with the desired capabilities in a cost-effective manner. The decision was to design the system using a modular approach which would allow the implementation of each module as it was finalised. A good inventory system, already in place, was recognised to be fundamental to the establishment of the system.

The Alberta BMS at present in operation is significantly more advanced than the New Zealand BRIMMS, particularly in relation to the level of inspection information collected, and the automatic condition ranking of the bridge components.

The Alberta BMS generates 13 types of single inspection forms and 14 types of combination inspection forms. This ensures that the forms are appropriately tailored to the type of bridge being inspected. Before the inspection form is printed for a specific site, the system extracts selected bridge inventory data, traffic flow information, last inspection information including all condition ratings and maintenance recommendations, and special comments to be considered at the next inspection. All this information is printed on a new form generated for the inspection.

A *sufficiency rating* is calculated for each bridge using four major impact categories that are weighted in accordance with their relative importance. These categories are *structural condition, strength, service and safety,* and a *traffic reduction factor* which reflects the influence of traffic volumes and detour lengths. Each main impact category is further divided into sub-elements which are also weighted to reflect their importance.

8.3 System used by Roads and Traffic Authority, New South Wales

The Roads and Traffic Authority (RTA) in New South Wales, Australia, is responsible for the upkeep of approximately 6,000 structures on the classified road network in that state. These structures are predominantly bridges or large sized culverts.

Following a review of the available road maintenance management systems (MMS), the RTA embarked on the development of its own PC-based MMS in 1990. This program was commissioned in September 1991. Following the successful implementation of the MMS for roading, the system is currently being modified to suit bridge management activities.

The bridge version is still under development although several of the total number of modules have been released for trial. Of interest is that RTA is adopting the Pontis condition rating system and other features of Pontis where it appears to be superior to their own system. Development is being carried out in-house using software writers under contract.

A modular approach for the bridge system uses the following main components (Keogh 1991):

1. **Network Register**
   This is a PC-based database which stores bridge condition and inventory data.

2. **CMIS - Condition Management Information System**
   This module enables bridge data to be queried and displayed. The data can be photographs, inventory information, and structural condition information.

3. **MMS - Maintenance Management System**
   The MMS is used to plan and control maintenance activities. The efficiency of the maintenance activities can be monitored.

4. **BNOS - Bridge Network Optimisation System**
   BNOS is a budgeting tool that enables asset managers to predict the budget required to maintain the network at a specified condition level. This module is being adapted from the roading MMS and is making use of some of the analytical features included in Pontis. The module was expected to be operating by the end of 1993.

In a manner rather similar to the main operations of Pontis, each bridge element is rated, maintenance actions called treatments are defined, with the cost of each treatment contained in the database. A linear programming technique is used to find the minimum funding required to maintain a bridge network at a user-defined standard for up to 20 years into the future. Transitional probability matrices and a Markovian chain process are used to predict the deterioration of the bridge elements over time.

9. REQUIREMENTS FOR NEW ZEALAND CONDITIONS

9.1 Informal Discussions

To establish the need for a comprehensive BMS in New Zealand, and the main attributes required for any such system, discussions were held with a number of Transit New Zealand network managers and engineering consultants who had considerable experience in bridge maintenance operations.

The main findings from these discussions were:

1. Bridge maintenance operations in New Zealand are controlled by a wide range of agencies with the work on the State Highways (SHs) carried out by consultants through Transit New Zealand Inspection Contracts and a relatively large number of independent Territorial Authorities (TAs) administering work on other bridges. Apart from Transit New Zealand bridge policy statements (Transit New Zealand 1991), no uniform standards are applied and even the Transit New Zealand Inspection Contracts may vary between regions.

2. From a national view point, a bridge maintenance system may have considerable benefit but, because of the fragmentation of the present operations, the benefits to the individual bridge authorities are less obvious.

3. Although a BMS will be difficult to implement, the fragmentation of, and lack of uniformity in, inspection procedures suggests a clear need for a BMS and more standard procedures for inspections and setting maintenance strategies. A BMS should be set-up initially for the State Highways network and within the larger Territorial Authorities. When the system has been fully implemented and the benefits are clearly demonstrated, the system could be extended for application within the smaller authorities.

4. The experience of bridge inspectors is probably diminishing with time. Transit New Zealand Inspection Contracts are let for a period of three years and are then re-advertised. This administrative procedure may lead to frequent changes in inspection personnel, making it difficult to develop the inspection experience required to maintain a high standard of field work.

   A well operated BMS could assist by simplifying the inspection and recording work and defining more clearly the features that are required to be recorded and assessed. Administration work would also be reduced.

5. The smaller Territorial Authorities are not, in general, dealing with high traffic volumes and their bridge maintenance expenditure is small in relation to other activities. Now that a large number of the timber bridges have been replaced, the amount of replacement and improvement activity is also quite low.

6. Transit New Zealand managers recognise the need for a BMS to carry out effective asset management and for setting replacement priorities and objectives. However, the benefits obtained from the maintenance planning capabilities of a comprehensive BMS are not well understood.

7. A very clear need exists for a standardised bridge inventory and basic asset management system for bridges in New Zealand. The longer the delay in setting-up a uniform inventory system, the more difficult it will be to rectify the present shortcomings. The present Transit New Zealand descriptive inventory does not appear to be adequately maintained by present procedures.

8. Advantages could accrue from using a comprehensive BMS at different levels of complexity depending on the size and needs of a particular authority.

9. Demonstrating a BMS to the main bridging authorities would illustrate the capabilities of comprehensive systems and give them a better feel as to whether the potential benefits would be cost-effective at a local level. There are difficulties in evaluating the benefits from the technical and promotional literature that invariably seems to overstate the capabilities and advantages of the more sophisticated systems.

10. Unlike some overseas countries, traffic and de-icing salts are not the major causes of deterioration on many New Zealand bridges. Environmental effects, including river scour and earthquakes tend to be much more significant. These differences will need to be considered if an overseas BMS is adopted.

9.2 Mail Survey

9.2.1 Background

To establish more formally the perceived requirements of a BMS for use in New Zealand, a questionnaire was sent to 36 New Zealand bridging authorities. The questionnaire listed the capabilities of recently developed computer-based bridge maintenance management systems. The respondents were asked to identify which capabilities they considered would be of value in the bridge management and maintenance work carried out by them.

9.2.2 Questionnaire

The capabilities listed in the questionnaire (and numbered 1-18 in Figures 2 - 4) were:

1. Provision of a descriptive inventory of the bridges and other roading structures (e.g. retaining walls, culverts) on a roading network.

2. Recording posting information and overweight limits as part of the inventory database.

3. Recording geometric and overall structural deficiencies including vulnerability to earthquakes and river scour.

4. Recording bridge traffic statistics and safety records.

5. Analysis and reporting of information and statistics available from the descriptive inventory.

6. Management of bridge inspection schedules including reporting past and scheduled inspection dates.

7. Preparation of appropriate inspection forms for each bridge or class of bridge.

8. Recording the inspection history of the bridges.

9. Recording general condition of main elements and overall structure of bridges.

10. Recording location, extent and severity of defects within each element.

11. Analysis and reporting of statistics on general condition and extent of bridge defects.

12. Recording maintenance work completed and maintenance costs.

13. Ranking bridges in terms of condition, deficiencies, and importance to public use.

14. Setting replacement and maintenance priorities based on ranking and condition information.

15. Monitoring replacement and maintenance programmes.

16. Evaluating optimal maintenance and replacement strategies and budget allocations on a regional or national basis.

17. Evaluation of overweight routes by use of a structural analysis capability.

18. Input of detailed bridge information to a general roading network Geographic Information System (GIS).

The questionnaires were sent to State Highway Network Managers (Transit New Zealand), WORKS Consultancy Services offices, Territorial Authorities (mainly District Councils), and Consulting Engineers. Of the 36 questionnaires sent out, 28 replies were received. The returns covered a reasonably good geographic spread with at least two returns from each of the seven Transit New Zealand regions. Figure 1 summarises the numbers sent and returned by each group.

9.2.3 Responses

Only two of the 28 replies suggested that a BMS was unnecessary. The response to the need for each of the 18 capabilities listed in the Questionnaire and Section 9.2.2, is shown in Figure 2. At least 60% of the respondents stated a capability need for all except capabilities 4, 5, 13 and 16, 17 and 18 (see p.33 for list of capabilities.)

Over 80% of the respondents indicated a need for a descriptive inventory and the capability of recording bridge structural information such as posting and overweight limits (Capabilities 1 and 2).

Recording the geometric and overall structural deficiencies (Capability 3) was seen as somewhat less important, with 76% indicating a preference for this capability.

A high number of respondents (83 to 92%) were in favour of including the more general capabilities related to the management of maintenance (Capabilities 6, 8 and 9).

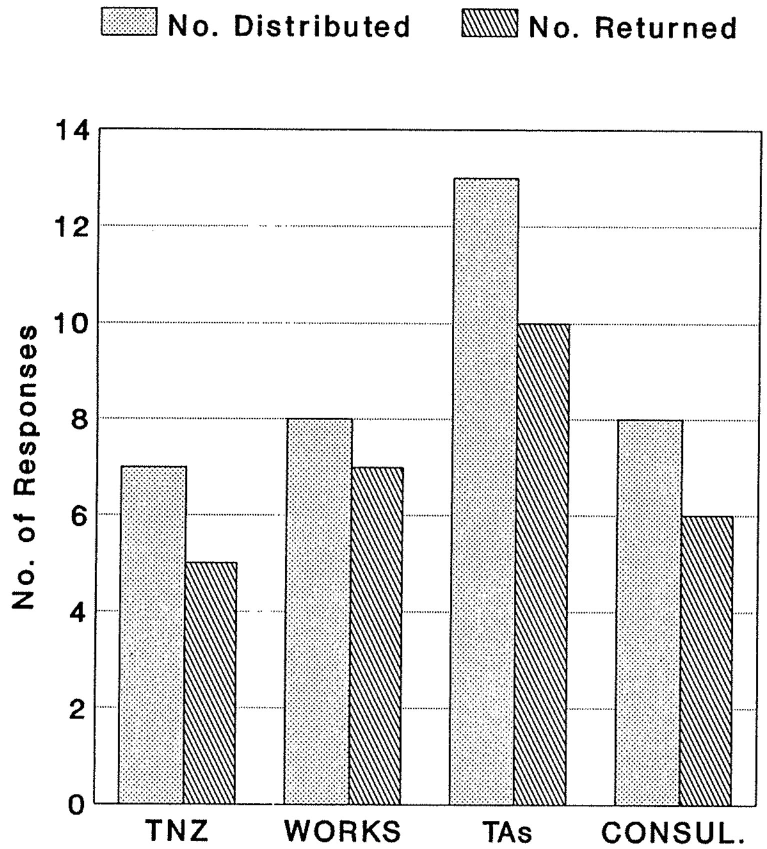
A lower number (68 to 75%) were in favour of providing more detailed maintenance management capability, such as the location and extent of defects, statistical analysis of bridge condition, and recording of maintenance activities and cost (Capabilities 10, 11 and 12).

Recording traffic statistics and safety records information (Capability 4) would provide some of the necessary input for the assessment of the need to improve or replace a bridge but received only a 57% response. Low responses were also made to ranking of bridges (Capability 13), and to evaluating optimal replacement and maintenance strategies (Capability 16). The need to set improvement or replacement priorities therefore did not appear to be regarded as one of the more important functions of a BMS.

The reason for the low response for analysis and reporting of information collected in the descriptive inventory (Capability 5) is difficult to follow. Use of such statistical information would seem logical for the planning and reporting work required in the operations of most major roading authorities.

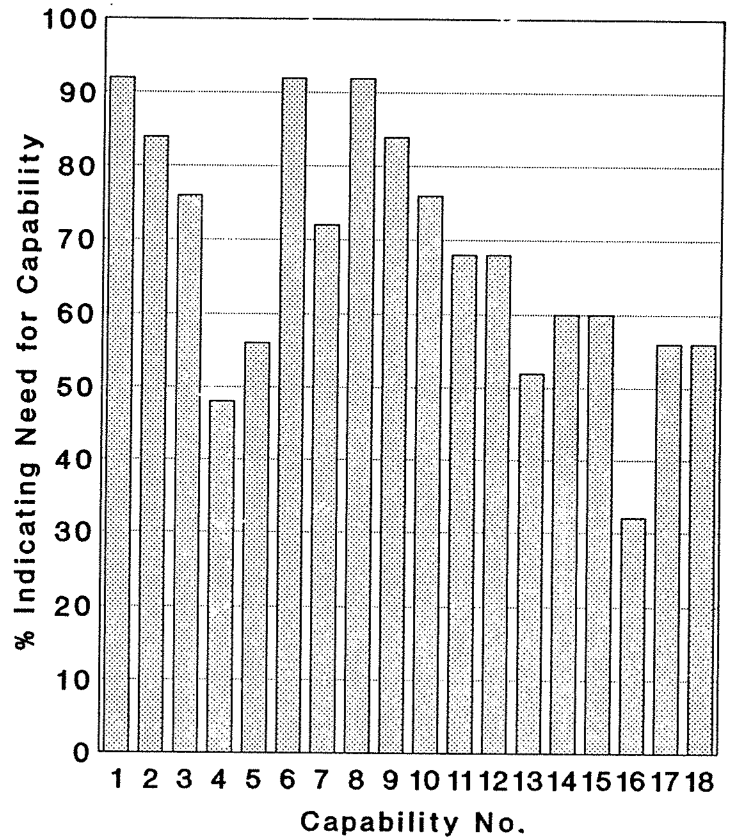
The evaluation of overweight routes (Capability 17), and linking the BMS to a GIS (Capability 18) are not directly related to maintenance and possibly for this reason were not regarded as important.

Figure 1. Questionnaire distribution and responses.



Abbreviations: TNZ - Transit New Zealand;
WORKS - WORKS Consultancy Services Ltd;
TAs - Territorial Authorities; CONSUL. - Consulting Engineers.

Figure 2. Analysis of all returns



(See Section 9.2.2 for number and description of capabilities)

9.2.4 Further Analysis

To further analyse the returns, the results were subdivided into sets from Transit New Zealand Managers, Consultants and Territorial Authorities. These sets contained totals of 5, 13 and 10 returns respectively. Initially the responses from the Works Consultancy Services offices were separated from the private consultants, but as the differences in the responses between these sets were not very significant they were combined for the presented results. Based on the response to the 18 listed capabilities, the average number indicated as desirable by the Transit New Zealand Managers, Consultants, and Territorial Authorities were 14, 11 and 16 respectively.

9.2.5 Responses from Territorial Authorities and Consultants

The responses of the Territorial Authorities are compared with the responses of the Consultants in Figure 3. The comparison shows clearly that the Territorial Authorities would prefer a much wider range of capabilities than the Consultants. The largest differences in the responses between these two groups occur for capabilities 5, 7, 11, 13, 14, 16 and 18 where the Territorial Authorities indicate a much stronger need than the Consultants.

Capability 5 is related to analysis and reporting of information collected in the descriptive inventory. Capability 7 involves the preparation of appropriate inspection forms for each bridge or class of bridge. Capabilities 11 and 13 involve the analysis and reporting of statistics on general condition and extent of bridge defects and ranking bridges in terms of condition, deficiencies and importance to public use. Capabilities 14 and 16 involve setting replacement and maintenance priorities and evaluating optimal maintenance and replacement strategies and budget allocations. Capability 18 involves interfacing the bridge system to a GIS.

In general terms, the Territorial Authoritiess indicated a stronger need than the Consultants for asset management reporting, programming and setting priorities, and financial planning.

9.2.6 Responses from Consultants and Transit New Zealand Managers

The responses of the Consultants are compared with the responses of the Transit New Zealand Managers in Figure 4. The comparison shows the Transit New Zealand Managers would also prefer a wider range of capabilities than the Consultants, especially in the responses for capabilities 5, 7, 12 and 16. Differences in the need for capabilities 5, 7 and 16 parallel the differences noted above in the comparison of the returns from the Territorial Authorities and the Consultants. Capability 12 involves recording maintenance work completed and maintenance costs.

Overall the Transit New Zealand Managers indicated a stronger need than the Consultants for some of the management reporting, priority setting, and financial planning capabilities. However, the Transit New Zealand Managers did not generally indicate as strong a need in these areas as shown by the responses from the Territorial Authorities.

Figure 3. Comparison of responses from Territorial Authorities (TAs) with Consultants.

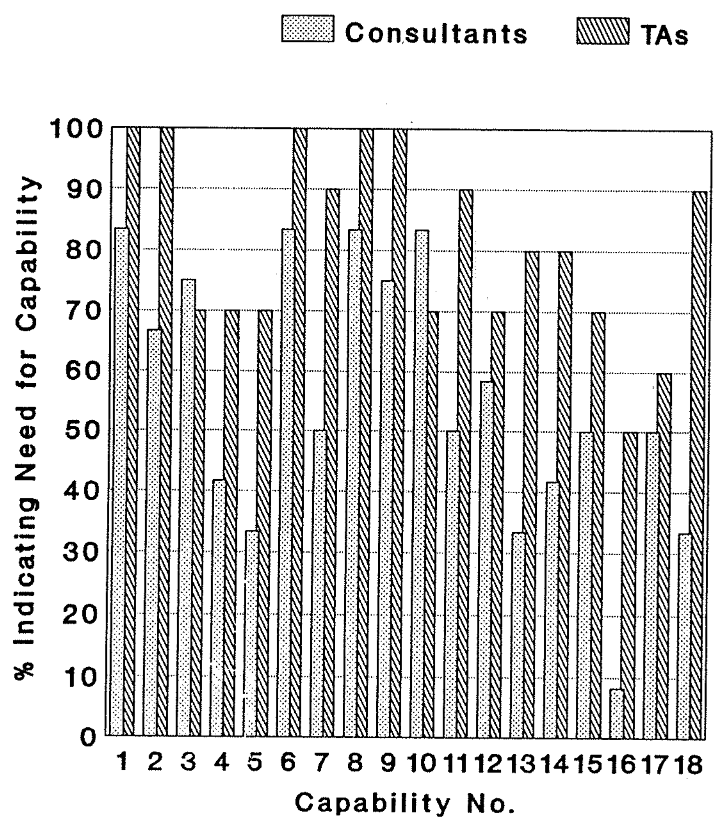
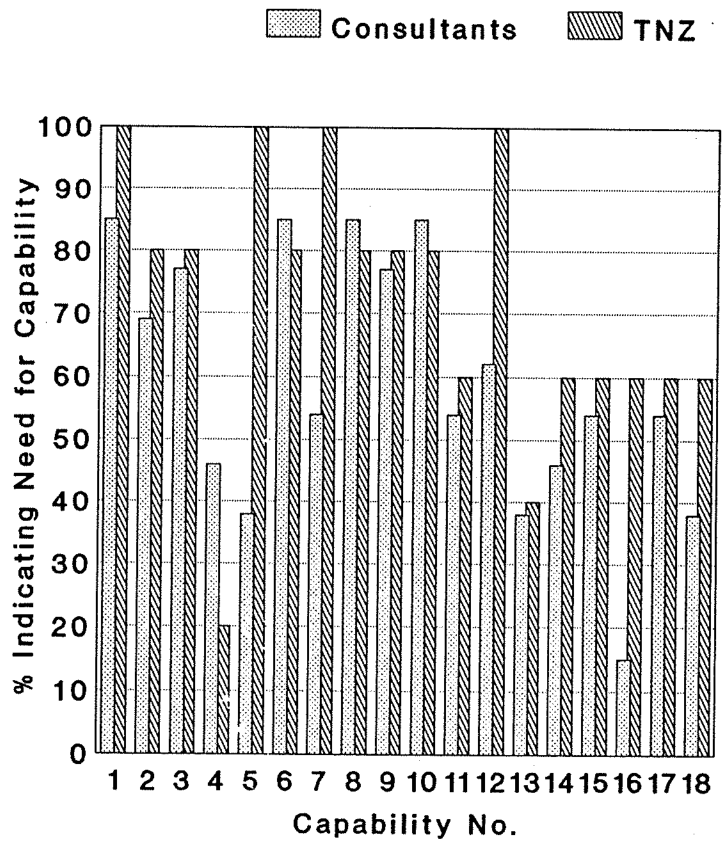


Figure 4. Comparison of responses from Consultants with Transit New Zealand Managers.



(See Section 9.2.2 for number and description of capabilities)

The questionnaire did not ask about present usage of BMS or BMMS. However, eight of the agencies indicated that they already were using a BMMS or a partially developed BMS. It is likely that a greater number than these respondents already use some computer-based inventory or management system.

9.2.7 Comments

The number of bridges administered by each responding authority ranged from 30 to 1000. Only three of the authorities administered fewer than 200 bridges. Two of these indicated an interest in a restricted range of capabilities. No obvious correlation existed between number of bridges administered and the range of capabilities considered necessary, and a formal regression analysis showed a slight negative correlation.

A number of the respondents suggested other desired capabilities including:

- More detailed structural information than in the present descriptive inventory
- Notebook recording of miscellaneous data
- Full overweight permit processing/route analysis
- Clearance check capability
- Link to spreadsheets for easy manipulation of data
- Link to Transit New Zealand's Road Assessment and Maintenance Management System (RAMM)

Several comments were received on the desirability of using a PC/DOS-based system rather than a centrally based system operating under Unix.

10. CONCLUSIONS

From the literature survey work and information obtained from New Zealand bridging authorities during the course of this project, the following conclusions were reached.

1. A comprehensive BMS is a need that most New Zealand bridging authorities appreciate. It is clear that a modular approach, allowing varying degrees of complexity to be included, is essential so that a single system can satisfy the needs of most of these authorities.

   The system adopted must be used nationwide so that a uniform standard of maintenance can eventually be achieved throughout New Zealand. The ranking of replacement and improvement work projects should also be carried out on a national basis. This may require changes to the present administrative structure for bridge management.

2. BRIMMS needs further development before it can usefully carry out any of the main functions expected, such as condition recording and optimisation of maintenance and improvement work. If available to Transit New Zealand, it could be used as a starting point for further development.

3. The bridge inspection system originally developed by the former New Zealand Ministry of Works and Development and incorporated into BRIMMS is deficient in many respects. More detailed bridge condition information can be accumulated with little increase in effort by using a better planned approach and a more detailed and appropriate data recording form.

4. Integrating the present bridge management functions, such as the descriptive and structural inventories, posting records, and overweight permit analysis procedure so that these functions operated under a unified software system, would be of advantage. Ideally these functions should also be integrated with any BMS system that is used.

5. The present descriptive bridge inventory is a suitable starting point for developing a BMS and should form the key database or main module.

6. Important steps required to set-up a New Zealand BMS include a detailed review of the information stored in the present descriptive inventory and the establishment of more satisfactory inspection and reporting procedures to improve the database.

7. A comprehensive BMS will require continual maintenance and upgrading. To operate a BMS successfully a full time manager will need to be employed by Transit New Zealand. Ideally this person should have a good working knowledge of both software development procedures and bridge engineering.

8. A considerable number of BMSs have been developed and trialed overseas. The task of setting-up a comprehensive system is considerable and it would therefore appear that there are significant advantages in adopting a system already in use and modifying it to meet local requirements.

9. Studying the technical literature was not a very satisfactory way of evaluating the capabilities of BMSs. There is considerable variation in input/output detail, analysis methods and overall philosophy making comparisons in performance and suitability difficult. In many cases the program capabilities and level of successful implementation appear to be overstated. Before deciding to adopt any of the presently available systems it is clearly necessary to carry out realistic trial operations using local bridge data.

10. The Pontis programme is likely to be widely adopted in both USA and Australia. A wide number of users would result in the program being well maintained and continuously improved.

11. Inspection of the documentation and a demonstration program indicated that, with some modifications, Pontis would be suitable for the maintenance management of New Zealand bridges. It already incorporates many of the 18 desired capabilities listed in Section 9.2 and it has the flexibility to be modified to include other specific features for local conditions.

12. From the information at present available, operating Pontis on a trial basis in New Zealand would have advantages. This trial would be helpful in demonstrating the capabilities of a comprehensive BMS and would determine whether it was necessary to adopt the alternative approach of developing a special purpose system for New Zealand conditions.

13. The BMS chosen for use in New Zealand should be capable of operating successfully on Personal Computers using the Microsoft DOS or compatible operating system.

11. RECOMMENDATIONS

1. It is recommended that Transit New Zealand adopt a policy to set up a bridge maintenance management system based on the principles used in advanced systems developed in other countries. The system should be modular and include the capabilities for optimising maintenance and improvement activities to achieve minimum operational costs.

   A further recommendation is that the system is suitable for application by all bridging authorities in New Zealand, so that with time a unified inventory and inspection procedure is developed on a nationwide basis for highway bridges and other major roading structures.

2. Because of the very large investment in time and cost required to develop a BMS, it is recommended that trial evaluations of systems developed overseas, that appear to best suit the local requirements, are carried out. Even if considerable modification is required to adapt available software to meet local conditions, this is likely to be a more efficient approach than the complete development of a new system.

3. As the initial step in setting-up a BMS, it is recommended that Transit New Zealand carry out a trial of the Pontis program. The following steps are required to set-up the trial and to evaluate the performance:

(a) Consult the agencies using Pontis to update information on operational experience gained since the time of writing this report.

(b) Set up a review committee to comment on the trial procedure and to evaluate the performance at the conclusion of the trial.

(c) Invite the developers of the program to demonstrate the program in New Zealand.

(d) Assess the suitability of the present descriptive inventory as a database for the trial.

(e) Estimate the costs of a trial.

(f) Select an agency with a relatively large bridge stock to host the trial. Ideally the personnel involved should have had previous experience with BRIMMS.

(g) Arrange with the program developers to assist with the modifications and setting-up the program for the trial. This should include making arrangements for converting the present descriptive inventory to a suitable form for access by Pontis.

(h) Operate the trial for a minimum period of one year. The trial should include bridge inspections carried out using the Pontis inspection and reporting procedures.

(i) Carry out a detailed assessment of the trial.

(j) Depending on the outcome of the trial, make recommendations regarding implementation of Pontis on a nationwide basis or select other systems for further evaluations.

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APPENDIX

Abstracts from a number of the references identified in the literature review as good sources of information on bridge management systems are reproduced below.

Arner, R.C., Kruegler, J.M., McLure, R.M., Patel K.R. 1986. The Pennsylvania bridge maintenance management system. ***Transportation Research Record*** **1083: 25 - 34.**

The paper describes the development of the Pennsylvania Bridge Maintenance Management System. A Bridge Management Work Group was organised to develop, as well as to test and implement the concepts and requirements of a total bridge management system (BMS) for Pennsylvania, using highway planning and research funding.

The objectives of the maintenance management portion of the BMS were to:

(a) Utilise standardised bridge maintenance activities and costs
(b) Store activity needs on a bridge by bridge basis
(c) Rank activities and assign a priority to bridges for maintenance programming
(d) Transfer programmed projects to maintenance division scheduling system
(e) Store cost of completed work

The objects of the overall BMS were:

(a) Integration of data from existing structure inventory and other databases
(b) Enhance and expand the database
(c) Systematically evaluate the bridge deficiencies and associated costs
(d) Record maintenance and construction history
(e) Semi-automatic analysis to determine load rating
(f) Produce information to enable cost-effective management of the bridge system

Harding, J.E., Parke, G.A.R., Ryall, M.J. Eds 1990. ***Bridge management - inspection, maintenance, assessment and repair.*** **Civil Engineering Department, University of Surrey, Guildford, Surrey. 790pp.**

This volume consists of papers presented at the First International Conference on Bridge Management, held at the University of Surrey, Guildford, UK, March 1990. Included are 67 papers emanating from more than 25 countries, covering the fields of inspection, protection, structural assessment and evaluation, maintenance, repair, strengthening, rehabilitation and performance monitoring as well as important papers on bridge management systems currently operating in several countries.

Hosseen, C., Stanilewicz, B.A. 1990. ACT Government's information and management system - BIMS. ***Proceedings 15th ARRB Conference*****, Part 3: 223-237.**

Although the Australian Capital Territory's city infrastructure is relatively new when compared to other states, it is now requiring increasing maintenance. The ACT Government has recently developed a number of systems that allow assets to be effectively and efficiently maintained.

Among these systems is a bridge information and management system - a computerised bridge inventory, condition reporting and information system supported by inspection and works procedures, to allow the ACT programme managers to programme and keep track of inspections and identified maintenance.

The system is PC-based to perform the role of an asset register and to manage the inspection and maintenance of bridges, culverts, overpasses and underpasses. It has an information database comprising static and dynamic databases which record all physical and administrative data required to define the structures operational characteristics, funding arrangements, condition, and maintenance needs. The paper describes the development of the system, the benefits, and the deficiencies of the previous manual system. Also described are the system's design, capabilities and structure.

Hudson, S.W., Carmichael, R.F., Moser, L.O., Hudson, W.R., Wilkes, W.J. 1987. Bridge management systems. ***National Cooperative Highway Research Program, Report*** **300, Transportation Research Board, Washington, DC. 74pp.**

About one-half of the approximately 600,000 highway bridges in United States were built before 1940. Most of these bridges were designed for less traffic, smaller vehicles, slower speeds, and lighter loads than presently use the highway network. In addition, even in newer bridges, deterioration caused by service conditions and deferred maintenance is a growing problem. Nearly half of these bridges have been classified as structurally deficient or functionally obsolete by the Federal Highway Administration. The cost for rehabilitation and replacement of these bridges has been estimated at more than US$50 billion. However, only US$2 to US$3 billion annually has been available to address this problem.

Available funds will not permit total rehabilitation or replacement of all deficient bridges obviously. Therefore, the limited funds available must be carefully allocated to bridges required by the public and transportation industries to provide the most cost-effective treatment.

This report contains the findings of the first phase of the NCHRP Project 12-28(2) *Bridge Management Systems*. The overall objective of this project was to develop a model bridge management system at the network level that can be implemented by small to medium size transportation agencies. The system is intended to ensure the effective use of available funds and to identify the effects of the various funding levels on the bridge network.

Ramotar, J., Quinton, R. 1988. Alberta bridge inspection and maintenance management system. ***Roads and Transportation Association Canada Conference 1988, Halifax, Nova Scotia*** **4: B87-B110.**

In 1985 the Province of Alberta undertook a detailed review of its bridge management practice and concluded that several areas could be improved significantly. An eight-member committee consisting of staff members with varied backgrounds in bridge engineering was assembled in June 1986 to develop a comprehensive computerised inspection and management system. The primary objectives of the system were to ensure an appropriate level of safety to the travelling public, protect the investment in bridge structures (estimated replacement value of CAD$1.4 billion) and provide an improved management tool for bridge staff at all levels.

To meet these objectives the system was required to have the ability to store and process the inventory, inspection and maintenance data for use in inspection management, maintenance programming, budget development, strategic planning, and life-cycle planning.

A modular approach was used in the development of the management system allowing implementation of each module as it was finalised. The paper describes the first phase of the development which includes layout of the system to accommodate present and future needs, details on the 27 different types of inspection forms, the condition rating procedure, sufficiency rating programs, and operating guidelines that govern the use of the system.

Sinha, K.C., Saito M., Jiang Y., Murthy S., Tee A., Bowman M.D. 1991. ***The development of optimal strategies for maintenance, rehabilitation and replacement of highway bridges.*** **Joint Highway Research Project, School of Civil Engineering, Purdue University - Indiana Department of Transportation.**

This six volume report presents the findings of the research work undertaken to develop the frame work for managing bridge maintenance, rehabilitation and replacement activities in Indiana.

Like many other states, Indiana had a large number of bridges requiring immediate maintenance attention. Because of the imbalance between the bridge repair and replacement needs and budget constraints, a systematic bridge management system was employed to allocate available resources in an optimal manner. The research had the following objectives.

1. Development of a method to better use the existing bridge inspection data in selecting bridges for maintenance, rehabilitation and replacement.

2. Development of a method to provide consistent and state-wide uniform measurements of ratings for bridges.

3. Analysis of bridge maintenance, rehabilitation, and replacement costs; and analysis of relationships between bridge attributes and cost.

4. Development of a method to estimate remaining service life of bridges, and effects of bridge activities on condition rating and service life.

5. Development of a bridge traffic safety evaluation scheme that relates physical characteristics of bridge structure to accident potential.

6. Development of a project selection procedure using life-cycle cost analysis, ranking, and optimisation methods.

7. Development of a set of guidelines that can be used by the Indiana Department of Transportation in implementing a bridge management system including databases and organisational requirements.

The titles of the six volumes of the report are as follows:

Vol 1. The elements of the Indiana Bridge Management System
Vol 2. A system for bridge structural condition assessment
Vol 3. Bridge traffic safety evaluation
Vol 4. Cost analysis
Vol 5. Priority ranking method
Vol 6. Performance analysis and optimisation

Stukhart, G., James, R.W., Garcia-Diaz, A., Bligh R.P., Sobanjo J., McFarland W.F. 1991. Study for a comprehensive bridge management system for Texas. ***Research Report 1212-1F, Texas Transportation Institute*****, The Texas A&M University System, College Station, Texas. 224pp.**

This report covers a two-year study of the feasibility and development of specific recommendations for a comprehensive bridge management system for Texas State Department of Highways and Public Transportation. The study identified the problems that could advantageously be addressed by a BMS and recommended a scope for a proposed BMS which was believed to be appropriate for application at district and state level. The study also included a review of BMSs proposed, developed, and used in other states and reviews of theory and technology relevant to the problems related to the overall bridge management problem. Last, the study addressed the problem of identifying the data required for the application of a BMS in Texas.