Paper Title: Recent Development of Bridge Management Systems in Canada

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Abstract

With the aging of its infrastructure, Canada is facing a critical problem to deal with the complex and fragmental issues existing in current infrastructure management. Because Bridge Management Systems (BMSs) are not used universally in Canada, this paper aims at reviewing the current state of BMSs in Canada and suggesting an initiative to build a Canadian National Bridge Inventory. The Bridge Expert Analysis and Decision Support (BEADS) system currently used in Alberta is different from the BMSs of other provinces in its system structure and scope. The BEADS is an important part of a comprehensive system -- Transportation Infrastructure Management System (TIMS). The Ontario BMS integrates the deterioration model, cost model, and business rules for treatment selection and costing, and an analytical framework for calculating and representing information relevant to the decision at hand. The Quebec BMS has three main models (Deterioration Model, Treatment Model, and Cost Model) that are used to create work alternatives at the element, project, and program levels. Pontis is used as the BMS in Manitoba. Pontis can support the complete bridge management cycle, including bridge inspection and inventory data collection and analysis, predicting needs and performance measures for bridges, recommending an optimal preservation policy, and developing projects to be included in an agency's capital plan. In Nova Scotia and Prince Edward Island, the BMSs are similar to the Ontario BMS. The remaining provinces and territories in Canada do not have computer-based BMSs. After comparing the above BMSs, the paper discusses a new research project at Concordia University to build a Canadian National Bridge Inventory (CNBI) similar to the NBI used in the U.S.

1. Introduction

As the third millennium dawns, Canada is in the midst of a "bridge crisis", especially after the latest collapse of a bridge in Laval City [2]. With the aging of its infrastructure, Canada, like other developed countries, is facing a critical problem to deal with the complex and fragmental issues existing in current infrastructure management. Bridge management, as an important part of the infrastructure management, is attracting more and more attention. Using advanced Bridge Management Systems (BMSs) is not popular in some provinces in Canada. Furthermore, the available BMSs in different provinces are different in terms of their architecture, functionalities, and interfaces.

More than 40% of the bridges currently in use in Canada were built over 50 years ago [1], and a significant number of these structures need strengthening, rehabilitation, or replacement, using limited maintenance budgets. The highway-funding deficit estimated by TRIP Canada (The Road and Infrastructure Program of Canada) is more than $22.6 billion in 2006 [9]. The federal government plans $2.4 billion for Highways and Border Infrastructure Fund, $2.0 billion for Strategic Infrastructure Fund, and $2.2 billion for Municipal Rural Infrastructure Fund in 2006 [9]. The two latter programs are used to finance roads and highways. Table 1 shows a comparison of the BMSs at different provinces and territories in Canada. Figure 1 shows the distribution of the number of bridges managed by transportation agencies in Canada.

Province	No. of Bridges P: Provincial M: Municipal	State of Development of BMS	BMS	Condition Rating System	Distribution by Material Type	Agency Responsible of BMS
Alberta	9,800 (M) 4,100 (P)	Early 1970s to 2002	BEADS	9	N.A.	Department of Infrastructure and Transportation
British Columbia	20,000	Started in 1986 Rebuild in 2000	N.A.	5	N.A.	Ministry of Transportation
Manitoba	1200 (P)	N.A.	Pontis	5	N.A.	Department of Infrastructure and Transportation
New Brunswick	N.A.	N.A.	N.A.	N.A	N.A.	Department of Transportation
Newfoundland and Labrador	N.A.	N.A.	N.A.	N.A.	N.A.	Department of Transportation
Nova Scotia	4000 (P)	1999-2003	NSBMS	4	Timber: 60% Concrete: 20% Steel: 20%	Department of Transportation and Public Works
Ontario	3000 (P)	1989-1999	OBMS	4	N.A.	Ministry of Transportation
Quebec	4300 (P) 4400 (M)	Finished 2007	QBMS	5	Timber: 0.3% Concrete: 75.8% Steel: 16.7% Other: 7.2%	Ministry of Transportation
Saskatchewan	820 (P) 2200 (M)	N.A.	N.A	4	N.A	Department of Highways and Transportation
Prince Edward Island	200	Ongoing	PEIBMS	4	Timber: 50% Concrete: 25% Steel: 25%	Department of Transportation and Public Works

Table 1. Comparison of the BMSs at Different Provinces and Territories in Canada

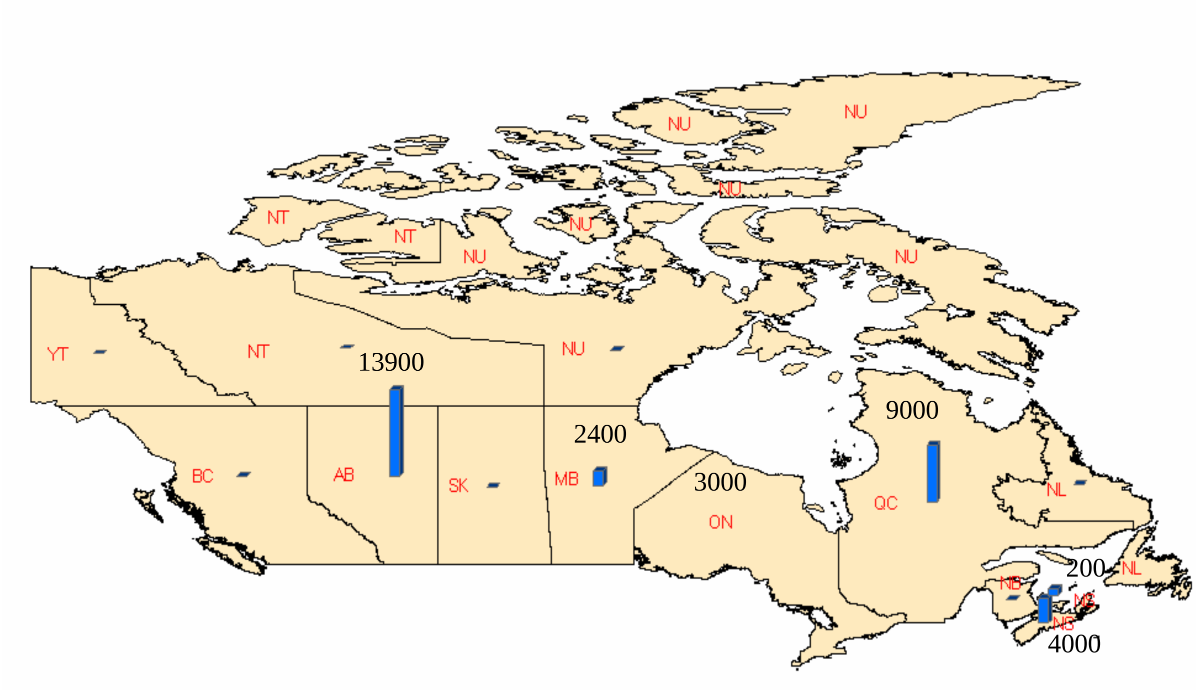

Figure1. Distribution of Number of Bridges in Canada

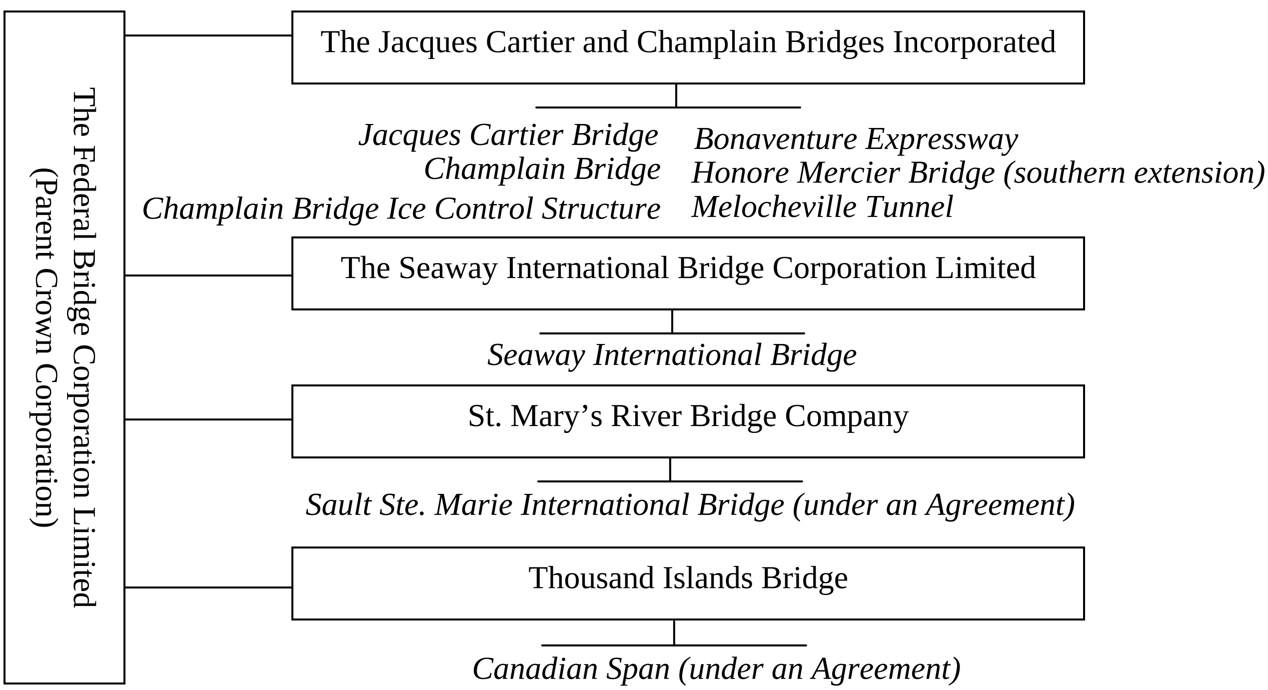

Figure 2. FBCL Organization Structure [17]

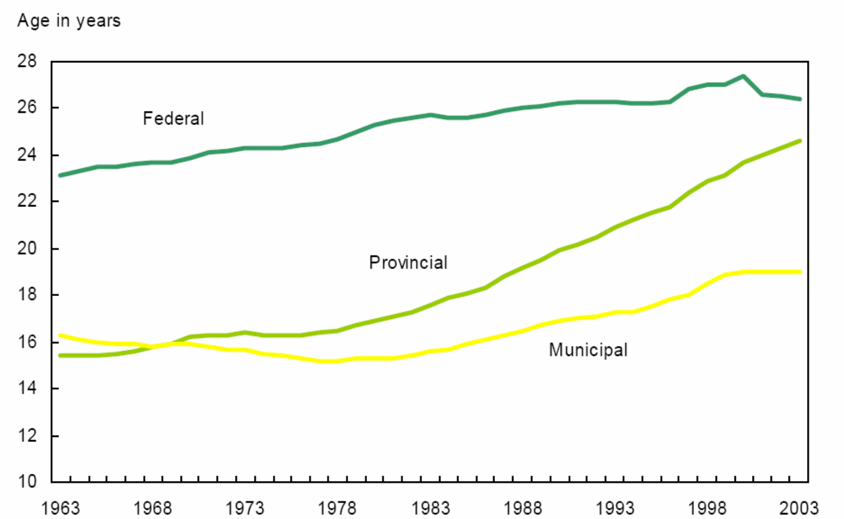

Figure 3. Average Age of Bridges by Level of Government [4]

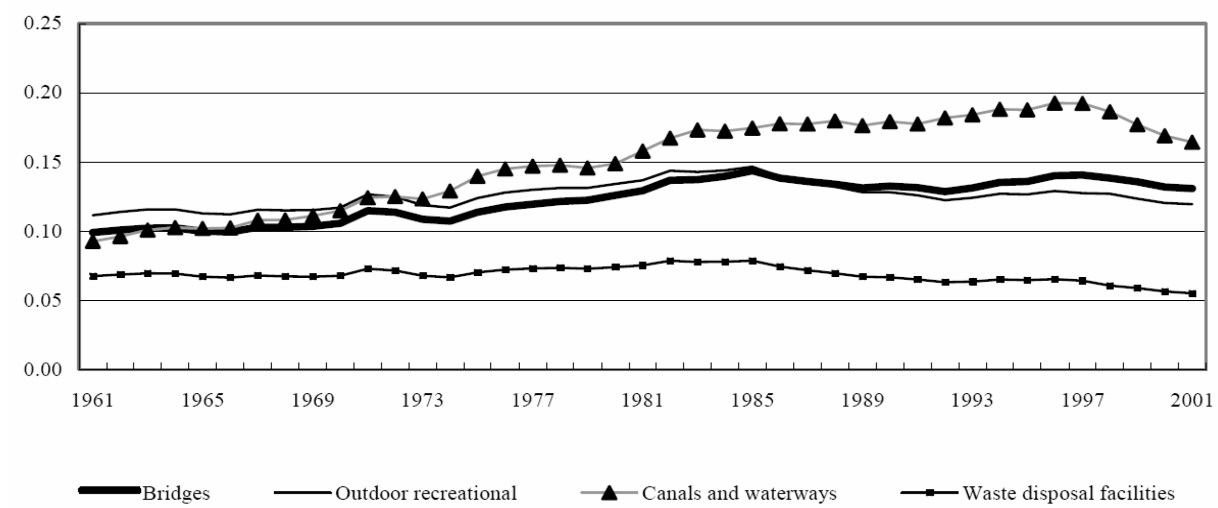

Figure 4. Share of the Local government Infrastructure Capital Stock by Asset Class in the National Tangible Produced Capital Stock (percentage) [5]

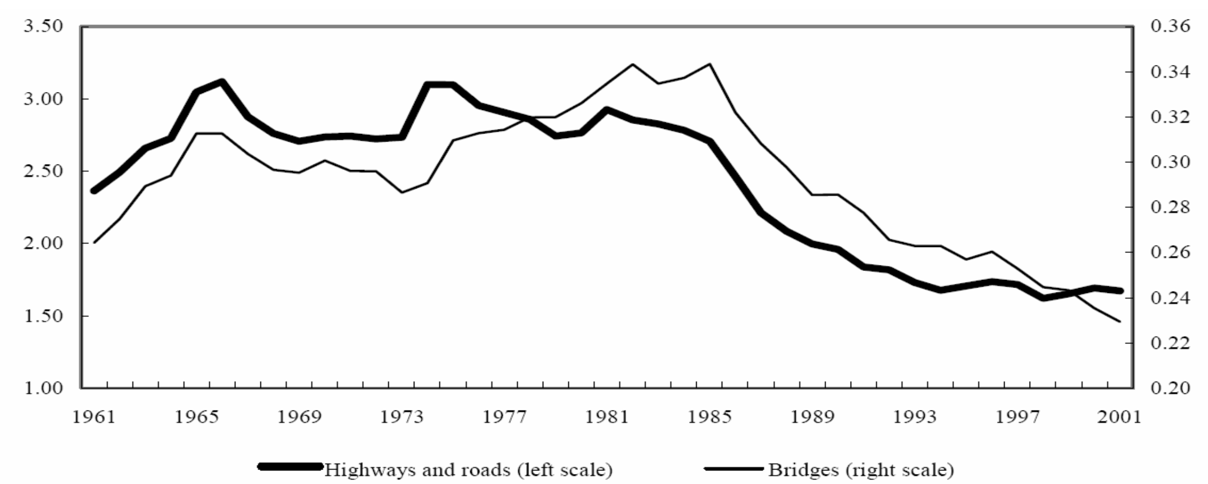

Figure 5. Share of the Provincial Government Infrastructure Capital Stock by Asset Class in the National Tangible Produced Capital Stock (percentage) [5]

1.1 Deterioration of Canadian Bridges by Level of Government

Bridges in Canada are managed by different agencies at the federal, provincial and municipal governments. The provincial transportation agencies in charge of the majority of bridges are summarized in Table 1. The Federal Bridge Corporation Limited (FBCL) was incorporated in 1998 to assume the non-navigational management responsibilities of the St. Lawrence Seaway Authority [17]. At the same time, the FBCL assumed responsibility for the management of the Canadian portion of the Thousand Islands International Bridge. In 2000, the FBCL acquired the Canadian half of the Sault Ste. Marie International Bridge and was represented on the Joint International Bridge Authority. Figure 2 shows the FBCL organization structure.

The average age of the bridges in Canada has been increasing continuously since 1973, which means that the bridges are always getting “older” as investment is not enough [4]. As shown in Figure 3, by 2003, federal and provincial bridges had passed the halfway mark of their useful lives (46 years): 57% in the case of the federal brides and 53% in the case of provincial bridges. In contrast, municipal bridges were younger, and had only 41% of their useful lives behind them [4]. Provincial bridges were primarily responsible for the aging of the total stock. Very low levels of investment by provincial governments had a direct impact on the average age of bridges, which rose from 15.4 years to 24.6 years between 1963 and 2003. Provincial bridges made up 57% of total bridge infrastructure in 2003. The average age of federal bridges was 26.4 years in 2003, but they account for only 3% of the total stock. Municipal bridges were 19.0 years old and made up 39% of bridge infrastructure that year [4].

As shown in Figure 4, Canadian bridges began to decline slowly in the mid 1980s, after which the ratio of the national tangible produced capital stock gets stable. In contrast, provincial bridges experienced a steady decline as shown in Figure 5 [5].

1.2 Accounting for Infrastructure in the Public Sector

In 2002, the Public Sector Accounting Board (PSAB) released a research report - *Accounting for Infrastructure in the Public Sector*. A key recommendation of this report is that municipalities should record and report their capital assets in their financial statements, including information on the condition of those assets. A new requirement for the recognition of capital assets - Tangible Capital Assets (TCA) will be applied in 2009. TCA is a significant economic resource managed by governments and a key component in the delivery of many government programs. It includes items such as roads, buildings, vehicles, equipment, land, bridges and other utility systems [15]. At present, Quebec has already a TCA policy. Nova Scotia, Saskatchewan, Alberta and British Columbia have been compliant with PSAB [12].

2. BMSs in the U.S.A.

Nowadays there are mainly two approaches to analyze the functions of BMSs that have both network-level and project-level functionalities, which are the top-down and bottom-up analytical approaches. These two approaches have been applied in two major BMSs in the U.S.A., i.e. Pontis and Bridgit [3]. The top-down approach is often used to analyze and develop the optimal treatment policies of the network-level. Then engineers can apply these policies to individual bridges to develop project-level recommendations with estimates of cost and benefits, such as the case in Pontis. The bottom-up approach is more useful to analyze one or more alternative strategies for each individual bridge. These accumulated alternatives in the network-level determine budgetary requirements and performance. Then decisions-making in the project-level are adjusted until the budget limitations in the network-level are almost satisfied, such as the case in Bridgit [18].

Pontis and Bridgit are the two main BMSs used in the U.S.A. Pontis was developed by the Federal Highway Administration (FHWA) in conjunction with six states Departments of Transportations (DOTs) and the consultant joint venture of Optima, Inc. and Cambridge Systematics [22]. Soon after the Highway Bridge Replacement and Rehabilitation Program (HBRRP) was passed, the FHWA determined that the gap between the funding needed to make the necessary repairs to bridges and the available budgets for many agencies was widening. In 1986, a demonstration project was initiated that supported workshops in almost every state which sought to develop bridge management practices. This demonstration project provided the foundation for the development of a generic BMS, later named Pontis, which could be adapted for use by any state. In 1989, the State of California administered the development of Pontis with the assistance of a technical advisory committee including the FHWA, National Cooperative Highway Research Program (NCHRP), and five other states, representing a wide range of bridge environments and size [3].

Pontis includes many innovative features. The condition data included in the system are more detailed than the requirement of the National Bridge Inventory (NBI) [10]. The bridge is divided into individual elements, or sections of the bridge, which are comprised of the same material and can be expected to deteriorate in the same manner. The condition of each element is reported according to a condition state, which is a quantitative measure of deterioration. The condition states are defined in engineering terms and are on a scale from 1 to 5 for most elements [21]. Pontis also views bridge deterioration as probabilistic, recognizing the uncertainty in predicting deterioration rates. The system models deterioration of the bridge elements as a Markov process. Pontis automatically updates the deterioration rates after historical inspection data are gathered. Cost models have been adapted from research performed by the DOT of North Carolina. Pontis has the ability to estimate accident cost, user costs resulting from detours and travel time costs. This information is used in the optimization models to examine trade-offs between options. In the optimization routine, maintenance, repair and rehabilitation (MR&R) actions are separated from improvement actions. Pontis also employs a top-down analytical approach by optimizing over the network before determining individual bridge projects. The speed of the optimization model allows for the investigation of impacts on the network with the variation of certain parameters such as the budget or delaying a certain action [16].

Currently, 45 states in the U.S.A. are participating in an AASHTOWare (American Association of State Highway and Transportation Officials) project to enhance Pontis. About 2/3rds of these states currently have plans to officially implement Pontis [21]. In an effort to standardize the reporting of elements among the different users of Pontis, the technical advisory committee completed the Commonly-Recognized (CoRe) Elements Report which defines bridge elements and corresponding condition states [3].

The Florida Department of Transportation (FDOT) is using Pontis to provide decision support to engineers in the headquarters and district offices as they make routine policy, programming, and budgeting decision regarding the preservation and improvement of the state's bridges. One of the most important advances in the FDOT version of Pontis is the recognition of the importance of a project level perspective to complement the network level, and the design of a framework for project level analysis [20].

Bridgit is a BMS developed by the NCHRP and National Engineering Technology Corporation (NETC) [22]. This project began in 1985 and completed its initial testing in 1993. Bridgit is similar to Pontis in terms of its modeling and capabilities. For instance, it uses Markov theory to model the deterioration process. The primary difference is in the optimization model. Bridgit adopts the bottom-up approach to optimization. It can perform multi-year analysis and consider delaying actions on a particular bridge to a later date. Pontis only has this capability at the network level. This Bottom-up approach provides better results for smaller bridge populations than top-down programming. Its disadvantage is that the system is slower than Pontis for larger bridge populations. The main uses of Bridgit include scheduling and tracking of MR&R activities, keeping history of MR&R, estimating the cost of MR&R, and creating and maintaining a list of MR&R actions [22].

3. BMSs in Canada

3.1 Alberta

Among all BMSs in Canada, the Bridge Expert Analysis and Decision Support system (BEADS) of Alberta has different architecture from other BMSs, such as Ontario BMS or Quebec BMS. Alberta Transportation is an authorized government department, which is responsible for more than 4100 bridges in provincial highways and 9800 bridges on the municipal road system throughout the province.

Alberta has a more comprehensive and wide transportation management system named Transportation Infrastructure Management System (TIMS), which consists of the Roadway Maintenance and Rehabilitation Application (RoMaRa), the Network Expansion Support System (NESS) and the Bridge Expert Analysis and Decision Support (BEADS) system. The BEADS system is an important component of TIMS. Figure 6 shows the structure of the TIMS and BEADS system [8]. The purpose of TIMS is to justify and rank the development, design, construction, rehabilitation and maintenance needs of the highway system on a province wide basis in order to optimize the allocation of funds to ensure long term value.

The BEADS system consists of a series of individual modules, which are Substructure, Superstructure, Paint, Strength, Bridge Width, Bridge Rail, Vertical Clearance, Replacement and Culvert modules. The Superstructure and Paint Modules are related to the condition state of bridges. The Strength, Bridge Width, Bridge Rail, and Vertical Clearance Modules are related to functionality states of bridges. They produce the improvement needs based on inventory and performance data, and predict the future timing of a functional need. Also, a cost estimate, the timing for each action and road user costs will be determined. The Substructure and Replacement Modules provide expected criteria for use by the Strategy Builder Module, which organizes life cycle strategies according to the received results from each of the above modules. As a separate and self-contained module, the Culvert Module is in charge of the MR&R activities of culvert structures under the Strategy Builder Module.

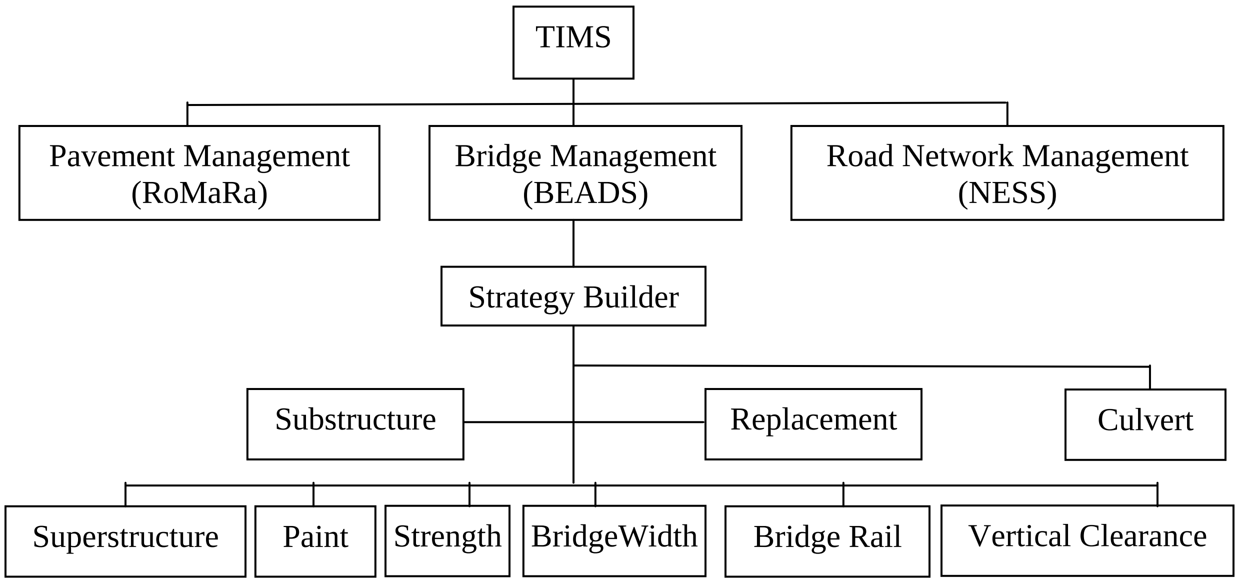

Figure 6. Structure of the TIMS and BEADS Systems [8]

In consistency with the existing bridge inventory and inspection system in the department, the BEADS system provides a project-level analysis, which systematically identifies condition and functionality-related improvement needs using site specific date. Based on existing and predicted condition and functionality states, the modules identify potential work activities throughout the economic life cycle, including the timing and cost of all actions. The Strategy Builder Module then assembles and groups the identified work activities into feasible life cycle strategies [8]. The condition related modules determine the improvement needs based on the element condition data, age, and rehabilitation history. In addition, they determine the cost estimate and the timing for each activity.

Finally, an action plan table is created including the year of replacement and all the information about possible work action plan, such as number of work actions, duration of the action plan, year, cost, and description of each work action, and net present value of the action plan costs. The result will display the year functional needs, possible work actions to rectify functional needs, cost of possible work actions, and annual road user cost of not completing work actions.

Based on the results of the BEADS system, the network level analysis facilitates short-term programming, analyze long-range budget scenarios, evaluate the status, and assess the impact of policy decisions.

3.2 British Columbia

The Ministry of Transportation of British Columbia is responsible for most of the management of the province’s bridges using the Bridge Management Information System (BMIS), which has

been developed over the last 20 years. The last major upgrade of the system was in 2000 for adding a map interface and a new module for inspection data entry and upload form the field. The BMIS has some key strengths and weaknesses as follows [12]:
Strengths:

- Requirements were designed by those who use the system.
- Inspection forms tailored to 6 different structure types - Bridges, Suspension/Cable Stayed Bridges, Culverts, Tunnels, Retaining Walls, and Sign Structures.
- Geometry, material, and component type information are tailored to 5 different structure types.
- Provide inspections record percentage of each component in each condition state.
- Provides good training.
- Has a map-based interface for recording inspection data on laptops and uploading to Oracle.
- Has an access to drawing lists and electronic versions of drawings.
- Has the ability to store images and copies of documents and scanned reports.
- Provides sufficiency ranking of structures.
- Has the ability to easily create custom reports using Oracle Discoverer.
- The system is integrated with the Ministry Road Inventory Management system.
- Provides various security levels.
- Can be accessed and uses by private bridge maintenance contractors.

Weaknesses:

- Does not have a module for budget forecasting and what-if scenarios.

3.3 Manitoba

The new Department of Infrastructure and Transportation in Manitoba is in charge of managing the province's major infrastructure projects including highways instead of the former departments of Intergovernmental Affairs and Trade, Transportation and Government Services and Water Stewardship. At present, Manitoba Infrastructure and Transportation manages its 2400 structures, which are 1200 bridges and 1200 culverts (greater than 2 meters of diameter) through an inspection program of approximately 640 structures per year [12]. The inspection results are currently stored in an Oracle database. This database is then queried for prioritized structure MR&R actions. Pontis is used to manage all of the province's bridges directly.

3.4 Nova Scotia

Nova Scotia Department of Transportation and Public Works (NSTPW), where are four regional offices and a central Bridge Office, is responsible for the safety and management of approximately 4000 bridges on the provincial highway system in Nova Scotia, of which about 60% are timber, 20% are concrete, and 20% are steel bridges. A large percentage of the bridges have already either reached the end of their service life or have passed their midlife of designed life cycle. In order to effectively manage these bridges, the NSTPW decided to develop a modern BMS to satisfy the increasing need of bridge safety. In 1998, the NSTPW launched a project named the Transportation Management Information System (TMIS) to help the Department achieve its mandate of safe highways, cost-effective highway infrastructure management, public satisfaction and support for economic development [14]. The NSTPW also developed the Nova

Scotia BMS (NSBMS) based on the Ontario BMS. The following are the main features of the NSBMS:

Inspection
In NSBMS, the Ontario Structure Inspection Manual and the Ontario Structure Rehabilitation Manual are selected as the inspection and the rehabilitation methodologies, respectively. The inspection philosophy is to record defect severity and extent separately, requiring the inspector to record the quantity of defects in each of 4 condition states for each bridge component and also Performance Deficiencies for each component based on the inspection results, the system can flag some follow-up actions such as a “Strength Evaluation”. Performance Deficiencies include “Excessive Deformations”, “Seized Bearings” or “Jammed Expansion Joints” [14].

Decision Support
The decision-making processes served by the NSBMS are inventory creation, monitoring, needs identification, policy development, priority setting, and budgeting and funding allocation. The system is established on three levels of analysis, which are element, project and network. The element level uses a deterioration model, a long term cost model, and a set of feasible treatments to produce multiple Element Alternatives, each of which is a possible corrective action to respond to deteriorated conditions. The project level combines Element Alternatives into Project Alternatives that are 1-5 year and 6-10 year implementation periods for each bridge, each of which represents a possible multi-year strategy to maintain service on a bridge. The network level combines the Project Alternatives on multiple bridges into Program Alternatives, each of which is a multi-year plan for work on all or parts of a bridge inventory, designed to satisfy budget constraints and performance targets while minimizing life cycle costs.

3.5 Ontario

In Canada, Ontario is one of the earliest provinces to develop a BMS. The Ministry of Transportation of Ontario (MTO) is responsible for the management of more than 16,500 kilometers of highway networks in addition to approximately 3000 bridges. In order to manage these old bridges effectively, the MTO decided to develop a brand-new system that has more powerful functions not only at the network-level but also at the project-level. As mentioned in Section 2, the two approaches are procedural, in that the user must follow a prescribed sequence of analytical steps, including one or more time-consuming optimization steps, before a full set of useful outputs in available. However, the MTO intended to achieve a full set of outputs immediately on any project-level and network-level input without intervening user steps or a time lag [18]. The MTO engaged ITX Stanley, Ltd. to develop the new system called Ontario Bridge Management System (OBMS). The project began in January of 1998 and was has completed by the end of 1999.

In the OBMS, there are three main models, which are Deterioration Model, Knowledge Model, and Cost Model. Figure 7 shows the structure of the domain model of OBMS [19].

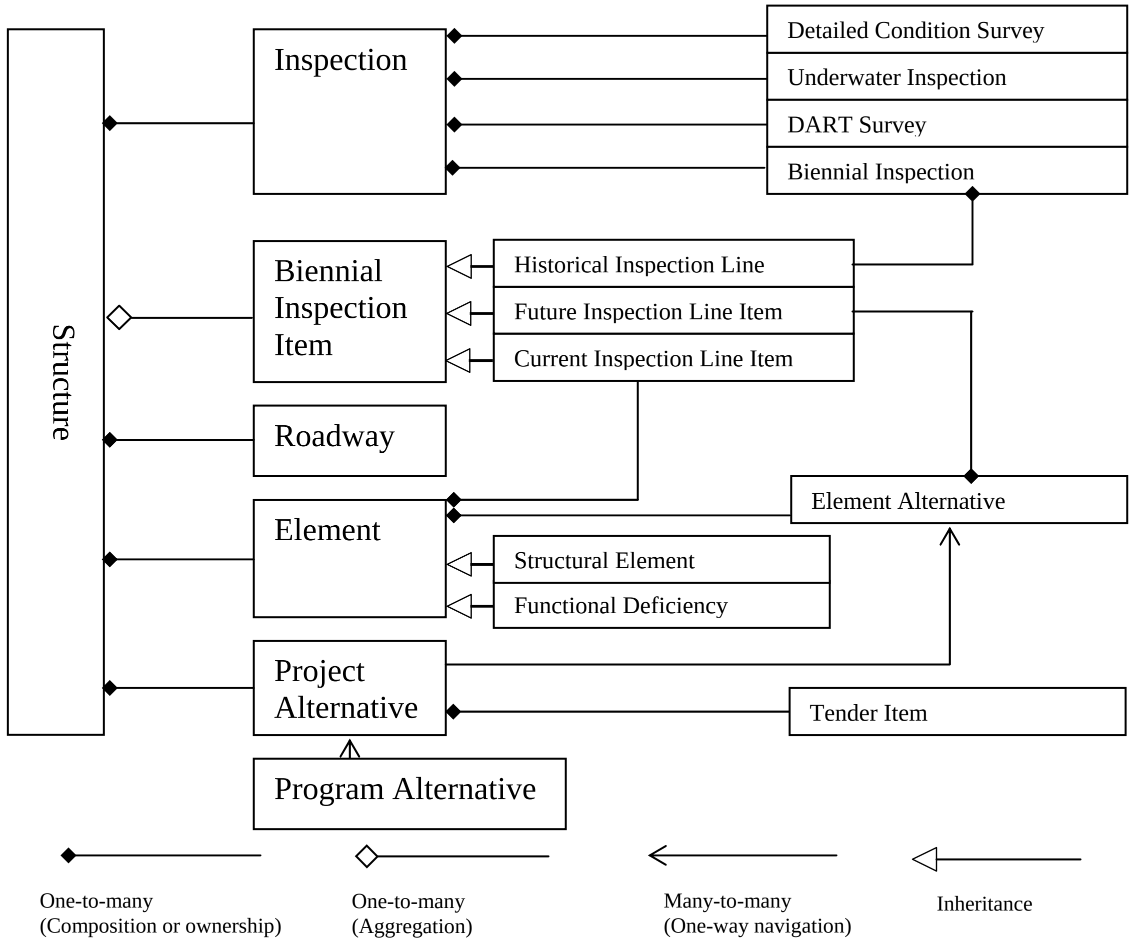

Figure 7. Structure of Domain Model of OBMS [19]

Like other BMSs, OBMS also takes the Markovian deterioration model as a method of predicting the deterioration of bridges. Because the Markovian model is based on the assumption that future deterioration depends only on the current condition state, any other features of the bridge do not influence the prediction results.

The task of the Knowledge Model is to select a proper rehabilitation method when there are possibly one or more alternatives. The model uses decision trees and tables based on the Ministry's Structure Rehabilitation Manual and Structural Steel Coating Manual.

In the Cost Model, the cost estimates for project alternatives are based on tender item unit costs. The MTO updates the unit costs according to actual contracts continuously covering the different unit costs among the 12 districts in the province of Ontario. The MTO has a comprehensive cost database at the project-level, called the Project Value System (PVS) that is organized by tender item and is used for cost estimates. Each Tender Item object is responsible for examining the project scope for relevant treatments and to determine the total quantity of the Tender Item required. The Tender Item object then consults PVS for a standard unit cost, and may modify that unit cost based on any known information about the bridge or the project [18]. In the OBMS, there are approximately 50 treatment types.

The decision making process includes the following steps, which occur simultaneously: Monitoring, Needs identification, Policy development, Priority setting, and Budgeting and funding allocation.

MTO developed a new performance measure for bridge conditions, which is the Bridge Condition Index (BCI). It is digital assessment of the bridge conditions based on the remaining economic value of bridges.
BCI = (Current Replacement Value/Total Replacement Value)*100
Where:

$$Current\_Replacement\_Value = \sum(Quantity * Weight\_Facor * Unit\_Replacement\_Cost)$$

Weight_Factor = Excellent (1), Good (0.75), Fair (0.4), Poor (0)

Like other systems, OBMS has some strengths and weaknesses [12].
Strengths:

- Complete system linking inventory and inspection data to project and network analysis.
- System set up to easily customized forms of other jurisdictions through changes to database tables rather than programming.
- Data check-out and check-in feature to allow data to be extracted from a central server, updated on a field computer and then reloaded to the server, saving time and paper input.

Weaknesses:

- Database structure is complex because the system was designed to be customizable for other jurisdictions. Queries are therefore more complex and the system is more difficult to maintain.
- Ad-hoc reporting limited in current version, requiring more standard or custom reports.
- Performance is noticeably slower when connecting to the central server database compared to a local database. Network should have a 50 Mbps connection for acceptable performance.

3.6 Quebec

Quebec is one of the earliest provinces in Canada in which the government applied a computer-based system to support the bridge management. The Ministry of Transports of Quebec (MTQ) is responsible for a total of about 9000 bridges, of which 4300 are provincial bridges, 4400 are municipal bridges, and the remainder is retaining walls and other miscellaneous structures. Figure 8 shows the distribution of time of construction of transportation structures in Quebec.

MTQ started with a small system in 1985 and improved it since then. In the early 2000's, it dedicated to develop a new BMS with a consortium Dessau-Nurun-Stantec. The new system, called Quebec BMS (QBMS), is based on the same technical background as the OBMS, but it is a completely new development with a central database and the software divided in two main parts. The first part is for the inventory and inspection. It can be operated in a connected (at the office) or disconnected way (in the field). The second part is called the Strategic Planning Module and works on a standalone computer with a copy of the central database directly on the engineer workstation due to the great number of requests to the database which is inefficient through a network. The Strategic Planning Module is developed mostly by Stantec during 2005 to 2007.

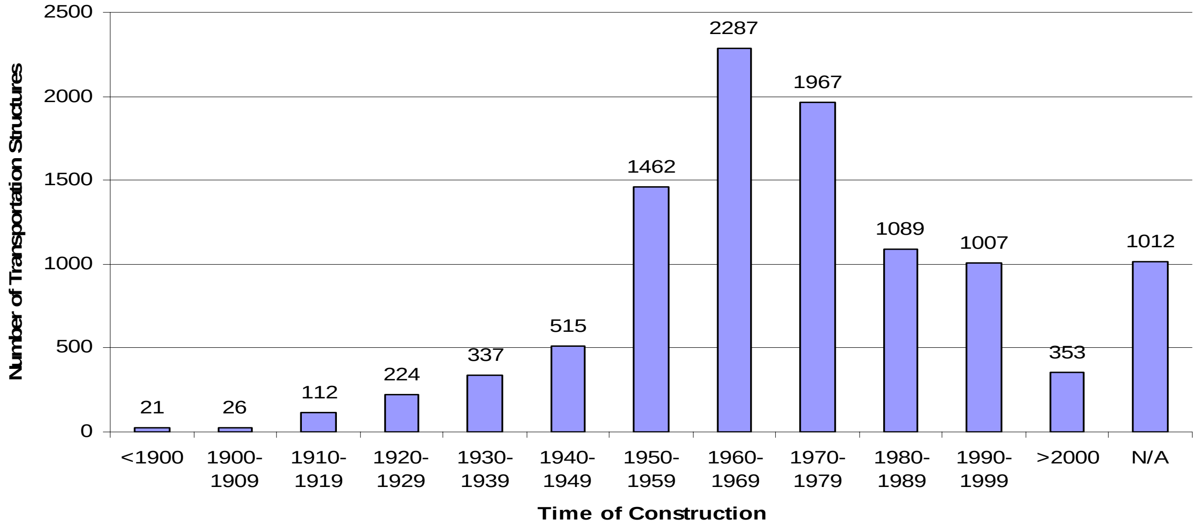

Figure 8. Distribution of Time of Construction Transportation Structures in

All activities are performed by the head office and 14 regional offices. Regional engineers would like to use the QBMS to develop information on life cycle costs and other performance measures, to help with decisions about project timing, scoping, cost estimation, and priority setting. Within the head office, the bridge office acts as an internal consultant, providing assistance to the regions as needed. In addition, the bridge office establishes standards and offers training. Each year the bridge office compiles budget proposals from the regions and forwards these proposals to the planning division. The bridge office provides technical support to planning during budget discussions. Together with the planning division, the bridge office develops regional performance goals. The planning division receives budget proposals from the bridge office and negotiates with the treasury board, via the deputy minister. At this level the major concern is the tradeoff between funding and performance. As each set of transportation interests competes for limited funding, the QBMS should provide a standardized set of information to show how the bridge-related budget proposals contribute to the overall ministry performance, and how changes in funding would affect this performance [13].

In the QBMS, there are five classes, which are inventory class, inspection class, project-level analytical class, network-level analytical class and model and policy class, and each class has data and functionality requirements associated with it. Figure 9 shows the structure of the domain model of QBMS [13].

The structure framework of the domain model of QBMS has the same general organization as the one of OBMS. Both have four types of branches from the class of structure. Then each class is customized to support similar functions. Furthermore, both systems have three levels, which are the element level, project level and network level. They have a relationship of one-way navigation.

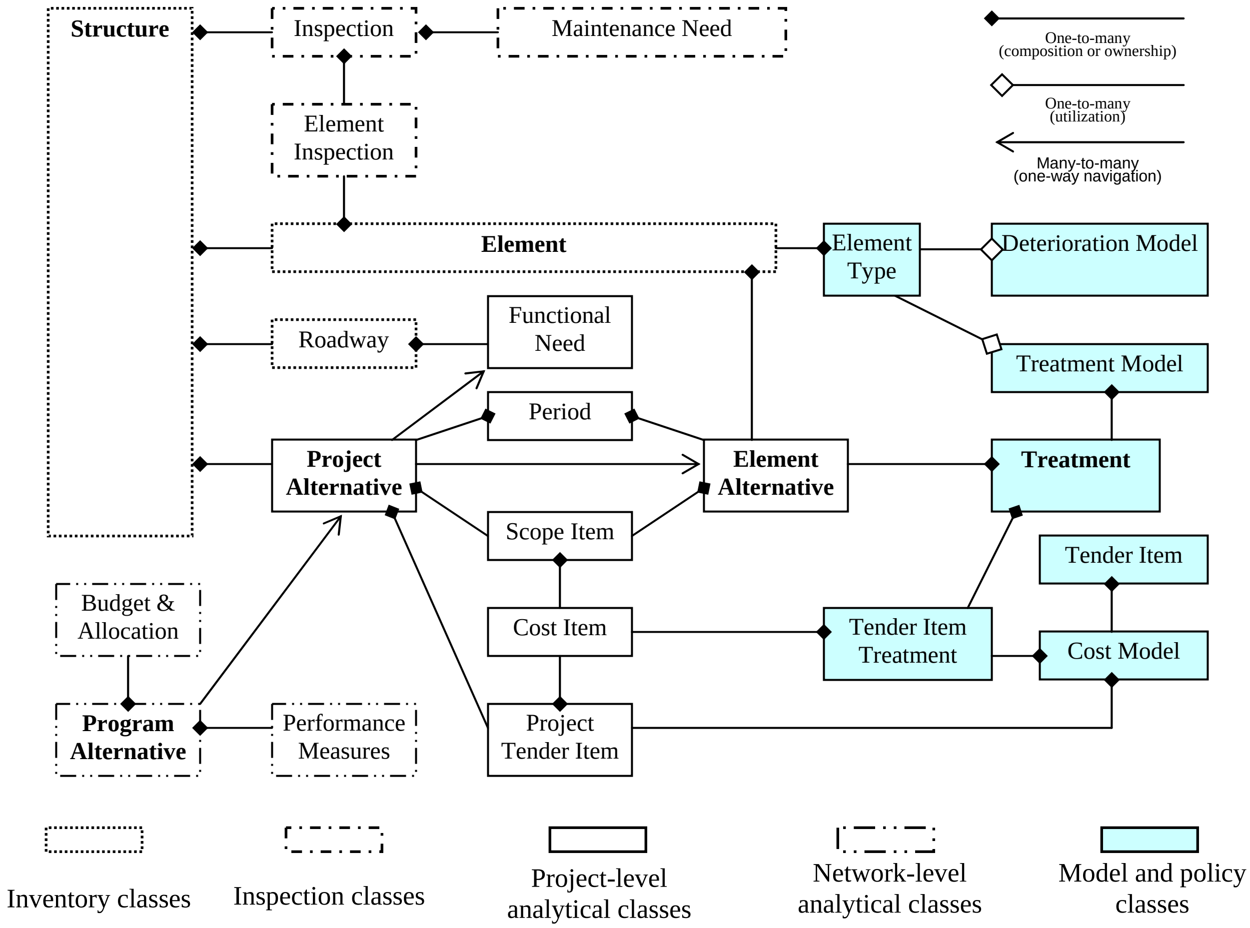

Figure 9. Structure of Domain Model of QBMS [13]

Inventory classes

Structure, *Elements*, and *Roadways* are the main physical assets managed in the QBMS. Roadway objects are important in the QBMS because they carry usage information, such as traffic and truck volumes. Elements are also essential to the QBMS because they organize condition data from inspections, and are the primary link between the inventory and the predictive models of the system.

Inspection classes

Inspection data in the QBMS are stored in a time series, so a typical structure has multiple inspections spaced at three-year interval. Each *Inspection* has a list of *Element Inspection* objects, describing the condition of each *Element* at the time of the *Inspection*. Also it has a list of maintenance needs identified by the inspection.

Model and Policy classes

These classes represent the “intelligence” of the QBMS, containing the analytical parameters, decision rules, and other general information that determines the behavior of the QBMS models. They are Deterioration Model, Treatment Model, and Cost Model. The Deterioration Model contains deterioration rates (transition probabilities) and rules for tailoring the deterioration rates to specific structures. The Treatment Model contains a list of *Treatments* considered relevant to a set of *Elements*. Each may have decision rules that determine whether the *Treatment* is feasible on specific structures based on service level standards. The Cost Model contains a list of *Tender Item Treatments*. Each Cost Model describes the cost estimation procedure for a single *Tender Item*, including its unit cost. *Tender Item Treatment* describes how to calculate the quantity of a *Tender Item* from the quantity of a Treatment.

Project-level analytical classes
To provide decision support information at the project level, the QBMS will create a related set of analytical objects describing the work alternatives available for each bridge. There are two levels of these objects: *Element Alternatives* and *Project Alternatives*. The Element Alternatives is responsible for a life cycle costing procedure that quantifies the benefits of performing the *Treatment*, given the condition predicted for that *Element* in that *Period*. Each *Project Alternative* describes a set of *Element Alternatives* and *Functional Needs* selected for implementation in a particular Period.

Network-level analytical classes
A *Program Alternative* is a set of *Project Alternatives* selected from among the *Structures* in the inventory, which satisfies constraints on total funding and the allocation of funding among parts of the inventory. The QBMS has an automated process for selecting the list of *Project Alternatives* in a way that maximizes program benefits and minimizes life cycle costs. Generation of a *Program Alternative* does not make any changes to the *Project Alternatives*, but merely determines which existing *Project Alternatives* will be presented in a priority list and budget analysis. As a part of selecting this list, the *Program Alternative* also accumulates total cost and performance statistics.

3.7 Prince Edward Island

The Department of Transportation and Public Works of Prince Edward Island is responsible for approximately 200 bridges and 1000 culverts. The material distribution is roughly 50% timber, 25% concrete and 25% steel for both bridges and culverts [12].

The department is currently embarking on obtaining a BMS software package called PEIBMS developed by the Stantec Company. The estimated cost of the initial development and conversion is $25,000.

3.8 Other provinces and territories

At present, other provinces and territories (New Brunswick, Newfoundland Labrador, and Saskatchewan, Northwest Territories, Nunavut, and Yukon) do not have a computer-based application system to support bridge management yet.

4. Unified Bridge Management Specifications

One of the major issues in Canada's bridge management is the lack of unified specifications for the inspection, maintenance, and rehabilitation because each province has its own specifications. For example there is no federal specification in Canada for the bridge inventory like its U.S.

counterpart “Specification for the National Bridge Inventory” developed by U.S. Department of Transportation [11].

The bridge inventory is developed to have a unified database for bridges including identification information, bridge types and specifications, operational conditions, and bridge data including geometric data, functional description, inspection data, etc. Identification information addresses the bridge location uniquely and classifies the type of the routes carried out on and/or under the structure. Bridge type and specifications classify the type of the bridge. This part provides defined standard categories for classifying bridges. It also identifies the material of the bridge components, deck and deck surface. Operational conditions provide information about the age of the bridge as well as construction year, rehabilitation year, type of services and traffic carried over and/or under the bridge, number of lanes over and/or under the bridge, average daily traffic, average daily truck traffic and information regarding bypasses, and detours. Furthermore, the bridge inventory contains information regarding geometry, inspection data, ratings assigned by inspectors and appraisal results. Table 2 summarizes the bridge inventory components.

Having such a unified data inventory and inspection procedures enables different provinces to have more collaboration. Also, it makes the data sharing and data exchange among provinces easier and faster especially in case of emergencies. Klatter and Thompson [7] stated that by using unified data specification and inspection procedures, transportation agencies are able to analyze data on a larger scale. Furthermore, it enables provisional agencies to get lesson learned by other provinces easily and it speeds up the development of common tools in BMSs in Canadian provinces.

Bridge Inventory Component	**Contents**
Bridge Identification Information	• Bridge location • Bridge spatial location • Identification of routes under and/or above the structure
Bridge Type and Specifications	• Type of the bridge • Deck, deck surface, and other bridge component materials
Operation Conditions	• Construction year, rehabilitation year • Type of services and traffic carried over and/or under the structure • Number of the lanes over and/or under the bridges, average daily traffic, average daily truck traffic and information regarding to bypasses, detours, etc.
Bridge Data	Geometry, inspection data, ratings and appraisal results

Table 2. Data Inventory Components

5. Conclusions

This paper reviewed the BMSs in Canada. OBMS is a typical representative of BMSs in Canada. QBMS and NSBMS are very similar to OBMS. OBMS offers a powerful, yet intuitive user interface and includes linkages to the Ministry's Bridge Document Image Management System, GIS mapping system, and tender item unit cost database. Element activities are based on Markovian deterioration models, which can be modified by knowledge-based factors. Project-level analysis and network-level analysis results are consistent because the network-level analysis is based on project-level models. Another BMS, the BEADS, in Alberta interacts with the corporate data storage and the other components of TIMS. It responds to highway network expansion plans and socio-economic decisions. Once the project-level analysis results have been determined, a network-level analysis may be performed to facilitate short-term programming, analysis of long-range budget scenarios, evaluation of the status of the network, and assessment of the impact of policy decisions. The paper also proposed developing a Canadian NBI to facilitate sharing the data and comparing performance measures as the user base in other provinces grows.

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