A Survey of the State of Bridge Management in Canada

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ABSTRACT

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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 in a systematic way in some provinces in Canada, this research aims at reviewing the current state of BMSs in Canada and suggesting an initiative to build a Canadian National Bridge Inventory. For example, 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. 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. After comparing the above BMSs, the research 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.A.

As a case study about the information that can be used in the CNBI, the database of Quebec BMS has been analyzed in detail and a graphical user interface (GUI) of Quebec

bridge database has been developed. The inventory part of this database is proposed as an example that can be modified in the future to be used as the base for the Canadian BNI.

Next, the database is used to perform some calculations related to replacement cost of bridges. The effect of three factors on the replacement cost of Quebec bridges are studied including the age of bridges, their structural type, and location. However, the current data are not enough to analyze the replacement cost. Therefore, personal records for each bridge to monitor bridge status from the design stage to the end of design service life should be included in bridge database.

Finally, a method for assessing Quebec bridges is explained. In addition, a new depreciation method is introduced based on the traditional straight line method and considering the effects of traffic volume. As the example demonstrated, the annual depreciation value and the depreciation period are related more closely to actual use. The proposed depreciation method would result in a more accurate assessment of bridge assets as capital stock.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AMAH	Alberta Municipal Affairs and Housing
ABM	Area Bridge Manager
BCI	Bridge Condition Index
BEADS	Bridge Expert Analysis and Decision Support
BMIS	Bridge Management Information System
BMS	Bridge Management System
CICA	Canadian Institute of Chartered Accountants
DOT	Departments of Transportation
FASB	Financial Accounting Standards Board
FBCL	Federal Bridge Corporation Limited
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GASB	Governmental Accounting Standards Board
GDP	Gross Domestic Product
GFOA	Government Finance Officers Association
GIS	Geographical Information System
GUI	Graphical User Interface
HBRRP	Highway Bridge Replacement and Rehabilitation Program
HiSMIS	Highways Structures Management Information System
MIMS	Municipal Infrastructure Management System
MR&R	Maintenance, Repair and Rehabilitation
MTO	Ministry of Transportation of Ontario
MTQ	Ministry of Transports of Quebec
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
NESS	Network Expansion Support System
NSBMS	Nova Scotia Bridge Management System
NSTPW	Nova Scotia Department of Transportation and Public Works
OBMS	Ontario Bridge Management System
OECD	Organization for Economic Co-operation and Development
OSIM	Ontario Structure Inspection Manual
PIM	Perpetual Inventory Method
PSAB	Public Sector Accounting Board
PVS	Project Value System
QBMS	Quebec Bridge Management System
RoMaRa	Roadway Maintenance and Rehabilitation Application
SQL	Structured Query Language
TCA	Tangible Capital Asset
TIMS	Transportation Infrastructure Management System

CHAPTER 1 INTRODUCTION

1.1 GENERAL BACKGROUND

The transportation systems of a nation play an essential role in its economy, and keeping these systems in good condition is vital for improving economic strength. As a developed country and the second largest country in the world, Canada has to heavily rely on a strong transportation system. Canada's transportation industry is an important support for Canada's economy. According to the report of Statistics Canada of January 2008, transportation and warehousing at basic prices contributed $56,772 millions to the Gross Domestic Product (GDP). This accounts for 5% of total industry output (Statistics, 2008). Road transportation plays an essential role in Canada's transportation system. There is a total of 1,042,300 kilometers of roads in Canada including 17,000 kilometers of expressways (Transportation, 2008). From Table 1.1 (Transportation, 2008), it is clear that road transportation makes a more important contribution to GDP than any other sector of the transport industry.

Table 1.1 Proportional contributions of various transportations to GDP (Transportation, 2008)

Industry	Share of Transportation GDP (%)
Air transportation	9
Rail transportation	13
Water transportation	3
Truck transportation	35
Transit and ground passenger transportation	12
Pipeline transportation	11
Scenic and sightseeing transport/Transport support	17
Total:	100

Although the transportation industry is such an important contributor to Canada's economic growth, overall investment in the transportation industry is not as high as in other industries. In 2005, investment needs for urban roads and bridges is much higher—$66 billion over 10 years. The municipal infrastructure gap as a percentage of national GDP has grown from 2.7% in 1984 to 5.0% in 2002. The municipal infrastructure gap is growing by $2 billion per year. Canada's infrastructure gap is estimated to be between $50 billion and $125 billion, which is 6-10 times the level of all current annual government infrastructure budgets combined. Canada's large western cities (Vancouver, Edmonton, Calgary, Saskatoon, Regina, Edmonton, and Winnipeg) reported an infrastructure deficit of $564 million in 2003. The current cost estimate to rehabilitate Canada's civil infrastructure system at the municipal level is $57 billion, which only represents 70% of Canada's total civil infrastructure (CCPPP, 2005). All of the above data indicates that investment for infrastructure is not enough to balance the growing deficit.

In Quebec, the situation seems somewhat better after the collapse of the La concorde overpass in Laval. Ministry of Transportation Québec (MTQ) plans to spend $500 million a year for 10 years on bridge and overpass repair and construction. On October 19th, 2007, the MTQ announced that the province's objective is to restore 83% of roads and 80% of structures to good condition within 15 years. A total of $11.6 billion will be invested over the next four years to complete the first five-year plan, $3.5 billion (29%) of which will be allocated to conservation of structures (Freek, 2007).

Bridges are critical part of infrastructure systems. The boom period for bridge construction in North America was the 1950s and 1960s. Therefore, most bridges are aging, sometimes with tragic consequences. Five people were killed after a section of De La Concorde overpass in Laval collapsed on September 30, 2006 onto the road below and crushed two vehicles (Mahoney, 2006). According to the report of commission of inquiry into the collapse, one reason of the accident is the lack of a condition evaluation of the structure (Johnson et al., 2007). Figure 1.1 shows the site of the collapsed overpass. Another recent accident is the collapse of the 35W Interstate Bridge over the Mississippi River, which killed 13 people in August 2007 (CNN, 2007). Figure 1.2 shows the site of this collapsed bridge.

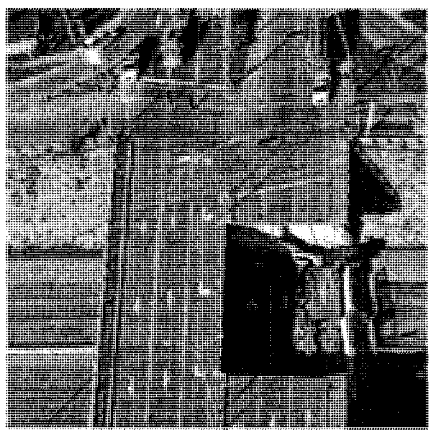


Figure 1.1 Site of collapsed overpass in Laval (Mahoney, 2006)

These two tragedies warn us that bridge management is a matter of life and death. It is crucial to manage bridges which are close to the end of their lifecycle or have passed the half-way point. Indeed, in the U.S., the National Bridge Inspection Standards (NBIS) came into being in 1971 after the Silver Bridge collapsed in 1967 (FHWA, 2002). Subsequently, other manuals were issued by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials

(AASHTO) (1993). In Canada, however, at present bridge management is under the control of the provincial governments. It is time for Canada to establish a national standard for bridge management systems.

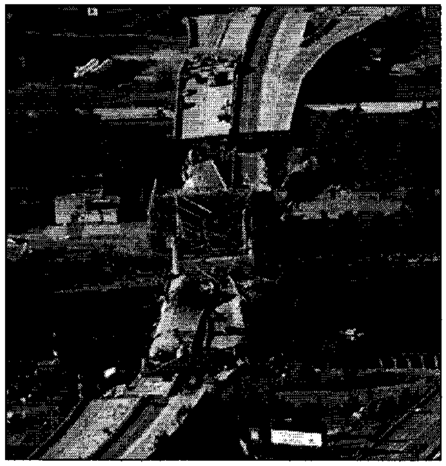


Figure 1.2 Site of collapsed bridge over Mississippi River (CNN, 2007)

Canada is in the midst of a "bridge crisis", especially after the latest collapse of the bridge in Laval City (Couvertte, 2006). 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.

More than 40% of the bridges currently in use in Canada were built over 50 years ago (Bisby, 2004), and a significant number of these structures need strengthening, rehabilitation, or replacement, using limited maintenance budgets. In Canada, the rehabilitation needs for the bridges are about $0.7 billion annually because 83% of all bridges need some sort of repair (Mirza and Haider, 2003). The highway-funding deficit estimated by TRIP Canada (The Road and Infrastructure Program of Canada) is more than $22.6 billion in 2006 (Miller, 2006). 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 (Miller, 2006). The two latter programs are used to finance roads and highways.

In order to solve these issues above, the Public Sector Accounting Board (PSAB) in Canada released a recommendation, which is that municipalities should record and report their capital assets in their financial statements. The recommendation could be a good way to allocate the limited funds to needs of the asset of bridges.

1.2 RESEARCH OBJECTIVES

Efforts in this research are directed towards exploring the current state and future development of bridge management in Canada. Our specific research objectives are:

(1) To survey the recent state of bridge management in Canada and the U.S.A., to propose specifications for a unified bridge inventory in Canada, and to analyze the Quebec Bridge Inventory, which can serve as a model for a Canadian National Bridge Inventory.

(2) To assess the value of Quebec's bridges and analyze the factors which influence bridge replacement cost. This assessment would be useful for bridge capital asset management as part of the new requirement from PSAB.

1.3 THESIS ORGANIZATION

This study will be presented as follows:

Chapter 2 Literature Review: First, This chapter presents the definition and components of bridge management systems (BMSs). Next, we describe BMSs in the U.S.A.: National Bridge Inventory, Pontis, and Bridgit. After this, the accounting concept of bridges as tangible capital assets will be explained from two sources: GASB 34 in the U.S.A. and PSAB in Canada. Finally, the application of the perpetual inventory method in bridge management systems will be reviewed.

Chapter 3 Survey of Bridge Management systems in Canada: This chapter introduces the BMS of each province in Canada. Information has been collected based on literature review, on-line survey, and direct communications (telephone calls and emails) with agencies and engineers related to BMSs including Statistic Canada, Transport Canada, Infrastructure Canada, and all provincial transportation agencies in Canada. In addition, detailed information about the BMS in Quebec has been obtained from the MTQ including the database of bridges of Quebec and the GIS data of bridges. Based on the above survey, the specifications for a Canadian bridge inventory are proposed.

Chapter 4 Case Studies: In this chapter, a perspective for a Canadian national bridge inventory and a graphical user interface example for a Quebec bridge database are introduced, in the hope that this will provide a paradigm for a Canadian National Bridge Inventory. Then, Quebec bridge replacement cost analysis and the assessment of bridges in Quebec will be presented as examples of using the Quebec bridge database based on structure type, construction period and location.

Chapter 5 Summary, Contributions and Future Research: This chapter summarizes the present research, highlights its contributions to the filed of bridge management, and suggests recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 BACKGROUND

The collapse of the Silver Bridge at Point Pleasant, West Virginia, in 1967 aroused people to emphasize on safety inspection and maintenance of bridges. In 1968, the FHWA created the National Bridge Inspection Program (NBIP) to address the problem of safety of bridges (Czepiel, 1995). This program mandated every Department of Transportation (DoT) in the U.S.A. to keep track of the condition of bridges under their jurisdiction. Data collected from applying the NBIP were submitted after every inspection cycle to the FHWA to be included in the National Bridge Inventory (NBI) database. Once again, the two tragedies mentioned in Chapter 1 emphasized that improvement of bridge management should not be delayed.

2.2 ASSET MANAGEMENT

Asset management is a framework for making cost-effective resource allocation decisions. It is based on a wide systems view of all the assets (e.g. roads and bridges) under the transportation agency's umbrella, and it reflects an extended time horizon. Figure 2.1 shows the components of a generic asset management system (Asset Management Primer, 1999).

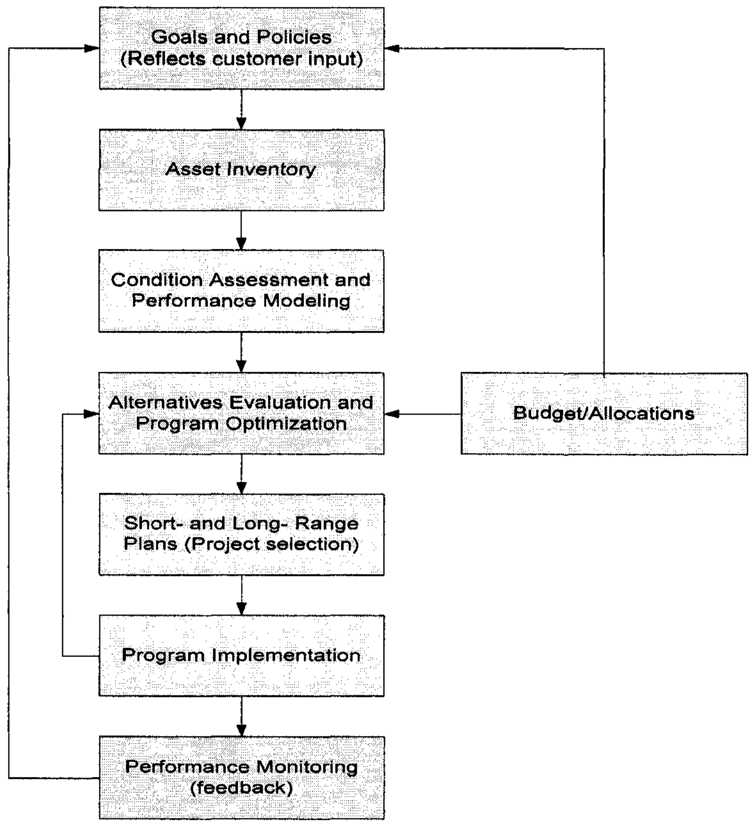


Figure 2.1 Generic asset management system components (Asset Management Primer, 1999)

The process works as follows: first, performance expectations, consistent with goals, available budgets, and organizational polities, are established and used to guide the analytical process, as well as the decision-making framework. Second, inventory and performance information are collected and analyzed. This information provides input on future system requirements. Third, the use of analytical tools and reproducible procedures produces viable cost-effective strategies for allocating budgets to satisfy agency needs and user requirements, using performance expectations as critical inputs. Alternative choices are then evaluated, consistent with long-range plans, policies, and goals. The entire process is reevaluated annually through performance monitoring and systematic processes.

The asset management approach is a logical sequence of decision steps, constituting a decision framework. The framework is supported by (1) information regarding organizational goals, policies, and budges, (2) horizontal and vertical organizational integration to implement the decision steps in practice, and (3) technical information to support the decision-making process.

Technology enables an asset management system to function. Asset management relies on technology in two key areas. First is the collection, storage, and analysis of data. For example, with the advances in geographical information system (GIS) and global positioning system (GPS), the important spatial component of analysis can be more fully explored. A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, reports, and charts. The second important aspect of technology relates to the presentation and communication of the analytical results to decision makers inside and outside the agency.

The key asset management system components include (McNamee et al., 1999):

- asset inventory database linked to a GIS
- asset valuation processes
- performance measures and standards
- condition assessment processes
- asset management planning/programming systems

- asset renewal/replacement analysis methods
    - life-cycle costing
    - cost-effectiveness analysis
    - equivalent annual cost
    - longevity cost index
- asset disposal policies and procedures

2.3 DEFINITION AND COMPONENTS OF BRIDGE MANAGEMENT SYSTEMS

Just as bridges have developed from primitive structures to modern bridges, so too has bridge management developed from the traditional card index system to modern computer-based systems. Whether traditional or modern, a Bridge Management System (BMS) enables the bridge manager to be kept fully informed of the "health" of the bridges under his control, and to make informed decisions about future maintenance activities (Ryall, 2001).

There are different components for different individual BMSs. But every BMS includes some basic components that make it a fully integrated system, able to analyze the data and then to promote interaction with other components, as well as the integration of incoming information (Ryall, 2001). However, basically all BMSs will have modules dealing with *Inventory, Inspection, maintenance, and Finance*. Embracing, analyzing and processing all of this information will be the management control.

A basic BMS, including the components mentioned above, is shown diagrammatically in Figure 2.2 (Ryall, 2001). The Highways Structures Management Information System (HiSMIS) was a typical BMS developed by High-Point Rendel (HPR) in the UK. The System Administration module allows the user to adjust and maintain the system for its particular use. The HiSMIS database is made up of five modules (History, Inventory, Inspection, Maintenance/financial and Programme/study) which provide all relevant input information for the system. The output is via the Enquiry and reporting suite made up of seven modules. The Enquiry and reporting stage is very important and the output must be what the enquirer wants.

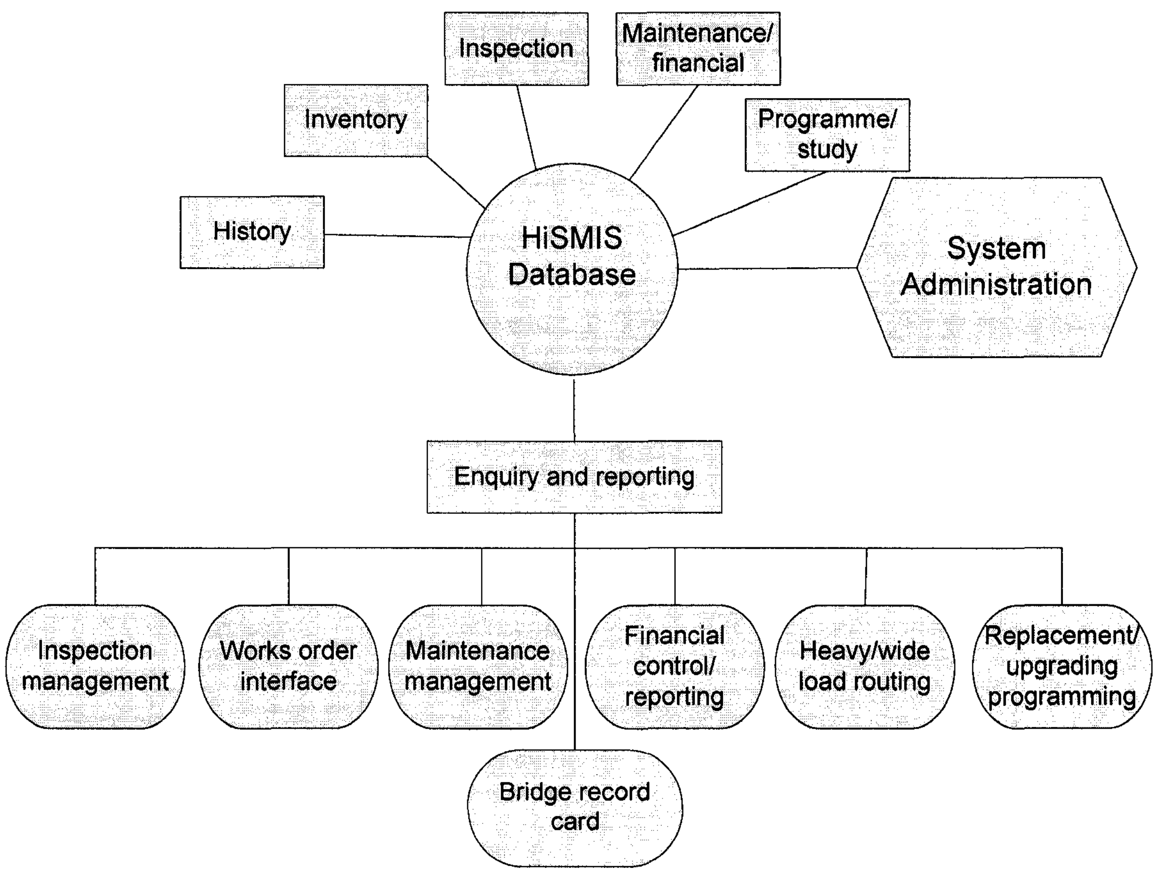


Figure 2.2 Basic structure of BMS (Ryall, 2001)

The management of bridges involves a large number of activities, which are broadly grouped as follows (Das, 1999):

- structure inventory details
- inspection
- assessment
- maintenance bids, prioritization and allocation
- works data and outturn
- network structures condition monitoring
- planning and forecasting
- database

2.4 BRIDGE MANAGEMENT SYSTEMS IN THE U.S.A.

The U.S.A. has advanced two important organizations, the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO). These organizations play very important roles in bridge management in the U.S.A. For instance, they enact inspection standards and regulations about bridge management as part of their responsibilities.

The FHWA developed Pontis, which uses the network-level, top-down approach to bridge management. The AASHTO originated Bridgit, a project-level program, which works from the bottom-up. Figure 2.3 shows these two kinds of BMSs (Thompson, 2008).

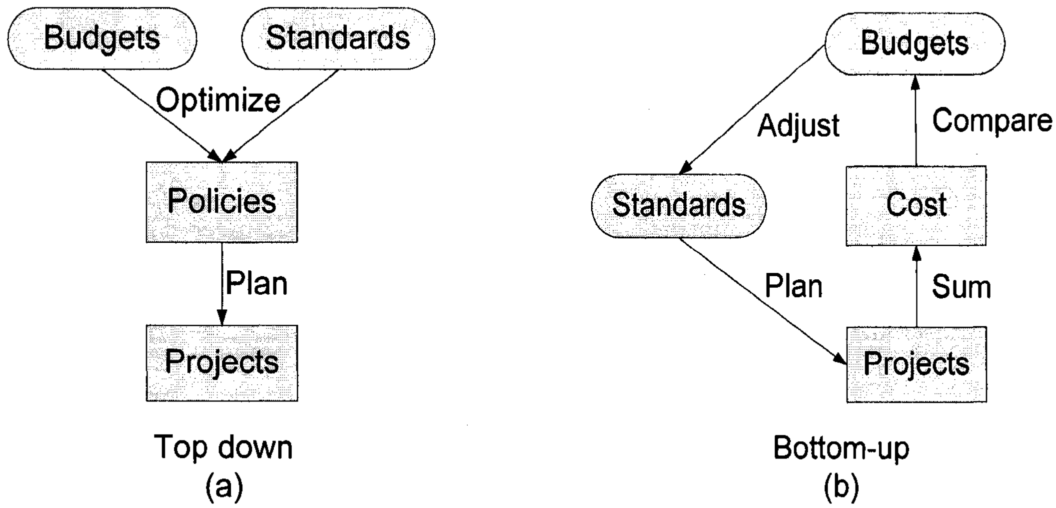


Figure 2.3 Two approaches used in BMSs (Thompson, 2008)

A top-down approach such as the approach of Pontis is often used to analyze and develop optimal treatment policies at the network-level. Then engineers can apply these policies to individual bridges to develop project-level recommendations with estimates of cost and benefits (Figure 2.3 (a)). A bottom-up approach exemplified by Bridgit is more useful for analyzing one or more alternative strategies for any given individual bridge (Figure 2.3 (b)). These accumulated alternatives at the network level determine budgetary requirements and performance. Then decision-making at the project level is adjusted until the budget limitations at the network level are satisfied (Thompson et al., 2000).

2.4.1 National Bridge Inventory

The National Bridge Inventory (NBI) is a database compiled by the FHWA, containing information on all bridges and tunnels in the U.S.A. (Nationalbridges, 2008). The NBI consists of these components: *identification information, bridge types and specifications, operational conditions, geometric data, functional description,* and *inspection data* (National, 2008).

Identification information addresses spatial bridge location exclusively and classifies the type of 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 classification of the bridges. It also identifies the material of the bridge components, deck and deck surface. Operational conditions provide information about the age of the structure as well as 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 and detours. Furthermore, the bridge inventory contains information regarding to inspection data, ratings assigned by inspectors and appraisal results (National, 2008). More details about the NBI are given in Appendix D.

2.4.2 Pontis

Pontis was developed by the FHWA in conjunction with six State Departments of Transportation (DOTs) and the consultant joint venture of Optima, Inc. and Cambridge Systematics (Wolfgram, 2005). 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 to support workshops in almost every state seeking 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, the National Cooperative Highway

Research Program (NCHRP), and five other states, representing a wide range of bridge environments and size (Czepiel, 1995).

Pontis includes many innovative features. The condition data included in the system are more detailed than the requirement of the NBI (NBI, 2006). The bridge is divided into individual elements or sections, 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 (Pontis Bridge Management, 2005). 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 budget or delaying a certain action (Technical Manual of Pontis, 2005).

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 (Thompson et al., 2003). 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 (Czepiel, 1995).

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 budgetary decisions 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 (Thompson et al., 2003).

2.4.3 Bridgit

Bridgit is a BMS developed by the NCHRP and National Engineering Technology Corporation (NETC) (Wolfgram, 2005). This project began in 1985 and completed its initial testing in 1993. The beta test was underway with a total of 8-10 states in 1995 (Czepiel, 1995). 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 until 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 the scheduling and tracking of MR&R activities, keeping a history of MR&R, estimating the cost of MR&R, and creating and maintaining a list of MR&R actions (Wolfgram, 2005).

2.4 ACCOUNTING OF TANGIBLE CAPITAL ASSETS

2.4.1 GASB 34 in the U.S.A.

The Governmental Accounting Standards Board (GASB) was set up in 1984 by the Financial Accounting Foundation. The GASB has been working to improve accounting and financial reporting standards for state and local governments. It is a private and non-profit organization consisting of seven members and a full-time staff. Like the Financial Accounting Standards Board (FASB), which sets accounting standards for private companies, the GASB is funded by the Financial Accounting Foundation.

In 1999, the GASB approved a new financial reporting standard that will fundamentally change the way that state and local governments report their financial results. GASB Statement 34 (GASB 34) is a basic financial statement about management's discussion and analysis for state and local governments. In GASB 34, revenues and costs are accounted for as they occur; and costs may not be shifted to a future year by delaying payment (Primer: GASB 34, 2000). Therefore, all long-lived capital assets, including infrastructure such as roads and bridges, should be reported in state and local government financial statements.

In basic financial statements, there are two statements: a government-wide financial statement and a fund financial statement. The government-wide financial statement consists of a statement of net assets and a statement of activities. The fund financial statement includes governmental funds, proprietary funds, and fiduciary funds.

The key requirement related to infrastructure in GASB 34 is to require all current and long-term assets and liabilities to be reported within the balance sheet of the government-wide financial statements. GSAB 34 concludes that in infrastructure asset reporting it is essential to provide information about financial position and changes in financial position, and about the cost of program and functions (GASB, 1999).

The key infrastructure features of GASB 34 are as follows:

- Infrastructure will be included in the asset base
- Infrastructure will be reported at historical cost
- Infrastructure will be reported at the network, subsystem, or individual asset level
- Infrastructure will be depreciated or reported using a modified approach

Therefore, there are several significant steps in the implementation of GASB 34. First, governments preparing to implement GASB 34 should study its requirements and those of related statements. Second, resources are of paramount importance in implementing the new financial reporting model which GSAB 34 introduced. Third, government should identify the information necessary to convert fund-based statements to government-wide statements and determine whether this information is currently available in government reporting systems. Then, governments must report revenues on an accrual basis in government-wide statements in accordance with Statement 33. Last, data on infrastructure assets are a required part of the new financial reporting model, and governments must decide when to begin recording them retroactively (Chase et al., 2001).

To report infrastructure cost of use, the GASB 34 provides two approaches: the traditional approach (depreciation) and the modified approach (preservation). The traditional approach (depreciation) is an annual valuation of the asset which uses the deflated historical costs, and depreciates those costs using (typically) straight-line depreciation over the estimated life of the asset. The costs of any preservation activities are included in the capitalization, and depreciated along with the historical costs. The modified approach (preservation) is applicable to assets that are long-lived relative to other types of capital assets and which can be preserved, through maintenance, repair and rehabilitation, for a significant period of time relative to their original service life. Preservation costs are included in the capitalization of the asset, but are not depreciated (Ellis et al., 2007).

As for methods of depreciation, there is straight line depreciation method (SLDM), which is often used on the depreciation for infrastructure. Other methods include declining balance depreciation method (DBDM), units of production method (UPM), and income forecast method (IFM). SLDM and DBDM use years as their basic factor. UPM and IFM, however, are related to the use of an asset or its production of income.

2.4.2 Accounting for Infrastructure in the Public Sector in Canada

The Canadian Institute of Chartered Accountants (CICA) recently required local governments to recognize capital expenditures as capital assets and to depreciate them over their expected useful life. This requirement is to come into effect for the 2009 reporting year. As a board within CICA, the Public Sector Accounting Board (PSAB) is responsible for setting the accounting and financial reporting standards for all levels of government in Canada.

In 2002, the PSAB released a research report entitled *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.

In the report, the definition of tangible capital asset is introduced. A tangible capital asset (TCA) is: "A significant economic resource managed by governments and a key component in the delivery of many government programs (Tangible 1, 2006)." It means that local governments in Canada will be required to record, report and amortize TCAs over their expected useful life. The annual amortization is to be recorded as an expense.

Local governments will gain a better appreciation of their infrastructure assets stock and the costs of using these assets. This will lead to improved decision making and accountability in the management of capital resources. In addition, better information will be available to determine future funding requirements and to establish user fees and tax rates. The new requirement for the PSAB has some additional future benefits (Tangible 2, 2007): better asset management, improved data to support funding needs and to explain the level of taxes and user fees, improved capital planning and data for reporting, 'first step' towards building a corporate infrastructure strategy and determining the value of a municipality's infrastructure deficit, and more accurate assessment of the cost of capital items and improved transparency in reporting.

Meeting the TCA requirement is also the first step towards determining the gap between infrastructure needs and available funding. TCAs are to be recorded at historical cost. A properly developed asset management system including replacement costs needs to be implemented to fully determine the 'infrastructure gap'.

TCAs represent a significant part of a government's assets. Therefore, non-compliance will probably result in a 'qualified' audit report. 'Qualified' reports attract concern and suspicion to an organization's operations, and future financial planning may thus be hampered.

To meet the new local government accounting standard by 2009, planning and project work has begun in earnest in municipalities across Canada (Tangible 5, 2007). At present, implementation manuals have been prepared by Ontario, as well as Saskatchewan, Alberta, British Columbia, and Nova Scotia. Quebec already has a TCA policy. The following paragraphs explain about the step to implement the new requirement in Alberta.

Alberta Municipal Affairs and Housing (AMAH) has taken a leadership role in enabling Alberta municipalities to develop technical materials and information, and in sponsoring training sessions.

The strategies of PSAB include the following (Tangible 2, 2007): establishing a Liaison Committee, drawing on the expertise of the Government Finance Officers Association (GFOA) members, providing funding for consultants to co-ordinate the project and prepare reports for sub-projects, such as valuation and balanced budget legislation, preparing quarterly newsletters for municipalities and municipal organizations, making use of materials and experience from other provinces, the GASB and PSAB, and including the accounting profession and other key stakeholders at all stages of the project.

Because this requirement is to be completed and reported for 2009 with a progress report in the financial statement notes beginning in 2007, there is much to be done in a short period of time. The Alberta GFOA has furthered the implementation of PSAB requirements by developing materials on the following specific topics: asset classification, amortization methods and useful life, capitalization thresholds, resources required, developing an implementation plan and budget, and networks, components and segmentation.

The GFOA and AMAH hosted a series of regional workshops. The TCA session focused on overall requirements and on how to prepare an implementation plan and a budget (Tangible 3, 2007). In Alberta, the Municipal Infrastructure Management System (MIMS) already maintains some of the TCA required information for each asset, such as asset description, location, and installation year (Tangible 7, 2008). PSAB provides $5 million in provincial funding for the TCAs project, allocated to help municipalities (Tangible 6, 2008).

2.4.3 Capital Stock of Infrastructure and Bridges in Canada

In 2003, Statistics Canada made a study about the age of public infrastructure in Canada. This study examined the aging of the four main components of engineering infrastructure, owned by governmental agencies, over the past 40 years: roads and highways, sewer systems, wastewater treatment facilities and bridges. In this study, assumed service lives of roads and highways, sewer systems, wastewater treatment facilities and bridges are 28, 35, 29, and 46 years, respectively. Figure 2.4 shows that bridges and wastewater treatment facilities have been aging almost without interruption since 1977, while the age of sewer systems has fallen slightly since 2001. Wastewater treatment facilities, the oldest infrastructure, had 63% of their useful life behind them in 2003 (Figure 2.4). Bridges, the youngest infrastructure, had reached 49% of their useful life. Road and highways had reached 59%, and sewer systems 52% (Gaudreault and Lemire, 2006).

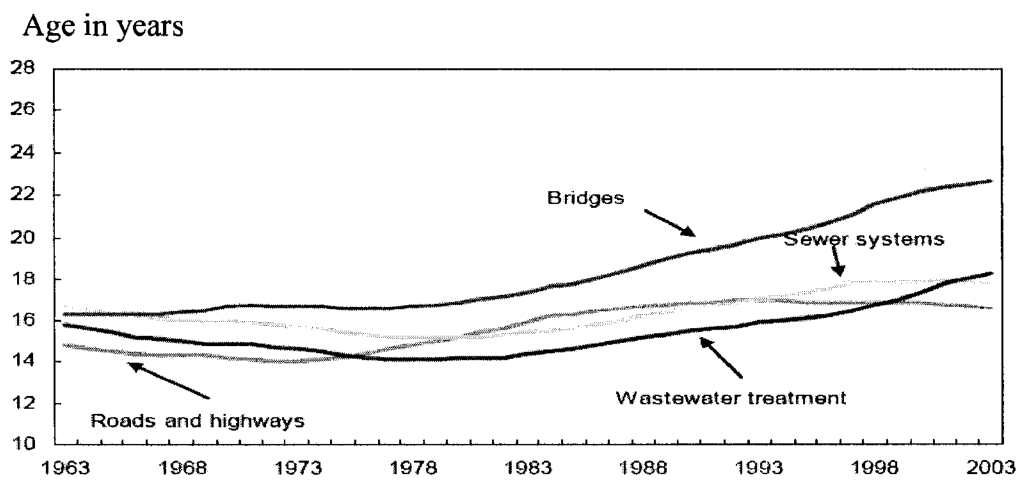


Figure 2.4 Average age of asset types (Gaudreault and Lemire, 2006)

From Figure 2.5, we can see that the average age of four components was 14.7 years in 1973. By 1999, this figure had increased to 17.5. In 2003, it went down to 17.4. A key factor in the slower pace of aging recently is a huge jump in investment in roads and highways, which has tended to rejuvenate the transportation network (Gaudreault and Lemire, 2006).

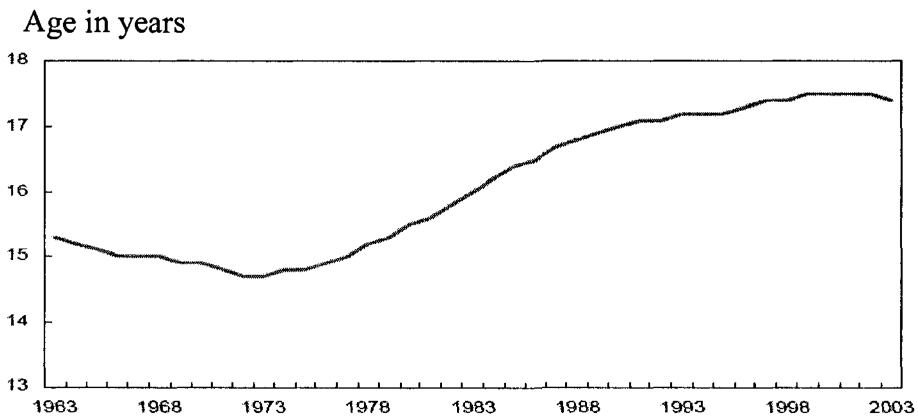


Figure 2.5 Average age of the four types of infrastructure (Gaudreault and Lemire, 2006)

Figure 2.6 shows that provincial and municipal infrastructure became younger, while the average age of federal infrastructure remained virtually unchanged. Nevertheless, federal infrastructure was already older than provincial and municipal infrastructure.

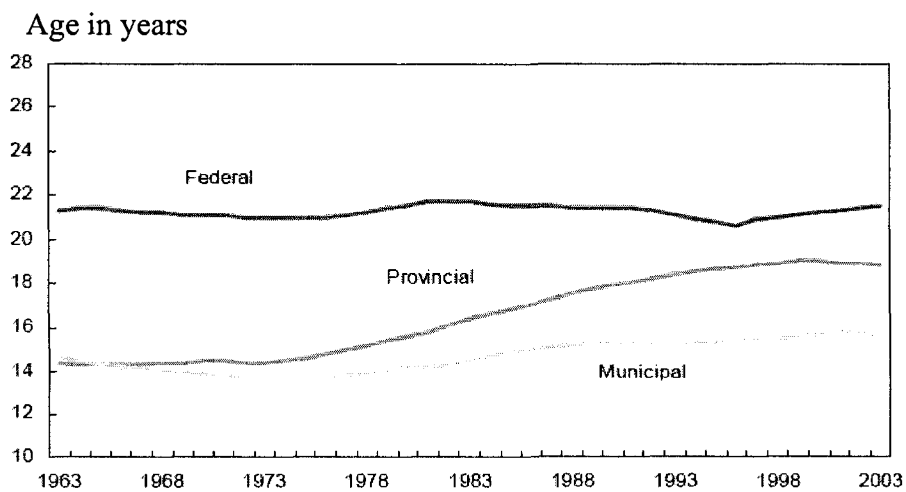


Figure 2.6 Average age of the four types of infrastructure, by level of government (Gaudreault and Lemire, 2006)

Provincial infrastructure aged the most, its average rising from 14.4 years to 18.8 years between 1963 and 2003. The age of municipal infrastructure also increased, though to a lesser extent (Gaudreault and Lemire, 2006).

By 2003, federal and provincial bridges had passed the halfway mark of their useful lives; 57% in the case of federal bridges and 53% in the case of provincial (Figure 2.7) (Gaudreault and Lemire, 2006). In contrast, municipal bridges were younger, and had only 41% of their useful lives behind them.

As shown in Figure 2.8, Canadian bridges at the municipal level began to decline slowly in the mid 1980s, after which the ratio of the national tangible produced capital stock becomes stable. In contrast, provincial bridges experienced a steady decline, as shown in Figure 2.9 (Harchaoui et al., 2003).

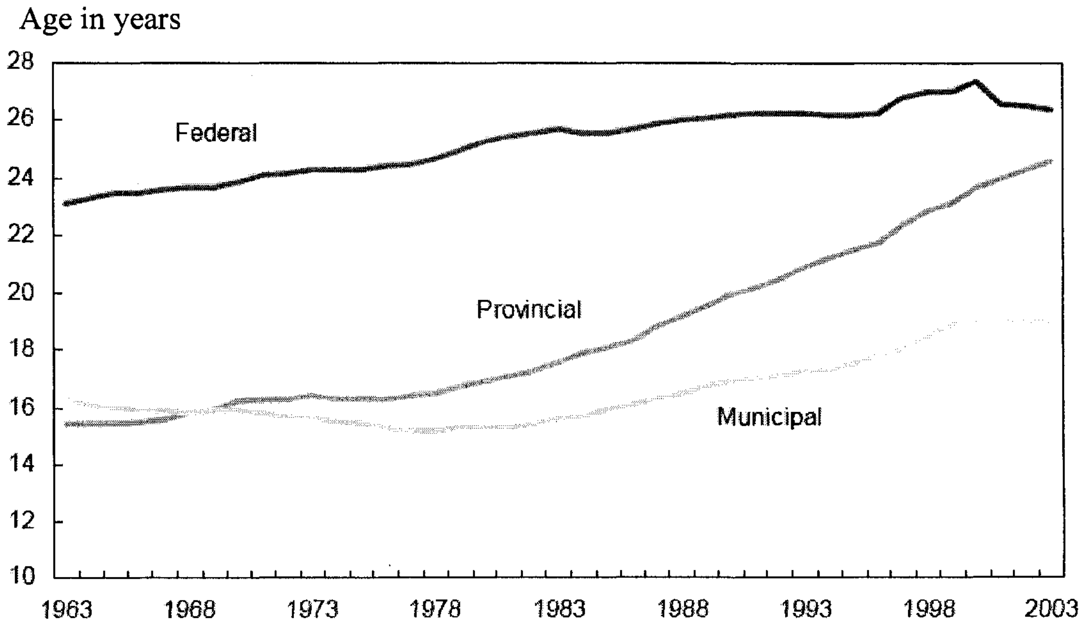


Figure 2.7 Age of bridges, by level of government (Gaudreault and Lemire, 2006)

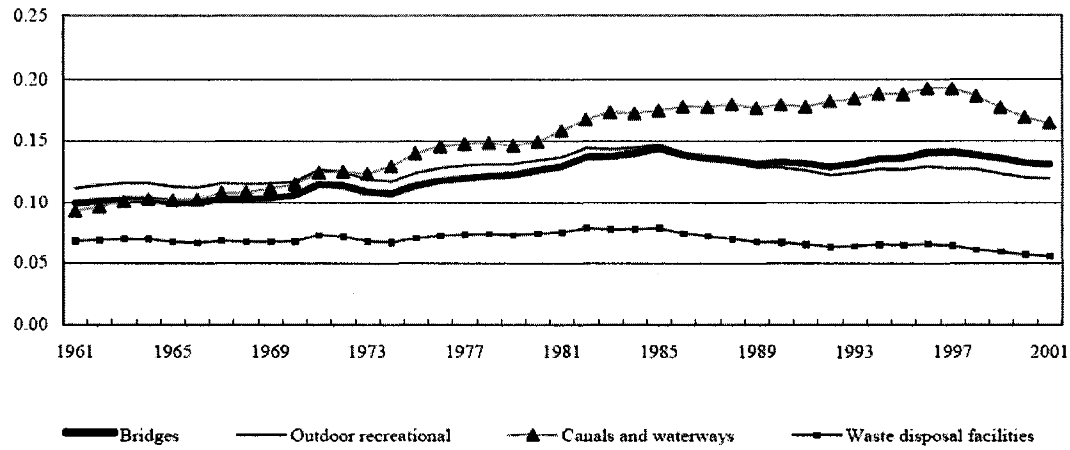


Figure 2.8 Share of the local government infrastructure capital stock by asset class in the National Tangible Produced Capital Stock (percentage) (Harchaoui et al., 2003)

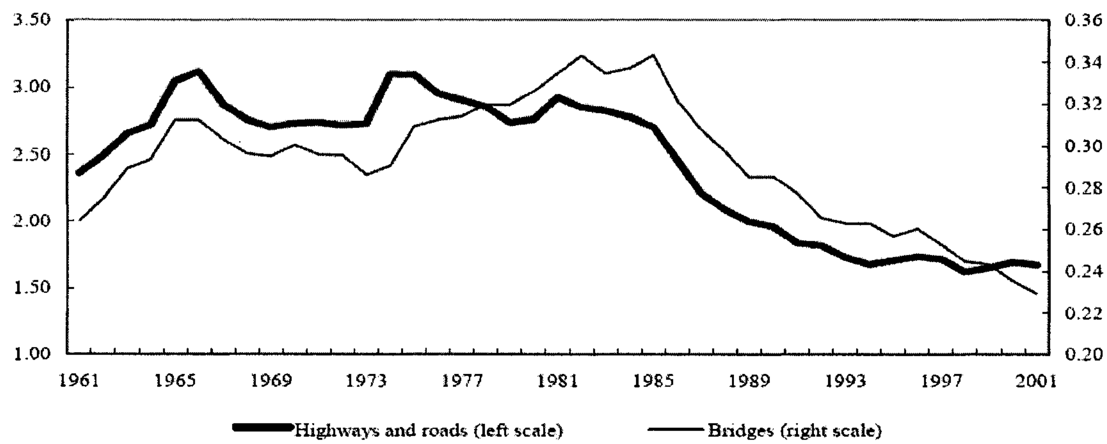


Figure 2.9 Share of the provincial government infrastructure capital stock by asset class in the National Tangible Produced Capital Stock (percentage) (Harchaoui et al., 2003)

2.4.4 Highway Infrastructure Asset Valuation in the UK

In the UK, asset valuation is reported annually in the organization's Balance Sheet and is one of the key components supporting Whole of Government Accounts (WGA) and public sector financial management. Asset valuation is an important mechanism for demonstrating proper stewardship of public assets and provides a means for quantifying the capital employed in the assets and the cost of use of the assets in delivering services to the public.

The UK government introduced new Resource Accounting and Budgeting (RAB) procedures for all government departments. WGA extends the RAB agenda by developing a consolidated standard and processes for the whole of the public sector in one set of accounts. Figure 2.10 shows the procedure of asset valuation particularly for highway infrastructure (Roads Liaison Group, 2005). In this method, the first step is to establish the principles, basis and rules for asset valuation. These should comply with the valuation requirements given by RAB. The second step is to compile an Asset Inventory that provides the base data for calculating asset values for all highway infrastructure assets. The third step is to produce the initial value of the highway infrastructure assets. This involves: (1) Deriving appropriate Unit Rates for the different asset groups and sub-groups; and (2) Calculating the Gross Replacement Cost for each asset within a group or sub-group. The fourth step is calculating the consumption of the assets, which involves: (1) Calculating in-year depreciation; and (2) Assessing for in-year impairment and calculating loss in value where required. The fifth step is to calculate the Depreciated Replacement Cost. The last step is to prepare the Valuation Report.

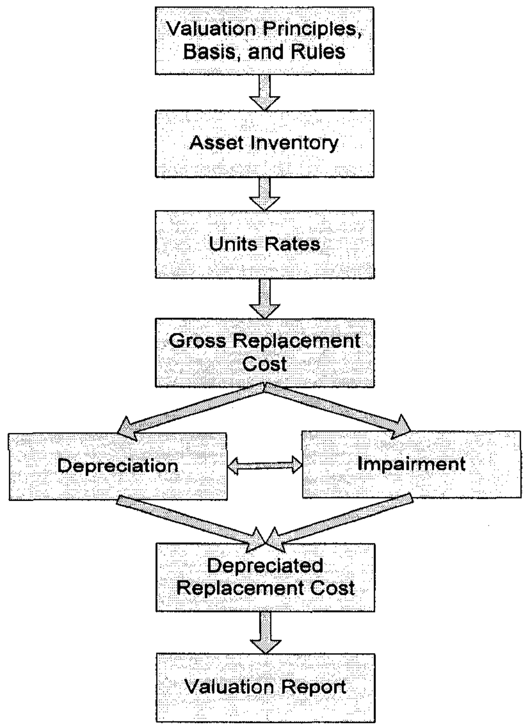


Figure 2.10 Overview of the procedure for highway infrastructure asset valuation (Roads Liaison Group, 2005)

In general, the replacement cost is an all inclusive replacement construction costs and should include all direct and indirect costs such as planning and engineering, construction, construction supervisor, traffic accommodation, etc. In addition to these costs, however, some agencies, such as Florida DOT, also include "product support" costs such as materials and research costs (Ellis and Thompson, 2007).

2.5 THE APPLICATION OF THE PERPETUAL INVENTORY METHOD IN BRIDGE MANAGEMENT SYSTEMS

The perpetual inventory method (PIM) is a method of constructing estimates of capital stock and consumption of fixed capital from the time series of gross fixed capital formation. PIM allows an estimate to be made of the stock of fixed assets in existence and in the hands of producers. This estimate is generally based on assessing how many of the fixed assets -- those installed as a result of gross fixed capital formation undertaken in previous years -- have survived to the current period (OECD, 2003).

Using the PIM, gross capital stock is calculated as the sum of previous gross fixed capital formation of which the service life is not yet expired. In order to apply the PIM, two requirements must be met. They are: (1) long time series of data on gross fixed capital formation must be available; (2) price index numbers for the revaluation of gross fixed capital formation of previous years should be available. Probably the most difficult element in these requirements is obtaining estimates of service lives detailed by type of asset and industry. In addition to the statistical data, assumptions must be made about the discard patterns and the depreciation pattern, which are part of the PIM (Meinen et al., 1998).

Alternative approaches exist for the discard patterns, using more elaborate survival functions. The gross capital stock, the depreciation model and the net capital stock can be determined by a general survival function.

Four typical survival functions are illustrated in Figure 2.11(OECD, 2001).

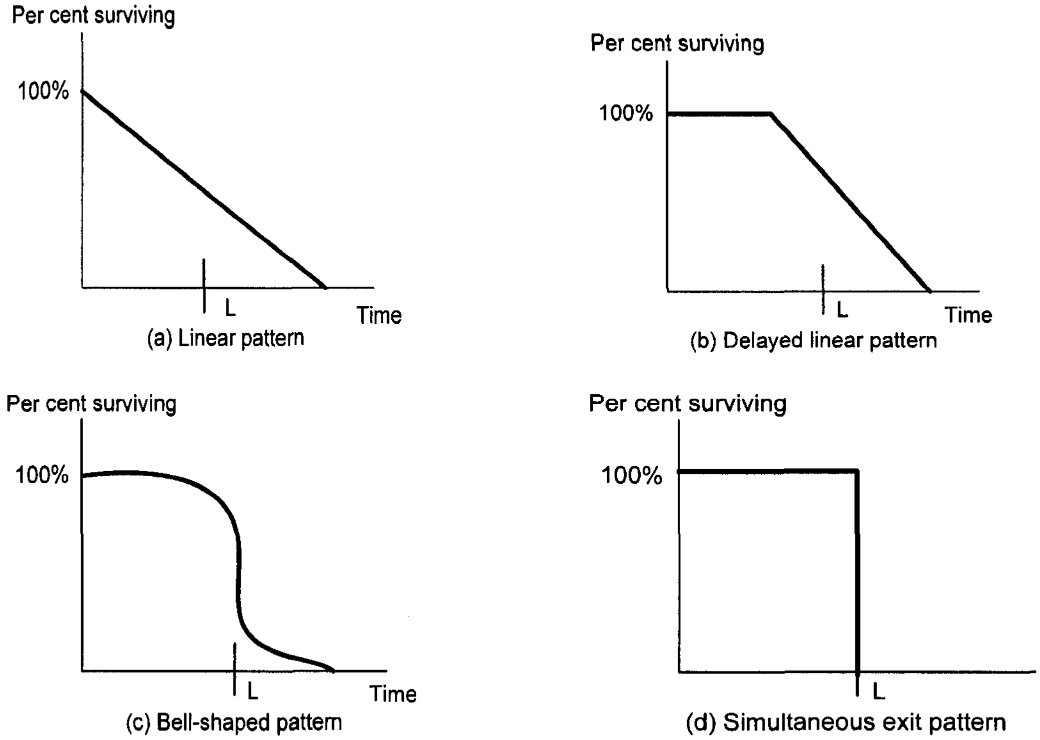


Figure 2.11 Four survival functions (OECD, 2001)

Figure 2.11(a) shows that linear pattern, according to which assets are assumed to be discarded at the same rate each year from the time of installation until twice the average service life has elapsed. This survival function shows that the surviving assets are reduced by a constant amount each year, equal to 50/L% of the original group of assets. This pattern assumes that retirements start immediately after assets are installed and this is generally regarded as an unrealistic assumption. It makes a more realistic assumption that discards occur over some period shorter than 2L. Retirements start later and finish sooner than in the simple linear case. The delayed linear pattern is shown in Figure 2.11(b).

Figure 2.11(c) shows the bell-shaped survival pattern. Retirement starts gradually some time after the year of installation, builds to a peak around the average service life and then tapers off in a similar gradual fashion some years afterwards. The last pattern shown in Figure 2.11(d) is called the simultaneous exit pattern, and it assumes that all assets are retired from the capital stock at the moment when they reach the average service life for the type of asset concerned. The survival function therefore shows that all assets of a given type and vintage remain in the stock until time L, at which point they are all retired together. As a member of OECD countries, Canada applies the pattern of simultaneous exit along with Japan and Norway (OECD, 1997).

2.6 SUMMARY

In this chapter, literature has been reviewed about the current situation of BMSs and bridges as tangible capital assets in the U.S. and Canada. New requirements for the recognition of capital assets in Canada will be applied in 2009. During the transition period from 2007-2009, each province in Canada will have much preparation to accomplish. In constructing estimates of capital stock and in the accounting and auditing of capital assets, PIM is one of the most useful tools at present (Businessdictionary, 2008).

The review identified the limitations of present BMSs and the need to collect more detailed information about the state of BMSs in Canada. The next chapter will explain about our survey of bridge management systems in Canada.

CHAPTER 3 SURVEY OF BRIDGE MANAGEMENT SYSTEMS IN CANADA

3.1 INTRODUCTION

Using advanced 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.

Table 3.1 shows a comparison of the BMSs at different provinces and territories in Canada and the provincial transportation agencies in charge of them. Figure 3.1 shows the distribution of the number of bridges managed by transportation agencies in Canada.

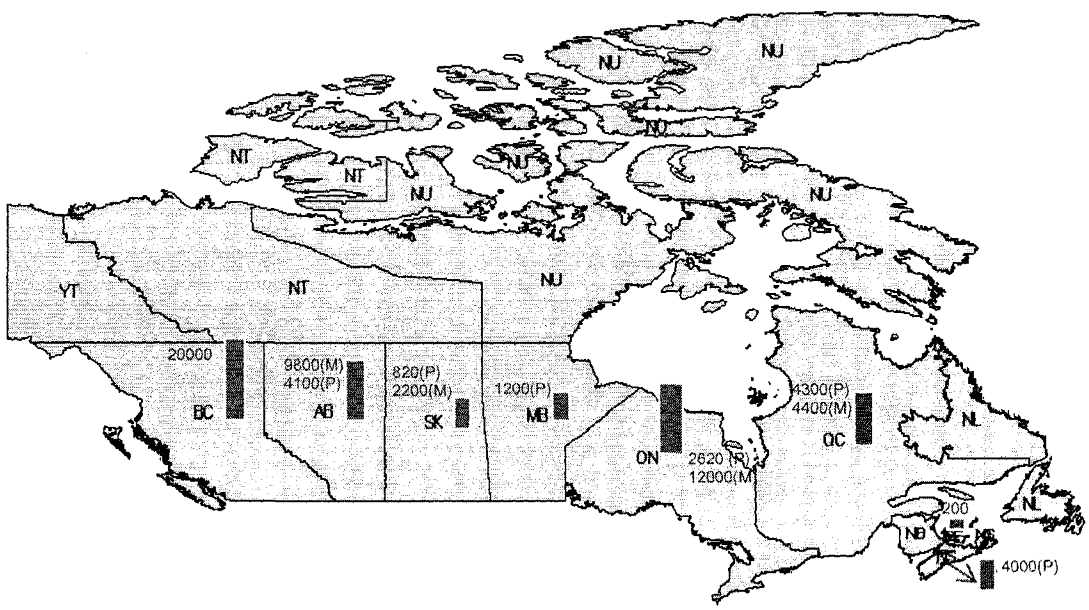


Figure 3.1 Distribution of number of bridges in Canada

There are about 80,000 (Lounis, 2006) bridges in total in Canada. Here are about 66,000 bridges because the situations of some bridges are unknown such as railway bridges. As for the category of bridge length, there are different definitions in different provinces. In Quebec, only bridges of more than 4.5 meters are considered in the BMS (Ministry of transportation Quebec, 2004b). In Manitoba, bridges of less than 6 meters are inspected differently from other bridges (Khanzada, 2007). Bridges in Canada are managed by different agencies at the federal, provincial and municipal governments. In this chapter, bridge management at different levels will be reviewed in detail. In addition, three surveys about BMSs are introduced and explained. The first survey is ours and focuses on BMSs at the provincial level. The second survey is made by MMM Group about the current state of Ontario's bridges. The third survey is from Transport Canada, which emphasizes particularly on bridge inspection at the municipal level. Furthermore, the new regulation about international bridges on the border between Canada and the U.S. will be introduced because they are an important part of the transportation network for the trade between Canada and the U.S. At the end of this chapter, a unified bridge inventory specification in Canada will be proposed.

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
British Columbia	20,000	Started in 1986 Rebuild in 2000	BMIS	5	N.A.	Ministry of Transportation
Alberta	9,800 (M) 4,100 (P)	Early 1970s to 2002	BEADS	9	N.A.	Department of Infrastructure and Transportation
Saskatchewan	820 (P) 2200 (M)	N.A.	N.A	4	N.A	Department of Highways and Infrastructure
Manitoba	1200 (P)	N.A.	Pontis	5	N.A.	Department of Infrastructure and Transportation
Ontario	2620 (P) 12000 (M)	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
New Brunswick	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
Prince Edward Island	200	Ongoing	PEIBMS	4	Timber: 50% Concrete: 25% Steel: 25%	Department of Transportation and Public Works
Newfoundland and Labrador	N.A.	N.A.	N.A.	N.A.	N.A.	Department of Transportation

Table 3.1Comparison of the BMSs at different provinces and territories in Canada

3.2 FEDERAL BRIDGE MANAGEMENT IN CANADA AND INTERNATIONAL BRIDGE REGULATIONS

3.2.1 FEDERAL BRIDGE MANAGEMENT

The Federal Bridge Corporation Limited (FBCL) was incorporated in 1998 to assume the non-navigational management responsibilities of the St. Lawrence Seaway Authority (Federal, 2007). 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 3.2 shows the FBCL organization structure.

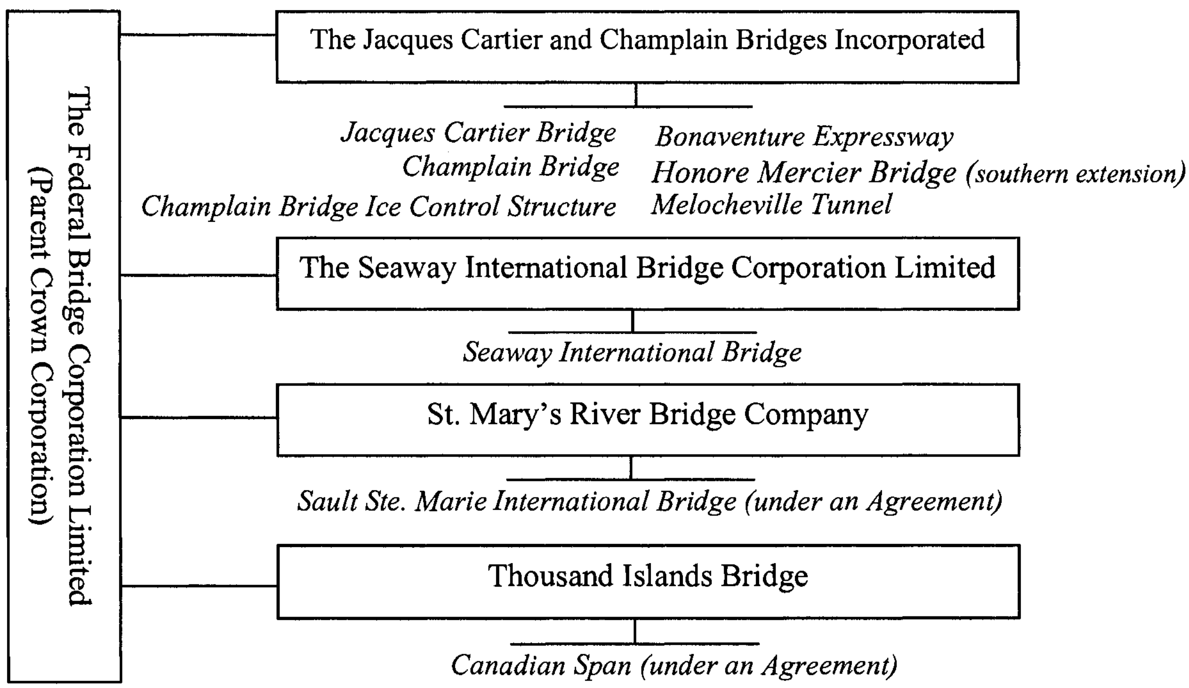


Figure 3.2 FBCL organization structure (Federal, 2007)

3.2.2 INTERNATIONAL BRIDGES REGULATIONS

As for crossing bridges between Canada and the U.S.A., they are an important part of the Canadian road network, particularly with respect to trade and the transportation of goods. There are 33 international bridges and tunnels between Canada and the U.S. Of these bridges and tunnels, 24 are vehicular crossings and 9 are railway crossings (Canada Gazette, 2008). Appendix E has more information about the 24 vehicular crossing international bridges and tunnels. These bridges belong to various governance regimes: crown corporations, joint authorities, and private companies. These different regimes do not necessarily have obligations to report on operations and maintenance to the Government of Canada (GoC).

In 2007, the International Bridges and Tunnels Act (IBTA) was adopted. It has given to the GoC an oversight responsibility for the operations, maintenance and security of these crossing bridges and tunnels. In order to take any necessary action for the GoC, necessary information must be available. Therefore, to ensure that these bridges and tunnels are in good condition, the proposed International Bridges and Tunnels Regulations (IBTR) are necessary to create a consistent approach for reporting on maintenance and operation of these structures.

At present, the proposed IBTR would apply to the vehicular crossings and would require reports every two years on maintenance and operations, which would include identifying necessary actions to ensure the structures are kept in good condition.

The IBTR consists of Part I: maintenance and repair, inspection, and reports; and Part II: operations and use. In Part I, international bridge inspection in Canada shall respect the following manuals and standards (Canada Gazette, 2008): (1) Bridge inspection manual—Bridge Engineering Highways and Bridges (Public works and government services Canada, 2001); (2) Ontario structure inspection manual (Ministry of Transportation Ontario, 2001); (3) Manuel d'inspection des structures—évaluation des dommages (Ministry of Transportation Quebec, 2004a).

3.3 PROVINCIAL BRIDGE MANAGEMENT SYSTENS IN CANADA

3.3.1 British Columbia

The Ministry of Transportation of British Columbia (MoT of BC) 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 (Baskin and Famden, 2007):

Strengths of BMIS:

- 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.

- Provides 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 used by private bridge maintenance contractors.

Weaknesses of BMIS:

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

3.3.2 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 responsible for more than 4100 bridges in provincial highways and 9800 bridges on the municipal road system throughout the province (Loo and Dasmohapatra, 2007).

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 3.3 shows the structure of the TIMS and BEADS system (Loo et al., 2003). 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.

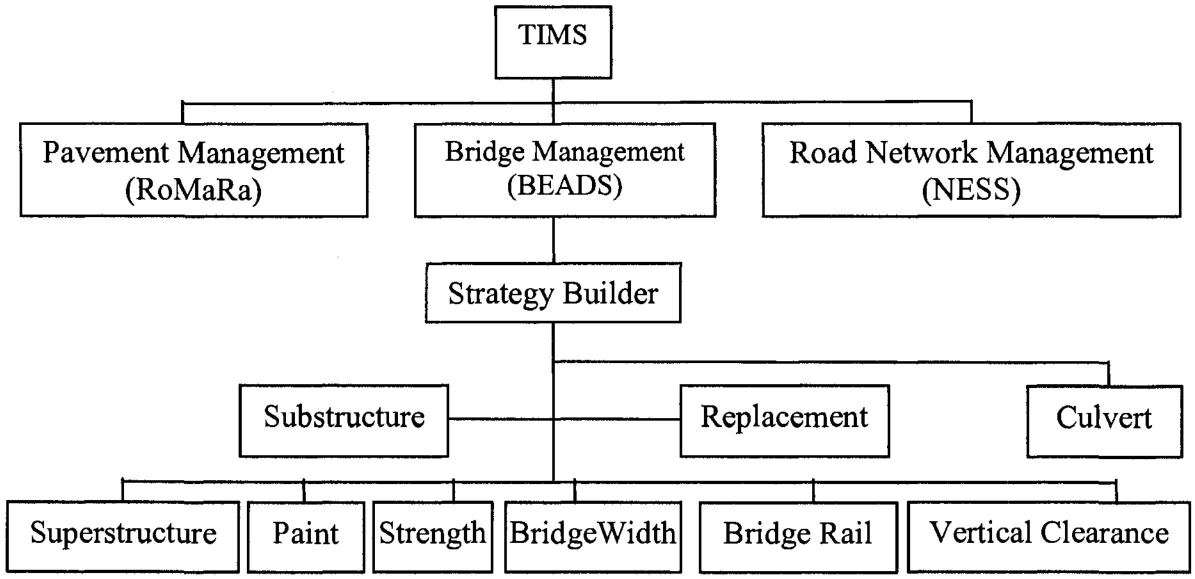


Figure 3.3 Structure of the TIMS and BEADS systems (Loo et al., 2003)

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 (Loo et al., 2003). 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.

3.3.3 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 (Richardson, 2007). 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.

3.3.4 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. 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 (Thompson, 2000).

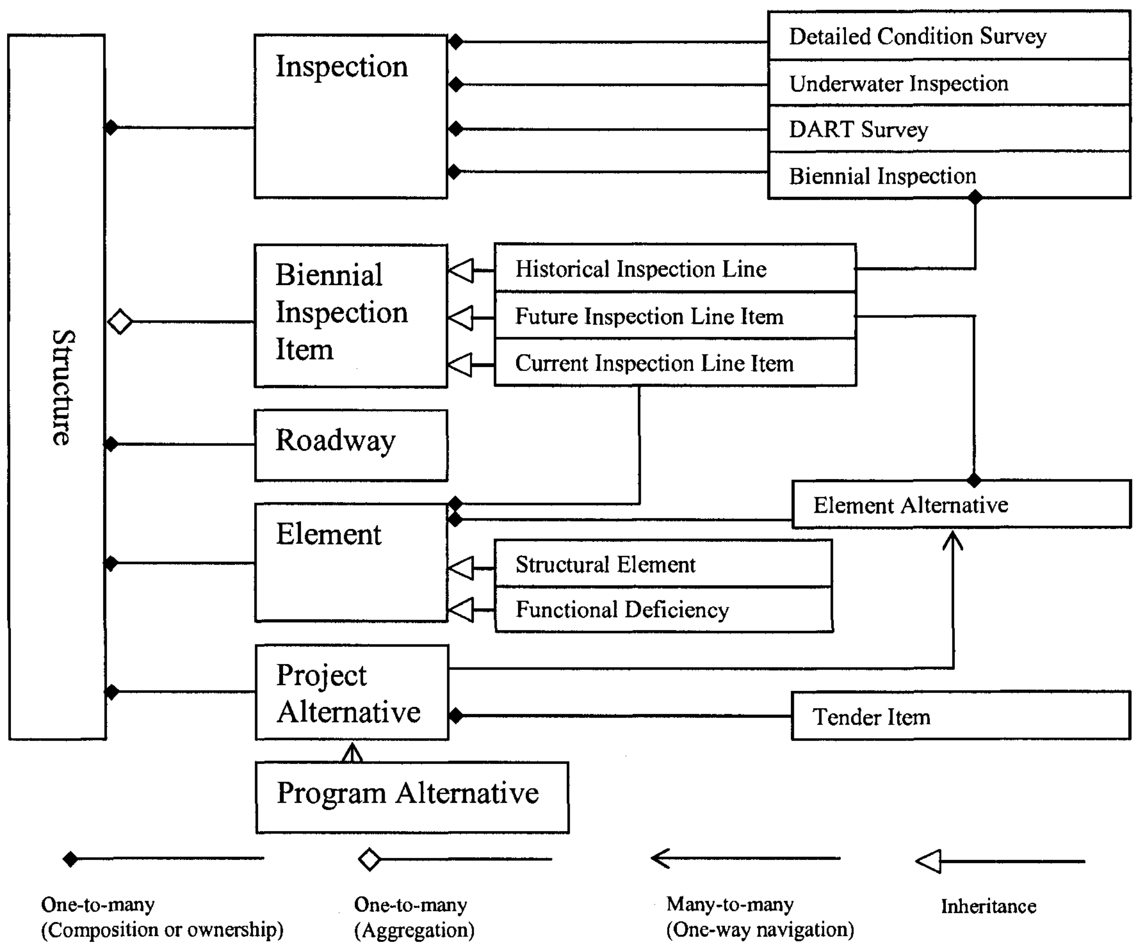


Figure 3.4 Structure of domain model of OBMS (Thompson et al., 1999)

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. Figure 3.4 shows the structure of the domain model of OBMS (Thompson et al., 1999).

Current Inspection Line Item behaves like any other inspection line item, providing a description of the condition of one element of a bridge, in the form of a distribution of element quantities among the four possible condition states. This class consults any or all of the four types of inspection (Detailed Condition Survey, Underwater Inspection, DART (Deck Assessment using Radar Technology) Survey, or Biennial Inspection) to find the most recent or relevant data for its element, then digests these raw data into a standardized form for use by the rest of the system. Future Inspection Line Item embodies a Markovian deterioration model and a set of decision rules to predict the distribution of element quantities among the four possible condition states at a given time in the future. Element Alternative provides a candidate treatment for a given element at a given time, with a cost and benefit. The information within this class is based on the predicted condition of the element, and is used to determine whether its treatment is feasible based on decision rules. Project Alternative provides a cost and benefit to be used in the priority-setting and network-level functionality of the system. This information within this class is used to examine the scope of the project (as a list of Element Alternatives) and formulate a cost estimate consisting of a list of Tender Items. In particular, network-level analysis is separated from project-level analysis because the Project Alternative class hides all the details of the inspection process, deterioration, and costing, presenting to the network-level (via the Program Alternative) only a simplified representation of the project in terms of cost, benefit, and performance measures.

In the OBMS, there are three main models, which are Deterioration Model, Knowledge Model, and Cost Model. 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 (Thompson et al., 2000). 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= ∑(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 (Merlo and Sabanathan, 2007).

Strengths of OBMS:

- 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 of OBMS:

- 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.

3.3.5 Quebec

Quebec is one of the earliest provinces in Canada in which the government applied a computer-based system to support bridge management. The Ministry of Transports of Quebec (MTQ) is responsible for a total of about 9000 structures, of which 4300 are provincial bridges, 4400 are municipal bridges, and the remainder is retaining walls and other miscellaneous structures (Richard, 2007a). Figure 3.5 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. In addition, Stantec (formerly ITX Stanley) gives technical supports for NSBMS and PELBMS.

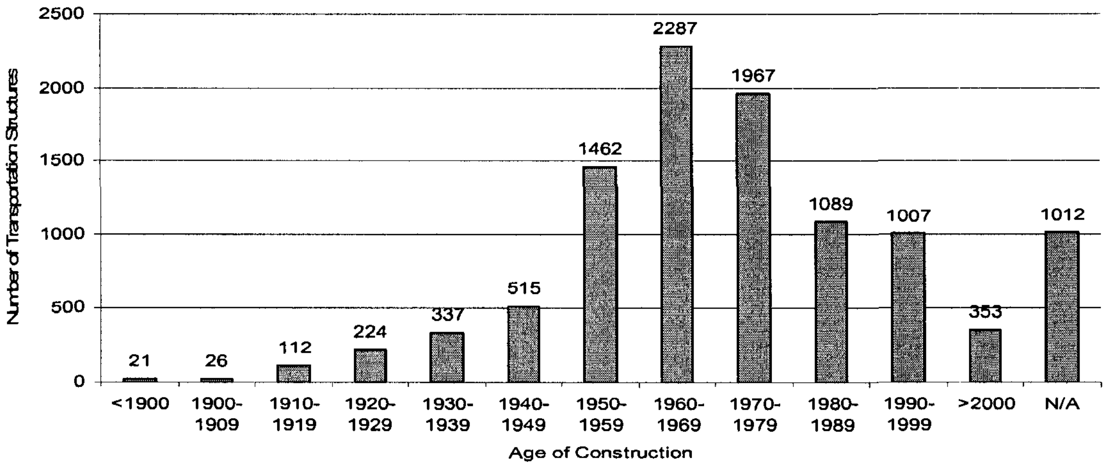


Figure 3.5 Distribution of time of construction of transportation structures in Quebec

All bridge 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.

In the QBMS, there are five classes, which are inventory classes, inspection classes, project-level analytical classes, network-level analytical classes and model and policy classes, and each class has data and functionality requirements associated with it. Figure 3.6 shows the structure of the domain model of QBMS (Quebec, 2002).

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.

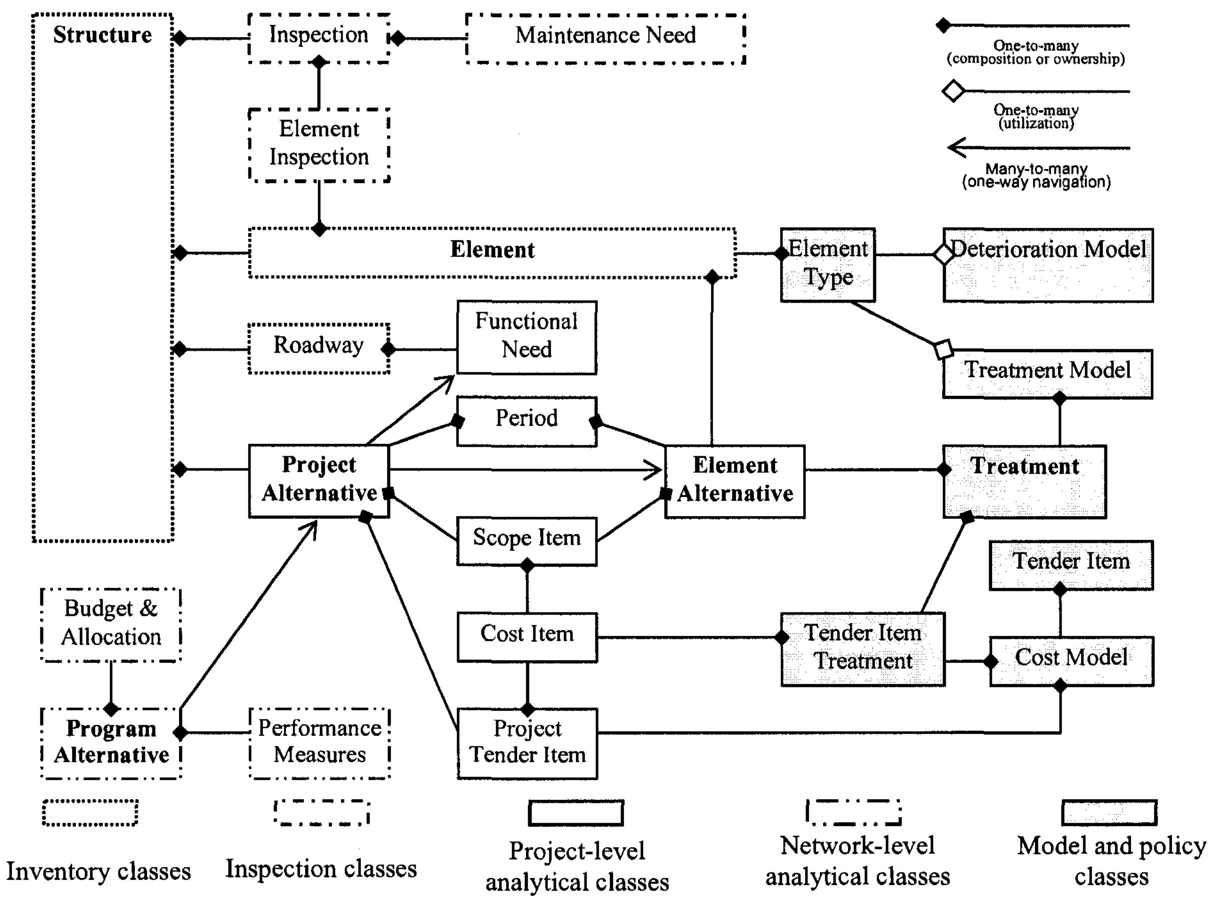


Figure 3.6 Structure of domain model of QBMS (Quebec 2002)

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*. An Element Alternative 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.

3.3.6 Nova Scotia

Nova Scotia Department of Transportation and Public Works (NSDTPW), which has 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 (MacRae, 2007). 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 NSDTPW decided to develop a modern BMS to satisfy the increasing need of bridge safety. In 1998, the NSDTPW 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 (Speiran et al., 2004). The NSDTPW 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" (Speiran et al., 2004).

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.

3.3.7 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 (Evans, 2007). 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.

3.4 STATE OF BRIDGES IN ONTARIO

Ontario is always at the forefront of bridge management technology development and implementation in Canada. Therefore, this section mentions its state of bridge management based on a survey done in 2007 (MMM Group, 2007). Many of the bridges in Ontario are more than 50 years old and require major rehabilitation and reconstruction. Figure 3.7 shows annual growth in roads and bridges capital infrastructure in Ontario

(MMM Group, 2007). The boom period of construction in Ontario was 1961-1971. It means most of bridges in Ontario are aging. However, because of the challenge of addressing a variety of other funding demands (e.g. health or social services), all levels of government have sought to defer the needed maintenance and rehabilitation work for years. For solving this problem, all levels of government have to address the extensive rehabilitation needs of those aging bridges.

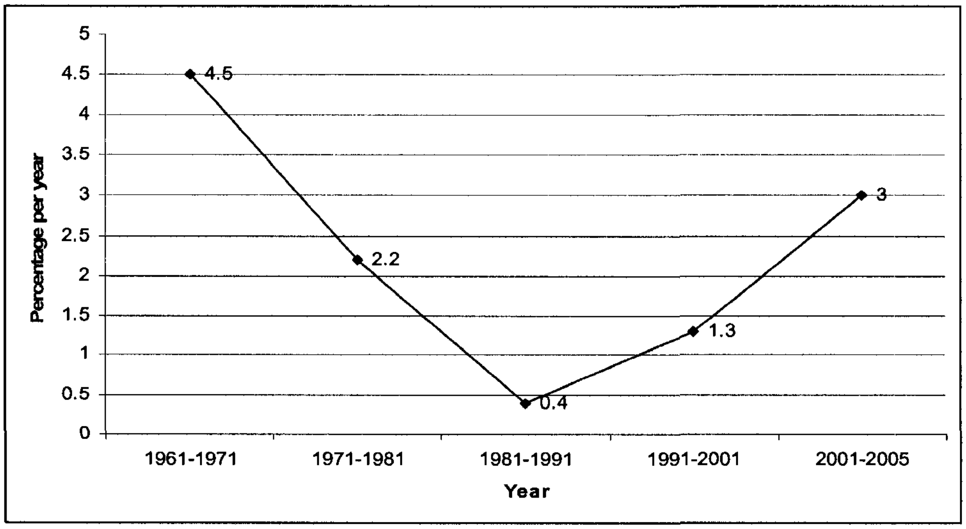


Figure 3.7 Annual growth in roads and bridges capital infrastructure--Ontario (MMM Group, 2007)

Because many bridges have been downloaded to municipalities in Ontario, municipalities are now the largest and most important bridge owners in Ontario. Table 3.2 shows annual growth in roads and bridges capital infrastructure by jurisdiction during 1961-2005 in Canada (MMM Group, 2007). Table 3.2 illustrates this trend although not reported separately for Ontario.

Table 3.2 Annual growth in roads and bridges capital infrastructure by jurisdiction during 1961-2005 in Canada (MMM Group, 2007)

Federal	Provincial	Municipal
-1.5% per year	1.3% per year	3.3% per year

At present, one time funding does not allow for the proper planning and programming of bridge infrastructure rehabilitation. Therefore, many municipalities cannot accommodate the bridge rehabilitation and reconstruction funding needs without the support of the federal and provincial governments.

There has been no single agency or government body that has all the information on the state of Ontario's bridges in the past decade. While the province has information on the bridges it owns, there is no comprehensive database of municipal bridges. Furthermore there is no agency responsible for ensuring that the municipal bridge inspection and rehabilitation work is carried out effectively. More details about this issue are given in Section 3.5.

The above-mentioned survey covered over 440 Ontario municipalities. Information was received from 150 municipalities. The questionnaire includes the following questions (MMM Group, 2007): (1) how many bridges do they have currently? and (2) what are the identified needs in terms of number and cost for three time periods? (now (highest priority), in 1-5 years, and in 6-10 years).

The result of the questionnaire is shown in Table 3.3. This table gives the following information: (1) On average, 28%, 48%, and 24% of municipality's bridges fall into the Now Needs category, 1-5 Year Needs, and 6-10 Year Needs, respectively; and (2) The average cost of repairs for each municipal bridge need is about \$663,000 in the Now Needs, about \$521,000 in the 1-5 Year Needs, and about \$892,000 in the 6-10 Year Needs, respectively.

Table 3.3 Estimated needs for Ontario municipal bridges (MMM Group, 2007)

Now Needs		1-5 Year Needs		6-10 Year Needs	
Needs	Estimate ($)	Needs	Estimate ($)	Needs	Estimate ($)
380	252,138,541	645	336,108,423	317	282,818,150

3.5 REGULATORY NATURE OF BRIDGE MANAGEMENT AT THE PROVINCIAL AND MUNICIPAL LEVELS

Transport Canada had a survey in 2007 aiming to clarify the regulatory nature of bridge at the provincial and municipal levels (Khanzada, 2007). Jurisdictions in a province, such as cities, towns, counties, municipalities, villages and districts, may have their own regulation or policy for bridge management, including inspection and maintenance methods and frequencies. The survey was send to the nine provinces of Canada and it has the following questions:

(1) Do you have a provincial regulation for bridge inspection? If yes, are other jurisdictions in your province such as cities, towns, counties, municipalities, villages, districts, etc. fall under the provincial bridge regulation?

(2) Who is responsible of inspecting bridges belonging to cities, towns, counties, municipalities, villages, districts, etc. in your province? Is this the responsibility of the province or the owner of the bridge?

(3) Who is responsible for maintaining inventory list of bridges belonging to cities, towns, counties, municipalities, villages, districts, etc. in your province? Is this the responsibility of the province or the owner of the bridge?

(4) What standards and manuals other jurisdictions in your province such as cities, towns, counties, municipalities, villages, districts, etc. use for inspecting bridges? Are they following provincial standards or they have their own?

(5) Who is responsible for maintenance, rehabilitation, and construction of bridges in other jurisdictions in your province such as cities, towns, counties, municipalities, villages, districts? Is this the responsibility of the province or the owner of the bridge?

(6) What types of inspections are done for in-service bridges, and frequencies for each type?

The following sub-sections will summarize the results of the survey from each province.

3.5.1 British Columbia

British Columbia has no provincial regulation for bridge inspection but has a written policy. Each owner is responsible for their own structures. Therefore, bridge owners are responsible for the inspection, maintenance, rehabilitation, and construction of their bridges. The provincial standard for inspecting bridges is Bridge Inspection Manuals (Books 1, 2, and 3, 1994) and Bridge Management Information System User Manual. For other jurisdictions, they have bridge consultants put together systems for them. In B.C., there are two kinds of inspections: Routine inspections and detailed inspections. B.C. Ministry of Transportation has Area Bridge Managers (AMBs) that undertake routine inspections annually (every bridge to be inspected once every calendar year). The scope of these inspections is to visually inspect as much of the bridge as possible using foot access on the ground and on the bridge deck augmented by the use of binoculars. For the detailed inspections, there is no current requirement regarding the frequency of detailed inspections but a period of once every five years is suggested. These inspections use access equipment to get close to all parts of a bridge so that small defects such as steel fatigue cracks can be detected.

3.5.2 Alberta

There is legislation/regulation for bridge inspection that indicates that the Responsible Road Authority is required to perform management/maintenance of the road network under their jurisdiction. Proper management of a road network would include bridge inspection, and to address that the Department has created a policy regarding bridge inspection. However, there is no specific regulation of inspection for highway bridges. These bridge inspection requirements are a policy and the other jurisdictions are encouraged to follow that policy. In general, inspections of bridges would be the responsibility of the Road Authority having the jurisdiction/management of the structure. However, there has been an exception for major bridges that are not within a city. The department has made a decision that inspection of major bridges on local roads will remain the responsibility of the department. All bridges that are the responsibility of a city would be inspected by that city.

The inventory lists are maintained by the owner of the structure. Within the cities, the majority of the structures are owned by the cities and the cities would maintain an inventory list. The majority of bridges on public highways outside of the cities are owned by the Province and an inventory list for these structures is maintained by the Province. It is the responsibility of the Local Road Authorities to keep the Province apprised of any inventory changes within their jurisdiction.

The Department has developed a Bridge Inspection and Maintenance System that it uses for inspecting structures that are department responsibility. The Local Road Authorities are encouraged to use the same system for inspecting their structures and other than for the cities, all local road authorities are using the Department's inspection system. Some cities have developed their own bridge inspection system that is different from the Department's system.

The Responsible Road Authority (County, City, Town, etc.) would be responsible for maintenance, rehabilitation and construction of bridges under their jurisdiction. In general, bridges on local roads are owned by the Province, but responsibility for their management is with the Local Road Authority. In general, bridges within the cities are owned by the cities and they are responsible for the management.

For inspection types and frequencies, there are two levels. (1) Level 1—Visual Inspection: Major Provincial Highways need 21 months, Secondary Provincial Highways 39 months, Local roads – standard bridges and culverts 57 months and major bridges 39 months. (2) Level 2—Detailed Inspection: Concrete deck inspections, Chloride Sulphate Electrode Testing, Chloride Testing, and Ultrasonic Truss Inspection 4 to 6 year cycle; Timber coring is done as recommended from a Level 1 inspection.

3.5.3 Saskatchewan

There is no regulation for bridge inspection but there is a policy. Each jurisdiction is responsible for the inspection and preservation of their bridges. In Saskatchewan, assistance is provided in the form of a grant to the rural municipalities to share in the cost of repair or replacement of bridges on their system. Saskatchewan Highways will inspect bridges on the municipal system on a requested basis, but are working towards ensuring a certain level of inspection is done on the Municipal System. Inventory list of bridges is the responsibility of the owners. Ministry of Highways and Infrastructure (MHI) keeps an inventory of highway bridges and also keeps an inventory of municipal bridges, but the municipal inventory database may not be current as municipalities do not advise MHI of changes to their inventory. The Province uses the Ontario Structure Inspection Manual (OSIM). Each individual jurisdiction (owner) is responsible for the maintenance and repair of bridges within its own jurisdiction. For inspection types and frequencies, inspection of bridges on the highway system is on a two year cycle in accordance to the methods described in the OSIM.

3.5.4 Manitoba

In Manitoba, there is no provincial regulation for bridge inspection but there is a written policy. Each owner is responsible for its own structures in terms of inspection, maintenance, rehabilitation, and construction. For standards and manuals of inspecting bridges, The Province uses the OSIM. For inspection types and frequencies, there are two levels. Level 1 is general visual inspections at all sites on an annual basis. Level 2 is detailed site inspections of major bridges (those in excess of 6 meters) on Provincial Trunk Highways (PTH) every 24 months and on Provincial Roads (PR) every 48 months. Inspection of bridges, which are less than 6m, located on PRs and Main Market Roads is every 72 months.

3.5.5 Ontario

Ontario has a provincial regulation for bridge inspection. It applies to all bridges in Ontario. For the responsibility of inspection, maintenance, rehabilitation, and construction, each owner takes activities for its bridges. Occasionally, the province has funding programs to assist municipalities for specific bridges. The provincial standard of inspection is the OSIM. As for the inspection type and frequencies, there is a detailed inspection of all bridges required every 2 years in accordance with the OSIM. This inspection must be done under the direction of a professional engineer. The inspection of elements should "close up" visual assessment. "Close up" is defined as a distance close enough to determine the condition of the element.

3.5.6 Quebec

In Quebec, there is no provincial regulation for bridge inspection but there is a written policy. MTQ does the bridge inspections for all municipal bridges for jurisdictions of less than 100 000 inhabitants. The large municipalities inspect their bridges themselves. In addition, MTQ maintains the inventory of municipal bridges for its network and for municipalities less than 100 000 inhabitants. It means MTQ is responsible for all bridges for maintenance, rehabilitation, and construction. In terms of inspection standards, MTQ inspects bridges with its standards. Large municipalities mostly have their own standards for bridge inspection, some use the MTQ standards. There are two inspections: (1) General Inspection – this is the key component of the inspection program. It involves a systematic examination of all components of a structure on a 2 to 4 years cycle; and (2) Summary Inspection – visual examination on annual basis of the components of a structure in order to identify anomalies and obvious defects.

3.5.7 New Brunswick

New Brunswick has no provincial regulation for bridge inspection but there is a policy. All other jurisdictions fall under the provincial policy. The New Brunswick Department of Transportation (NBDOT) assumes all ownership responsibilities including inventory, bridge maintenance and bridge inspection for all bridges within these jurisdictions. All bridges located on private property are the owner's responsibility. The province is responsible for maintaining an inventory list of bridges belonging to cities, towns, counties, municipalities, villages, and districts. Therefore, the NBDOT is responsible for maintenance, rehabilitation, and construction of bridges in other jurisdictions. Any new bridges constructed within municipalities are the municipalities' responsibility; however, the bridges must be constructed to NBDOT standards in order for the NBDOT to assume responsibility. The inspection standard is OSIM, too. The regular bridge inspection for in-service bridges is biennial.

3.5.8 Nova Scotia

There is no provincial regulation for bridge inspection but there is a policy. Each owner is responsible for its own bridges for inspection, maintenance, rehabilitation, and construction. The OSIM is used by the province for bridge inspection. There are three inspection levels. Level 1 Inspection is a yearly walk around inspection done on all bridges in Nova Scotia by operation supervisors. Level 2 Inspection is a detailed visual inspection performed by qualified inspectors. Level 3 Inspection is a detailed inspection performed by qualified structural engineer.

3.5.9 Prince Edwards Island (P.E.I.)

Like most provinces, P.E.I. does not have a provincial regulation for bridge inspection but have a policy. The province owns all bridges in the province. In other words, the province is responsible for its own bridges for inspection, maintenance, rehabilitation, and construction. P.E.I. uses the OSIM as its standard of bridge inspection and a visual walk around inspection is done on a triennial basis.

3.6 PROPOSED CANADIAN BRIDGE INVENTORY 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 (Office, 2006).

The bridge inventory should 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 3.4 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 (Klatter, 2006) 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.

As for the current situation of different specifications in different provinces, a unified bridge management specification does not mean that all inventories in provinces should be unique. For example, Alberta has 9 levels of condition rating, however, Quebec has 5. However, these different condition ratings can be mapped to the future unified condition rating of the national inventory.

Table 3.4 Data inventory components

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

3.7 SUMMARY AND CONCLUSIONS

This chapter surveys 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 data from the following surveys have been collected and analyzed: federal level, provincial level, and municipal level. Ontario is special because it has many municipal bridges and is the only province that has regulations about bridge inspection at both the provincial and municipal levels. From the survey about the status of bridges in Ontario, the results of the survey are: (1) On average, 28%, 48%, and 24% of municipality's bridges fall into the Now Needs category, 1-5 Year Needs, and 6-10 Year Needs, respectively; and (2) The average cost of repairs for each municipal bridge need is about $663,000 in the Now Needs, about $521,000 in the 1-5 Year Needs, and about $892,000 in the 6-10 Year Needs, respectively.

From the recent survey of Transport Canada about the regulatory nature of bridge management at the provincial and municipal levels, the results are: (1) Only one province—Ontario— has a bridge inspection regulation in Canada. The rest of the provinces have policies. (2) New Brunswick and P.E.I. assume all ownership responsibilities including inventory, bridge maintenance and bridge inspection for all public roadway bridges. (3) Alberta almost has a regulation for bridge inspection. In its regulation, it indicates that the Responsible Road Authority is required to perform management/maintenance of the road network under its jurisdiction. Proper management of a road network would include bridge inspection. (4) Quebec is responsible for bridge inspections for all municipal bridges for municipalities less than 100,000 inhabitants. The large municipalities inspect their bridges themselves. (5) Six provinces (Saskatchewan, Manitoba, Ontario, New Brunswick, Nova Scotia, and P.E.I.) are using the OSIM for inspecting their bridges.

The chapter also proposed developing a Canadian NBI to facilitate sharing the data and comparing performance measures as the user base in other provinces grows. Furthermore, the future Canadian NBI should expand the inventory data to include all life cycle data (i.e. design, construction, inspection, and maintenance) as suggested by Itoh et al. (1997) and Feek (2008).

In the future, the following steps should be taken towards building the Canadian NBI: (1) Comparing the inventory data of the BMS of each province; (2) Identifying a common set of data which is available in all provinces; (3) Getting feedback from transportation ministries of provinces based on the common set; and (4) Conducting a pilot study to collect the data based on the identified inventory specifications. The collected data should be updated annually and managed at the federal level by Transport Canada.

CHAPTER 4 CASE STUDY

4.1 INTRODUCTION

As was discussed in Chapter 3, most Canadian provinces already have individual bridge management systems. However, Canada does not have NBI for providing a systematic format of bridge data at the federal level. Even at the provincial level, provincial governments do not always have access to the bridge inventory of the jurisdictions within the provinces and these jurisdictions have their own way of managing their bridges. This problem has been identified by Transport Canada in a recent survey (Khanzada, 2007) as was explained in Chapter 3. This problem hampers the quality control of bridge data and limits the development of BMSs and sharing of Canadian bridge information.

This chapter represents, first, a perspective for a Canadian national bridge inventory based on the Quebec bridge inventory. In order to better understand the Quebec bridge data, the data obtained from the MTQ as an Access file has been analyzed and a graphical user interface (GUI) has been developed to improve the usability of the data. The inventory part of this database is proposed as an example that can be modified in the future to be used as the base for the Canadian BNI. Next, the database is used to perform some calculations related to replacement cost of bridges. The effect of three factors on the replacement cost of Quebec bridges are studied including the age of bridges, their structural type, and location. After that, a method for assessing Quebec bridges is explained. In addition, a new depreciation method is introduced based on the traditional straight line method and considering the effects of traffic volume.

4.2 PERSPECTIVE FOR A CANADIAN NATIONAL BRIDGE INVENTORY AND EXAMPLE FROM QUEBEC BRIDGE INVENTORY

4.2.1 Introduction

A complete bridge inventory is a comprehensive description of bridges. For example, the U.S. NBI has 432 items. It includes all the information about bridges, such as the year of construction, route number, and owner. As a first step towards developing an NBI for Canada, we started by analyzing the MTQ bridge database because of its availability. This analysis included the following items: (1) translation from French to English; (2) developing a GUI of the MTQ database using SQL queries; and (3) analyzing the contents of the data.

4.2.2 Translation work

The entire original MTQ database and all documentation are written in French. So translation into English, especially of some technical terms, is a big challenge. All interfaces shown below have been translated into English.

4.2.3 Source of data

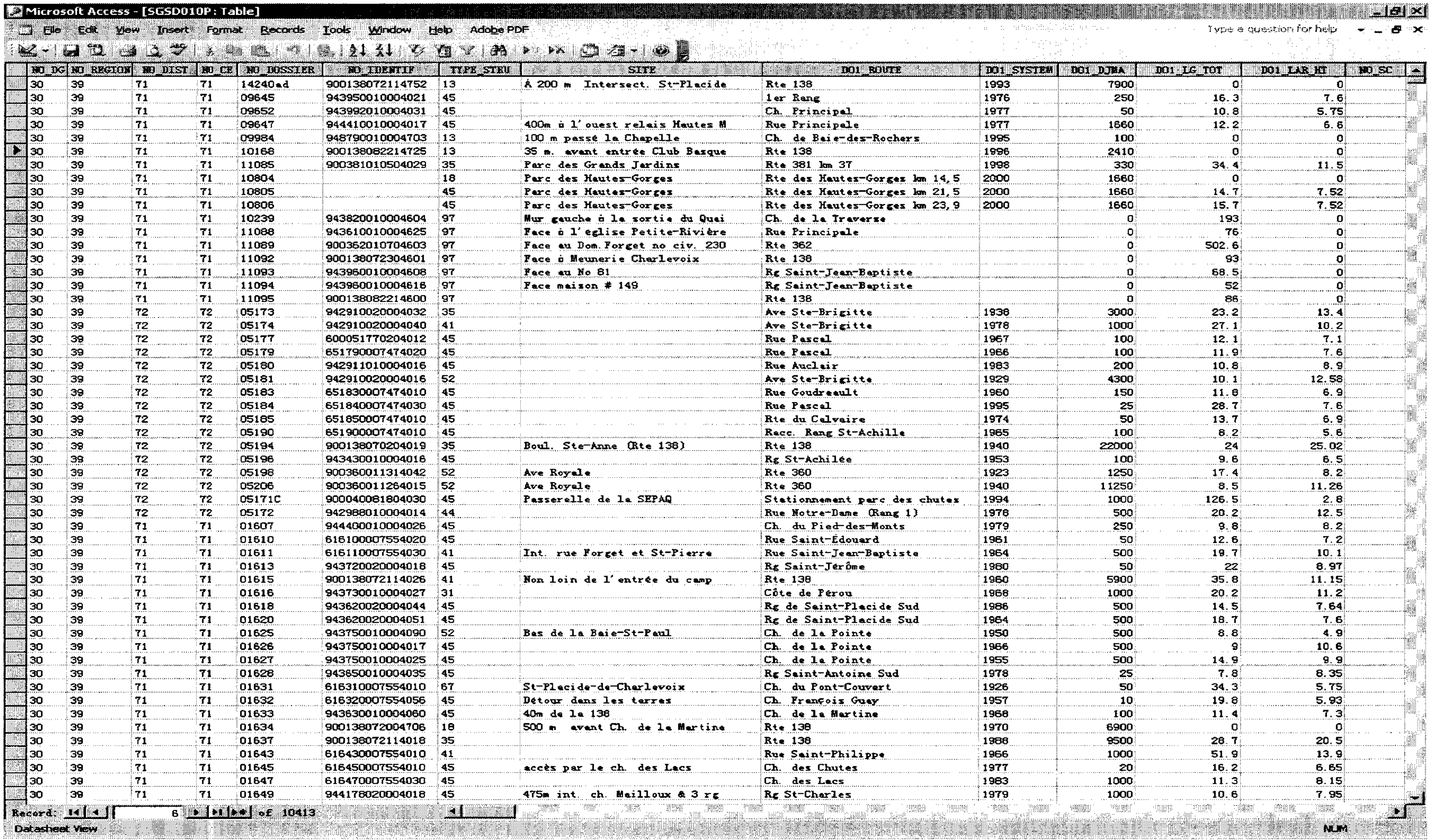
(1) The MTQ database obtained from the Structure Department of MTQ consists of 11 tables. Table 4.1 shows the 11 tables in MTQ database (Hu, 2006). Figure 4.1 shows part of Table SGSD010P (main information for the Quebec Bridge Database). The main fields in this table are: ID, type of structure, name of road, year of construction, length of bridge, width of bridge, and so on. Figure 4.2 shows a sample data of the NBI of the U.S. with similar items such as location, year of construction, and structure length. In addition, each of these items has a link to more detailed information. From this comparison, we can see that the tables from MTQ database are

not easy to read, even for professionals. With the development of the GUI, the data become more accessible.

Table 4.1 Tables in MTQ database (Hu, 2006)

	Table name	Description
Inventory	SGSD010P	General information about structure
Inspection	SGSD400P	Obstacles in the section inventory
	SGSD410P	The elements of foundation in the inventory
	SGSD420P	The structural systems of the inventory
	SGSD700P	Inspection form (type A - V)
	SGSD710P	Details about inspection form
	SGSD720P	The inspection evaluation
	SGSD730P	The inspection comment
	SGSD740P	The inspection summary
Maintenance	SGSD750P	Maintenance activities
	SGSD770P	Maintenance cost

(2) The digital map of bridges of Quebec, represented as points, has been from the Geomatics Department of MTQ. This GIS data has only the location of the bridges and their ID numbers. In addition, another digital map representing the main roads has been obtained as shown in Figure 4.3. In order to visualize the location of bridges and to facilitate spatial analysis, a GIS function is linked to the MTQ database system. The bridge ID is the common attribute between the GIS and Access data. First, the ID field in the GIS database is used to link with the corresponding field in Access database. Next, the particular data in Access can be added to GIS database. During this process, some data could be missing. For instance, there are 715 bridges with records of replacement cost in MTQ Access database, but only 656 of these bridges are available in the GIS database.



Microsoft Access - [SGSD010P : Table]

NO_DG	NO_REGION	NO_DIST	NO_CE	NO_DOSSIER	NO_IDENTIF	TYPE_STRU	SITE	DO1_ROUTE	DO1_SYSTEM	DO1_DJMA	DO1_LG_TOT	DO1_LAR_HT	NO_SC
30	39	71	71	14240ad	900138072114752	13	À 200 m Intersect. St-Placide	Rte 138	1993	7900	0	0	
30	39	71	71	09645	943950010004021	45		1er Rang	1976	250	16.3	7.6	
30	39	71	71	09652	943992010004031	45		Ch. Principal	1977	50	10.8	5.75	
30	39	71	71	09647	944410010004017	45	400m à l'ouest relais Hautes M	Rue Principale	1977	1660	12.2	6.6	
30	39	71	71	09984	948790010004703	13	100 m passé la Chapelle	Ch. de Baie-des-Rochers	1995	100	0	0	
30	39	71	71	10168	900138082214725	13	35 m. avant entrée Club Basque	Rte 138	1996	2410	0	0	
30	39	71	71	11085	900381010504029	35	Parc des Grands Jardins	Rte 381 km 37	1998	330	34.4	11.5	
30	39	71	71	10804		18	Parc des Hautes-Gorges	Rte des Hautes-Gorges km 14,5	2000	1660	0	0	
30	39	71	71	10805		45	Parc des Hautes-Gorges	Rte des Hautes-Gorges km 21,5	2000	1660	14.7	7.52	
30	39	71	71	10806		45	Parc des Hautes-Gorges	Rte des Hautes-Gorges km 23,9	2000	1660	15.7	7.52	
30	39	71	71	10239	943820010004604	97	Mur gauche à la sortie du Quai	Ch. de la Traverse		0	193	0	
30	39	71	71	11088	943610010004625	97	Face à l'église Petite-Rivière	Rue Principale		0	76	0	
30	39	71	71	11089	900362010704603	97	Face au Dom. Forget no civ. 230	Rte 362		0	502.6	0	
30	39	71	71	11092	900138072304601	97	Face à Meunerie Charlevoix	Rte 138		0	93	0	
30	39	71	71	11093	943960010004608	97	Face au No 81	Rg Saint-Jean-Baptiste		0	68.5	0	
30	39	71	71	11094	943960010004616	97	Face maison # 149	Rg Saint-Jean-Baptiste		0	52	0	
30	39	71	71	11095	900138082214600	97		Rte 138		0	86	0	
30	39	72	72	05173	942910020004032	35		Ave Ste-Brigitte	1938	3000	23.2	13.4	
30	39	72	72	05174	942910020004040	41		Ave Ste-Brigitte	1978	1000	27.1	10.2	
30	39	72	72	05177	600051770204012	45		Rue Pascal	1967	100	12.1	7.1	
30	39	72	72	05179	651790007474020	45		Rue Pascal	1966	100	11.9	7.6	
30	39	72	72	05180	942911010004016	45		Rue Auclair	1983	200	10.8	8.9	
30	39	72	72	05181	942910020004016	52		Ave Ste-Brigitte	1929	4300	10.1	12.58	
30	39	72	72	05183	651830007474010	45		Rue Goudreault	1960	150	11.8	6.9	
30	39	72	72	05184	651840007474030	45		Rue Pascal	1995	25	28.7	7.6	
30	39	72	72	05185	651850007474010	45		Rte du Calvaire	1974	50	13.7	6.9	
30	39	72	72	05190	651900007474010	45		Racc. Rang St-Achille	1965	100	8.2	5.6	
30	39	72	72	05194	900138070204019	35	Boul. Ste-Anne (Rte 138)	Rte 138	1940	22000	24	25.02	
30	39	72	72	05196	943430010004016	45		Rg St-Achilée	1953	100	9.6	6.5	
30	39	72	72	05198	900360011314042	52	Ave Royale	Rte 360	1923	1250	17.4	8.2	
30	39	72	72	05206	900360011264015	52	Ave Royale	Rte 360	1940	11250	8.5	11.26	
30	39	72	72	05171C	900040081804030	45	Passerelle de la SEPAQ	Stationnement parc des chutes	1994	1000	126.5	2.8	
30	39	72	72	05172	942988010004014	44		Rue Notre-Dame (Rang 1)	1976	500	20.2	12.5	
30	39	71	71	01607	944400010004026	45		Ch. du Pied-des-Monts	1979	250	9.8	8.2	
30	39	71	71	01610	616100007554020	45		Rue Saint-Édouard	1961	50	12.6	7.2	
30	39	71	71	01611	616110007554030	41	Int. rue Forget et St-Pierre	Rue Saint-Jean-Baptiste	1964	500	19.7	10.1	
30	39	71	71	01613	943720020004018	45		Rg Saint-Jérôme	1980	50	22	8.97	
30	39	71	71	01615	900138072114026	41	Non loin de l'entrée du camp	Rte 138	1960	5900	35.8	11.15	
30	39	71	71	01616	943730010004027	31		Côte de Pérou	1968	1000	20.2	11.2	
30	39	71	71	01618	943620020004044	45		Rg de Saint-Placide Sud	1986	500	14.5	7.64	
30	39	71	71	01620	943620020004051	45		Rg de Saint-Placide Sud	1964	500	18.7	7.6	
30	39	71	71	01625	943750010004090	52	Bas de la Baie-St-Paul	Ch. de la Pointe	1950	500	8.8	4.9	
30	39	71	71	01626	943750010004017	45		Ch. de la Pointe	1966	500	9	10.6	
30	39	71	71	01627	943750010004025	45		Ch. de la Pointe	1955	500	14.9	9.9	
30	39	71	71	01628	943650010004035	45		Rg Saint-Antoine Sud	1978	25	7.8	8.35	
30	39	71	71	01631	616310007554010	67	St-Placide-de-Charlevoix	Ch. du Pont-Couvert	1926	50	34.3	5.75	
30	39	71	71	01632	616320007554056	45	Détour dans les terres	Ch. François Guay	1957	10	19.8	5.93	
30	39	71	71	01633	943630010004060	45	40m de la 138	Ch. de la Martine	1968	100	11.4	7.3	
30	39	71	71	01634	900138072004706	18	500 m avant Ch. de la Martine	Rte 138	1970	6900	0	0	
30	39	71	71	01637	900138072114018	35		Rte 138	1988	9500	28.7	20.5	
30	39	71	71	01643	616430007554010	41		Rue Saint-Philippe	1966	1000	51.9	13.9	
30	39	71	71	01645	616450007554010	45	accès par le ch. des Lacs	Ch. des Chutes	1977	20	16.2	6.65	
30	39	71	71	01647	616470007554030	45		Ch. des Lacs	1983	1000	11.3	8.15	
30	39	71	71	01649	944178020004018	45	475m int. ch. Mailloux & 3 rg	Rg St-Charles	1979	1000	10.6	7.95	

Record: 6 of 10413

Figure 4.1Table SGSD010P of inventory from MTQ

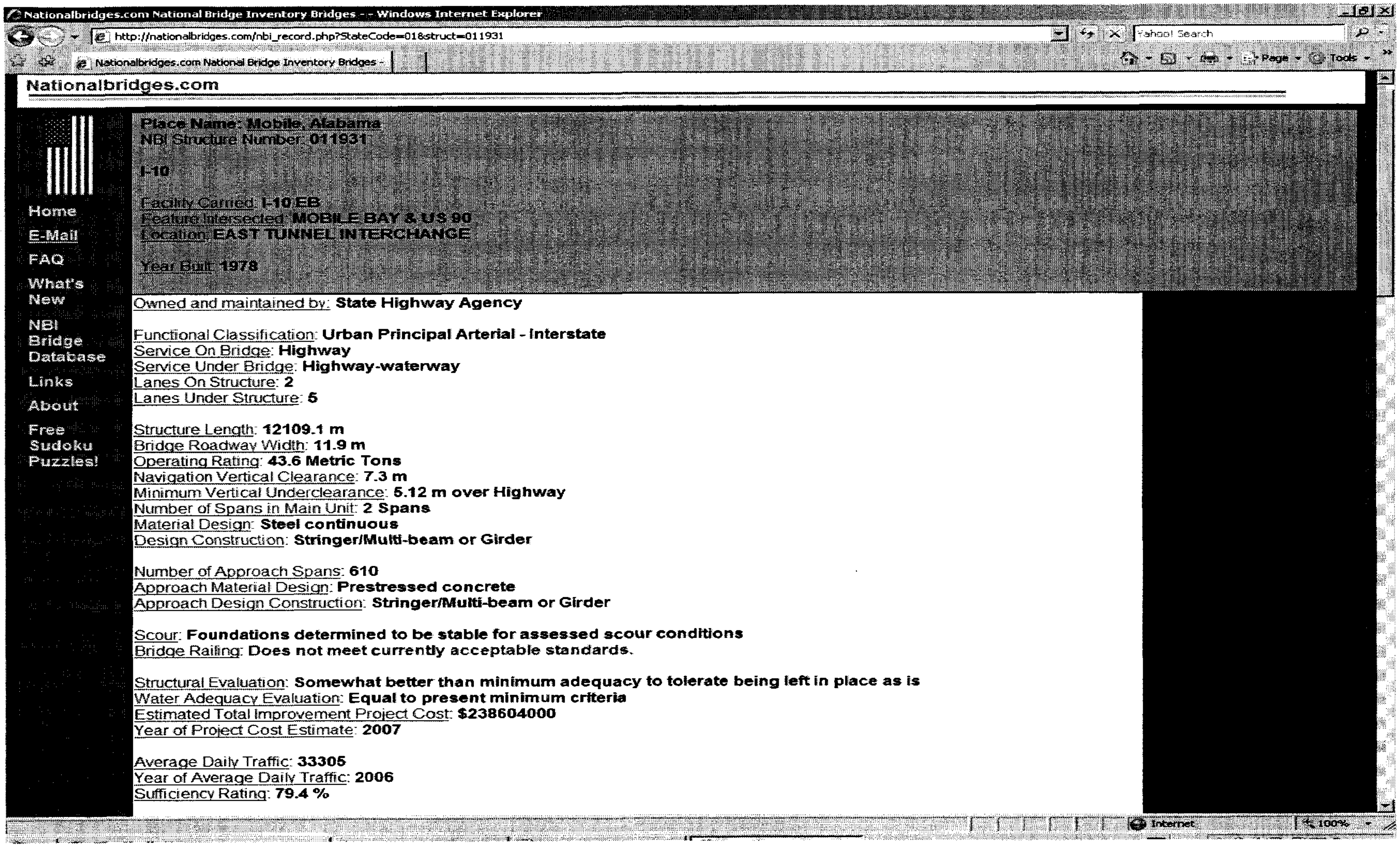


Figure 4.2 Sample data of National Bridge Inventory in the U.S.

Figure 4.3 Main roads in Quebec

This new GIS application can locate any bridge on the map and can retrieve the attributes of any bridge sought by the users, such as number of lanes, structure type, and bridge class. For instance, Figures 4.4, 4.5, and 4.6 show the distribution of bridge attributes in Montreal (329 bridges) as examples of bridges in Quebec. Figure 4.4 shows the structure types of bridges. Numbers 31 to 39 mean *slab bridge* and Numbers 41 to 49 indicate *beam bridge* (see Appendix C). Figure 4.5 shows the number of lanes of bridges. Numbers 9 and 0, however, do not indicate numbers of the lanes. They indicate that the number of lanes for a particular bridge is missing. Figure 4.6 shows the bridge class. There are 87 and 41 bridges belonging to Class 1 and Class 2, respectively. The remaining bridges in Montreal (201 bridges) are Class 3. From these examples it can be seen that GIS has very useful applications in the creation of a bridge inventory.

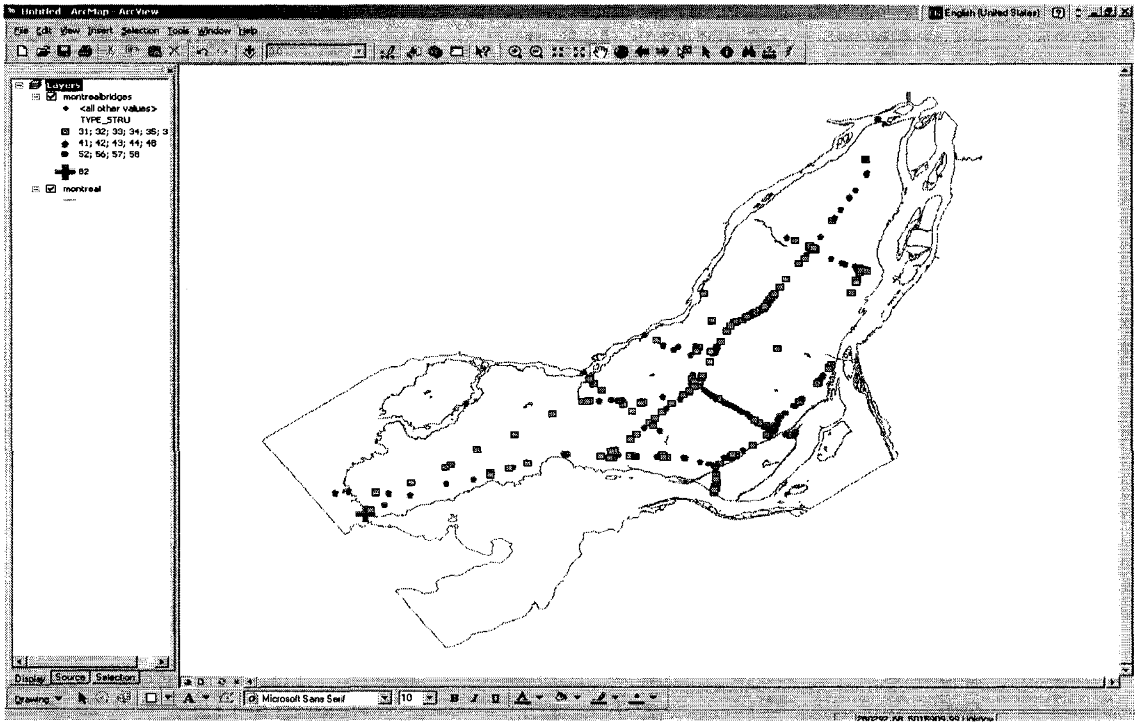


Figure 4.4 Structure types of bridges

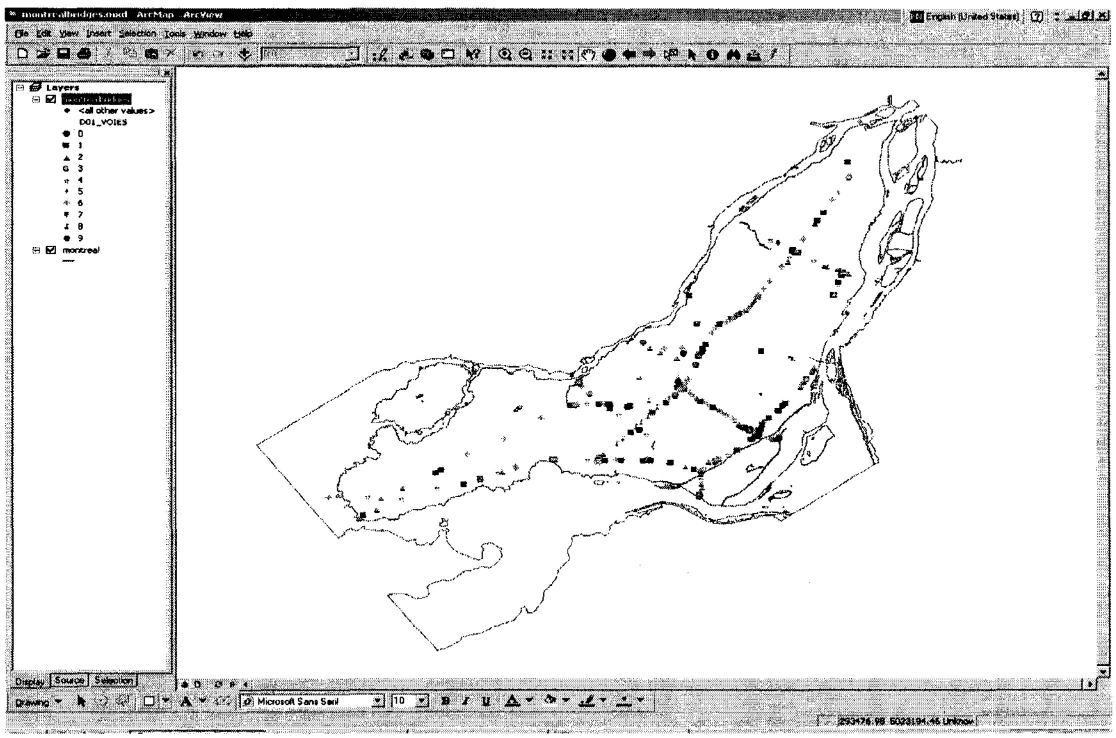


Figure 4.5 Number of lanes of bridges

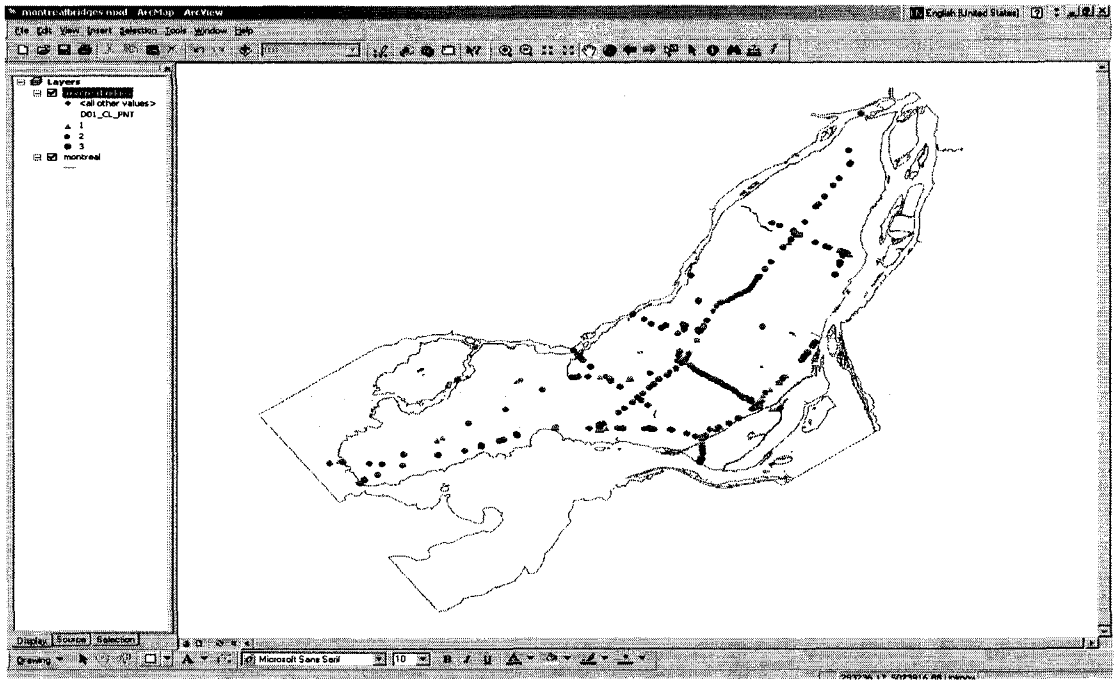


Figure 4.6 Bridge class

4.2.4 Application of SQL

During the process of developing the Quebec Bridge Inventory GUI, Structured Query Language (SQL) is utilized to handle the MTQ data. SQL is a standard interactive programming language for querying and modifying data and managing databases. Also, SQL can manipulate and retrieve data and provides an easy, intuitive way to interact with a database (Kline et al., 2004).

The following example shows the use of SQL to retrieve first from all bridges in Quebec a group of 656 bridges for which replacement cost is available; and second, to distinguish within this lager group some 322 bridge (Group B) found in southern Quebec from the bridges in northern Quebec (Group A). Then the combination of SQL and GIS will be used to display the separated 322 bridges. Here is an example of SQL query for the above selection:

```
SELECT *
FROM 656new
WHERE (([656new].NODOSS) Not In (select [322new].NODOSS from 322new
where [322new].NODOSS=[656new].NODOSS));
```

The result of the process combining SQL and GIS is shown in Figures 4.7, 4.8, 4.9, and 4.10. Figure 4.7 shows all bridges in Quebec. Figure 4.8 shows the 656 bridges, for which the replacement cost is available. Figure 4.9 and Figure 4.10 show the bridges of Group A and Group B, respectively.

The foregoing example clearly shows the advantage of combining GIS and SQL to manage the MTQ database. This application can be of great help to engineers or managers in utilizing the existing data and facilitating bridge management.

Figure 4.7 All bridges in GIS in Quebec

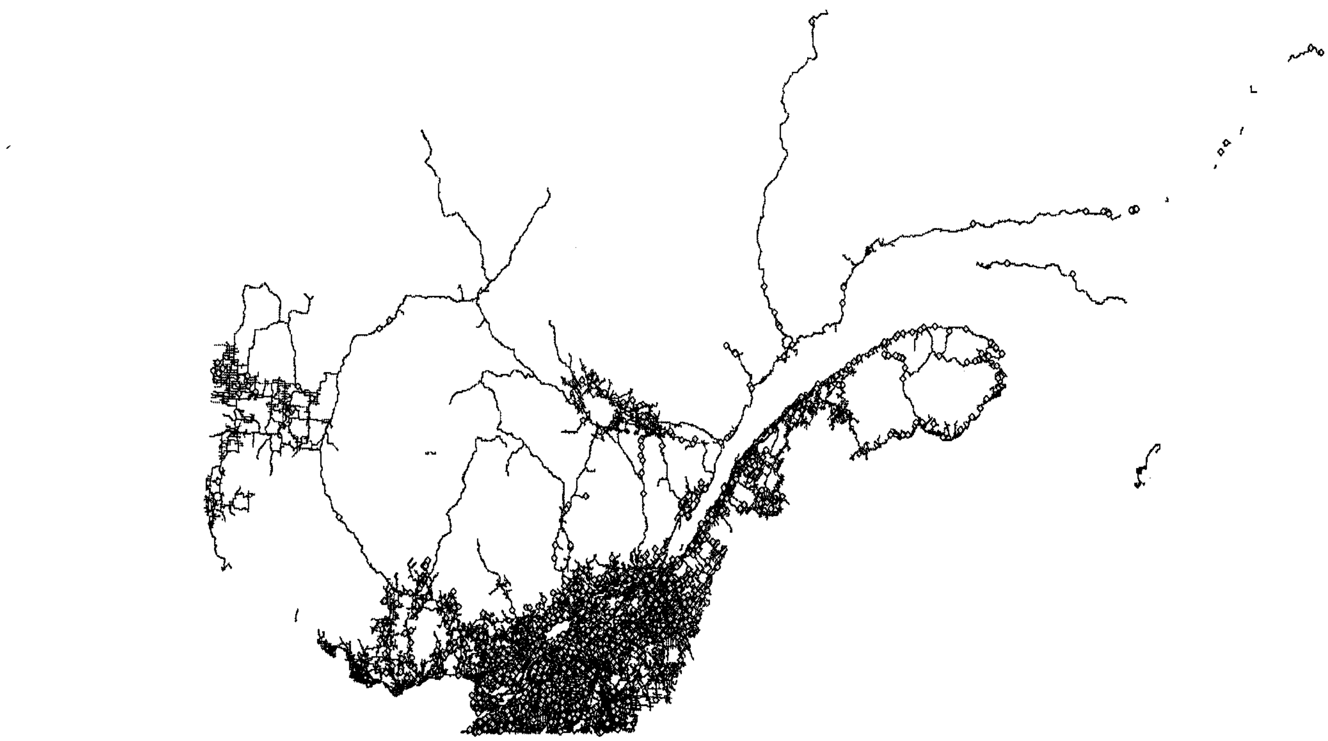


Figure 4.8 656 selected bridges in GIS in Quebec

Figure 4.9 Bridges of Group A (North)

Figure 4.10 Bridge of Group B (South)

4.2.5 Quebec Bridge Database GUI

Figure 4.11 shows the main interface of developed Quebec Bridge Database GUI (Table SGSD010P of the database). From this main interface, the following categories of basic information are displayed: General Information, Bridge Deck Inspection and Maintenance, Loading Capacity, Bridge State Evaluation, Coefficients, Cost, Comment and GIS Location Map. For instance, the bridge with file number 00002 was built in 1964. The replacement cost was $150,000 in 1995. From GIS Location Map, the exact location of the Bridge is marked clearly as a blue dot. It should be mentioned that many fields are missing data (i.e., those with blanks or zero values).

Each button under the interface is a link to a detailed interface of another table. For example, the link SGSD400P links to information on obstacles in the section (Figure 4.12). From the image shown in this figure, the recent situation of the bridge is recorded visually. Other links would display detailed bridge information such as inspection, maintenance and various costs as explained in the following.

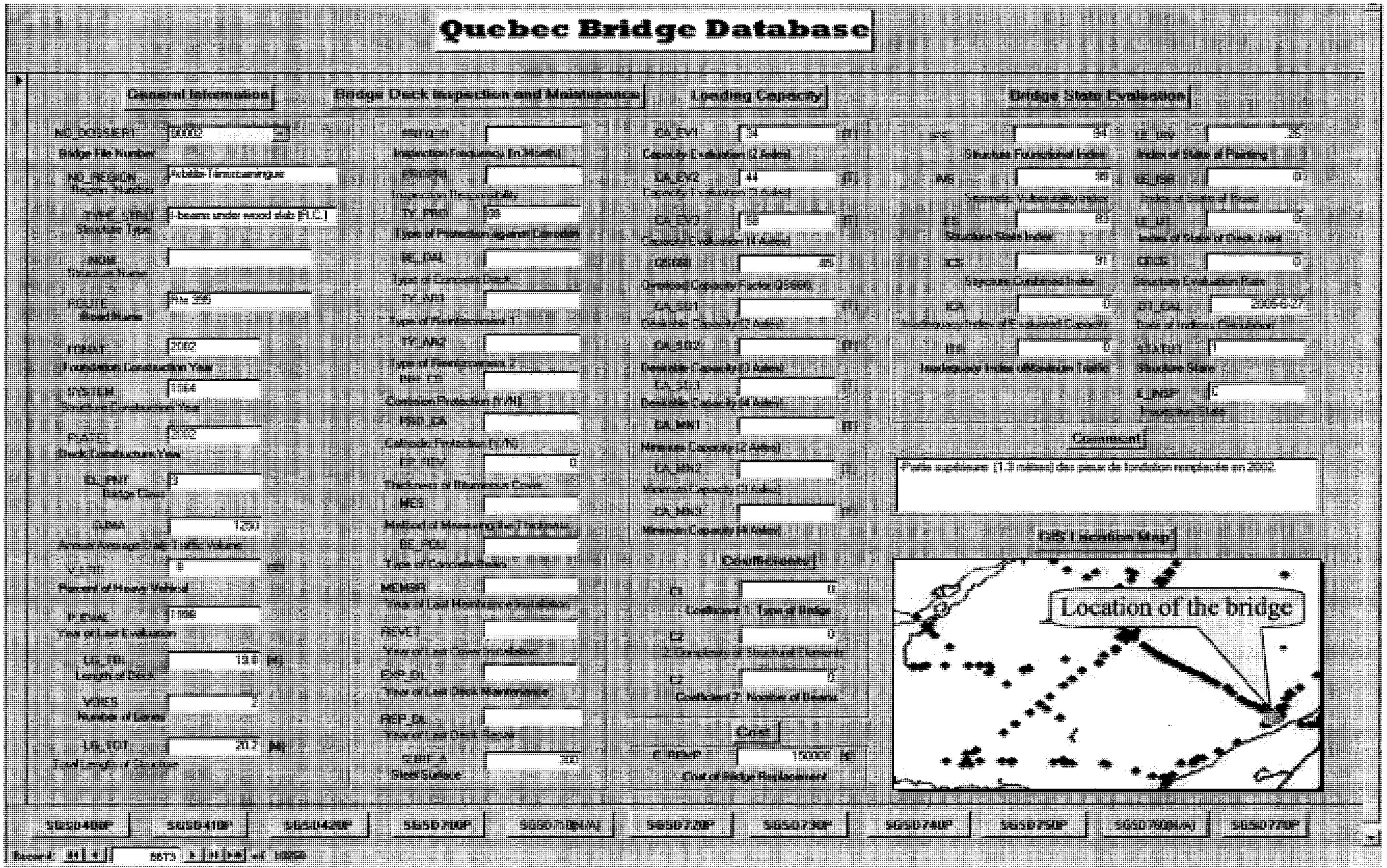


Figure 4.11 Main interface for the Quebec Bridge Database (Table SGSD010P of the database)

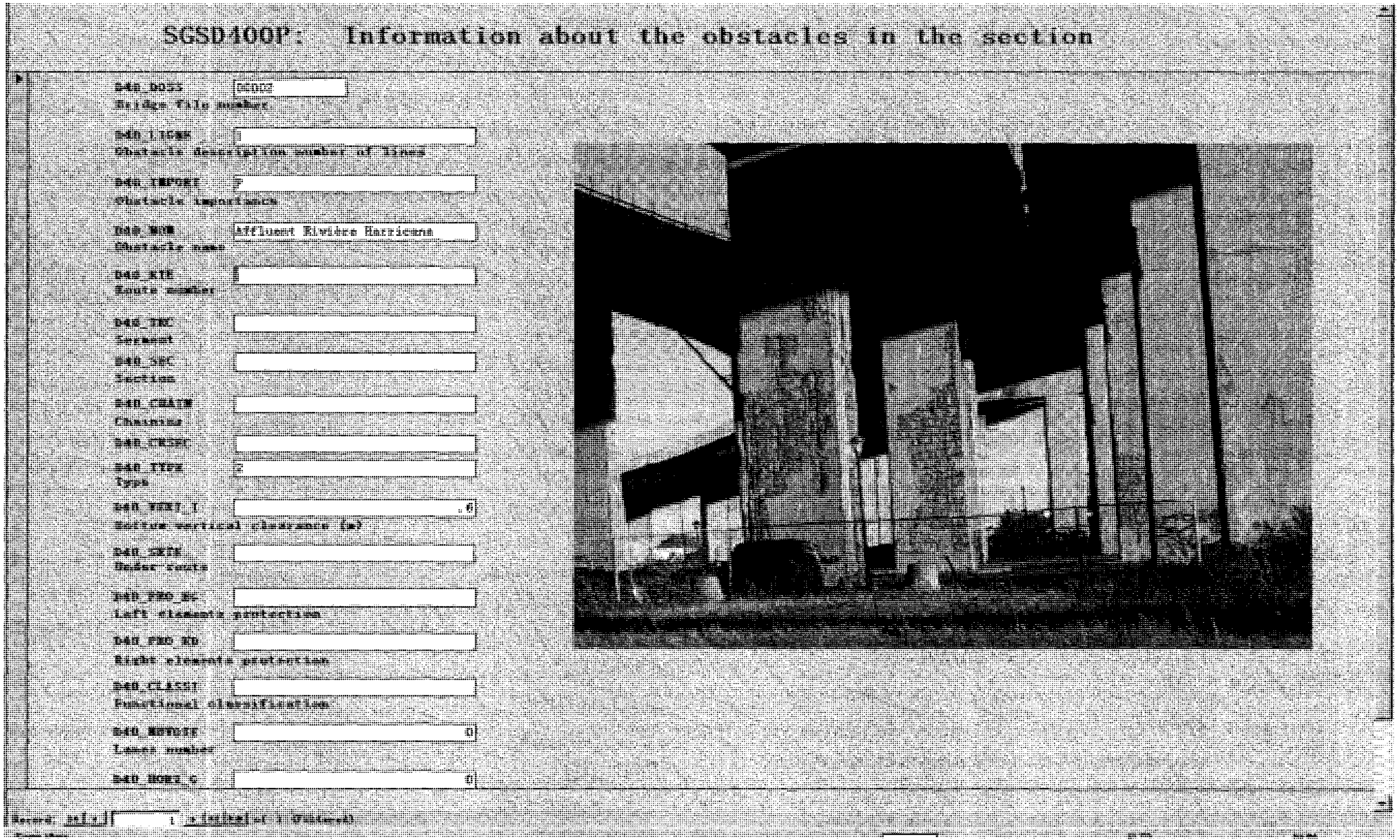


Figure 4.12 Information on obstacles

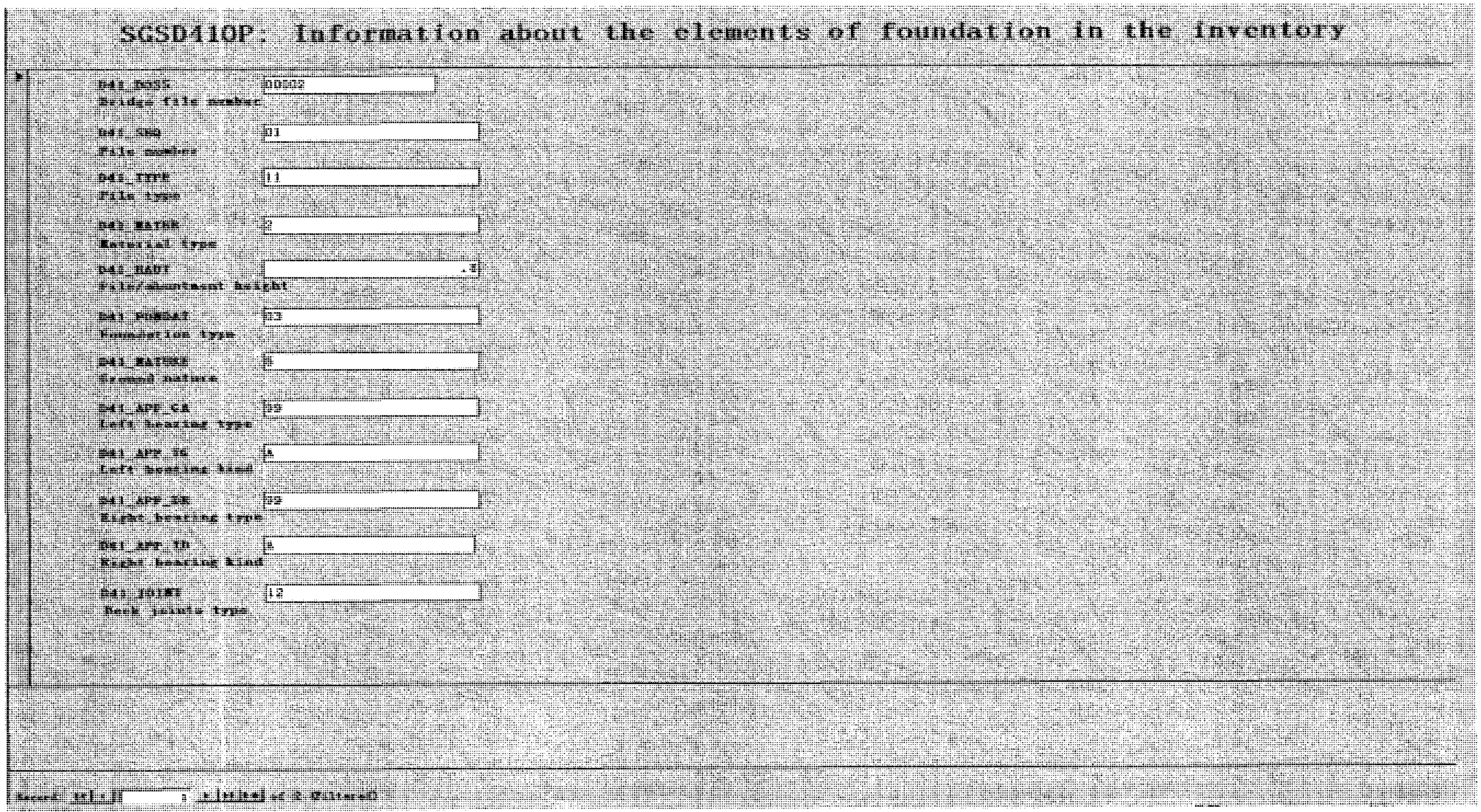


Figure 4.13 Information on foundation element

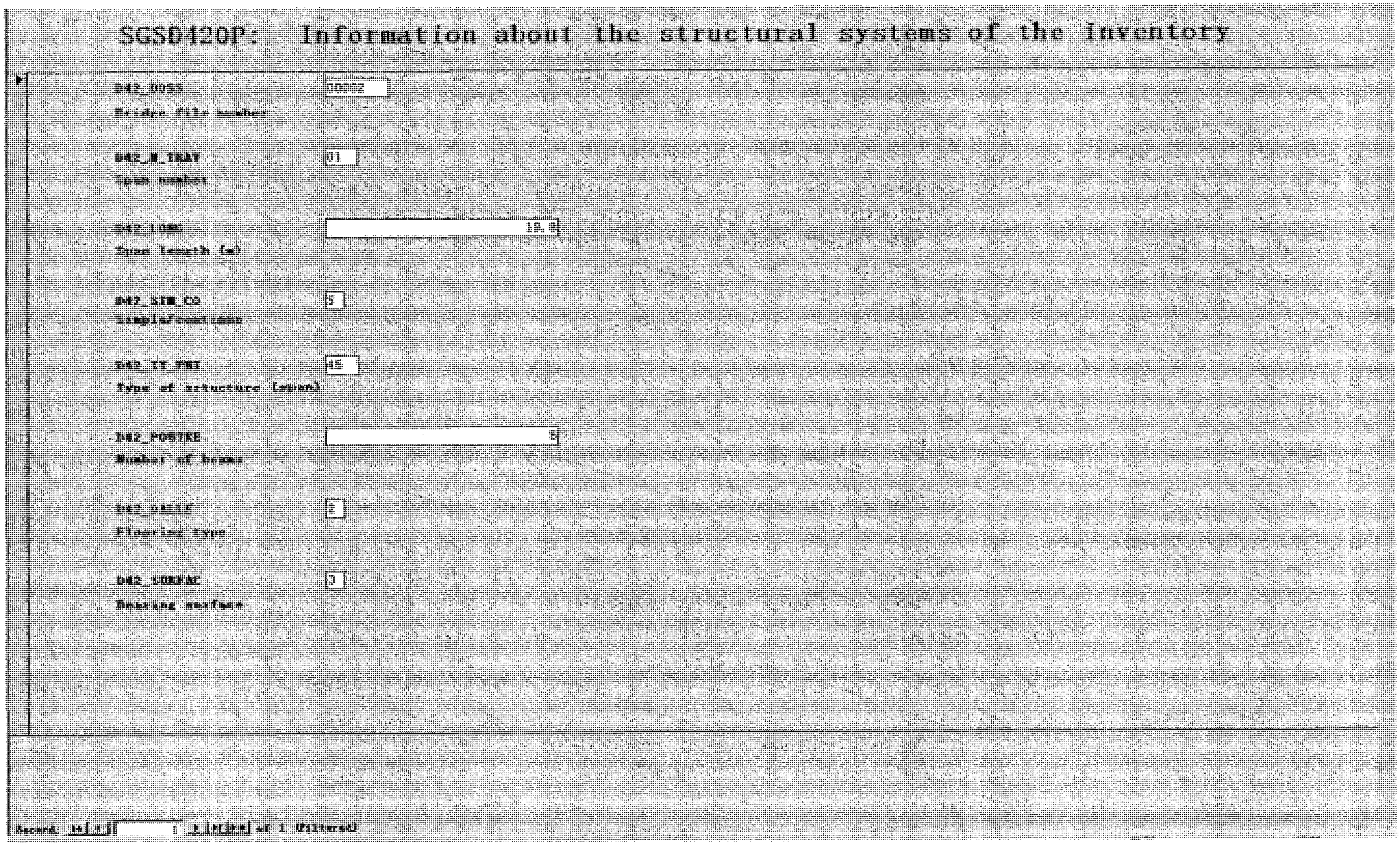


Figure 4.14 Information on the structural system

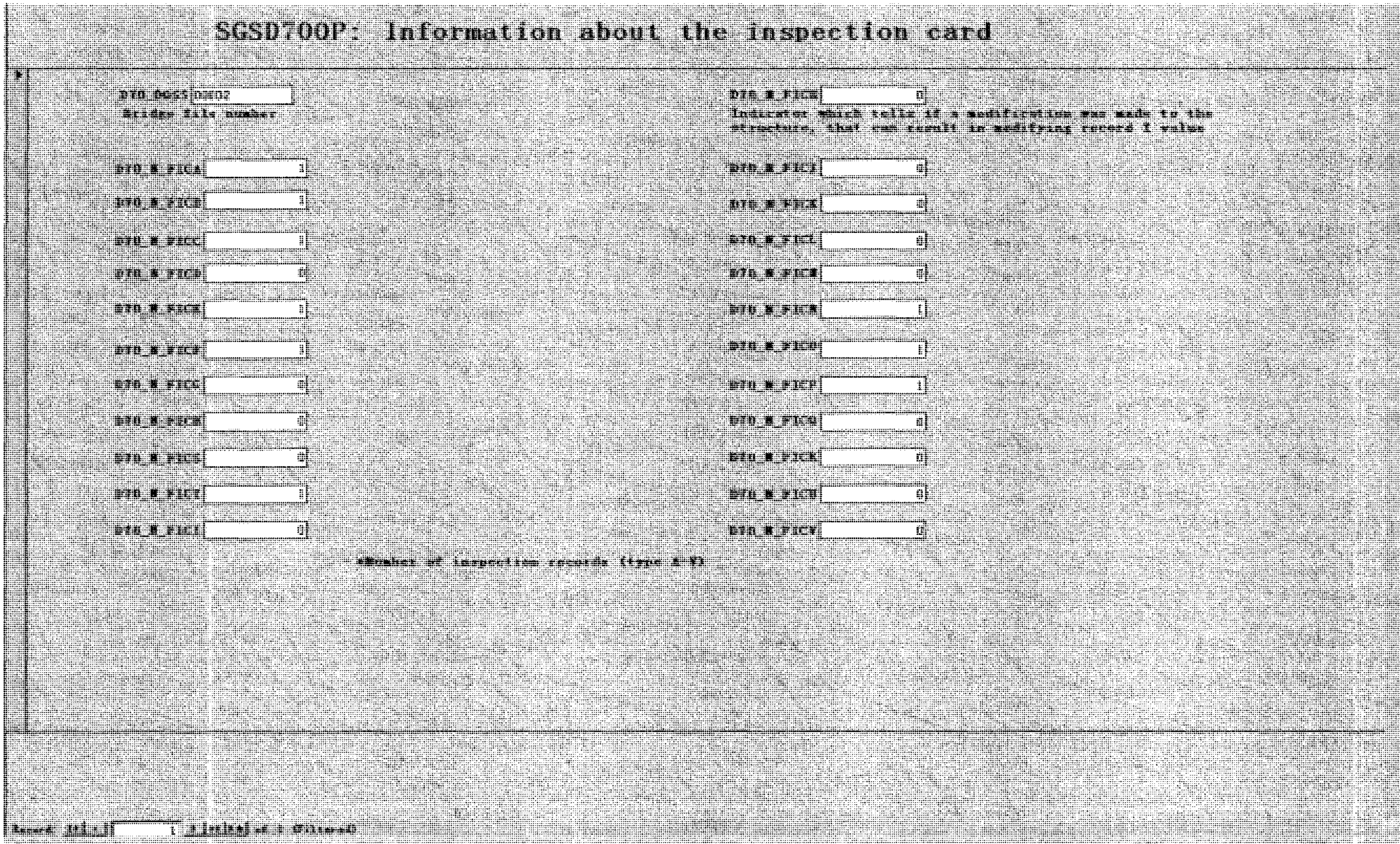
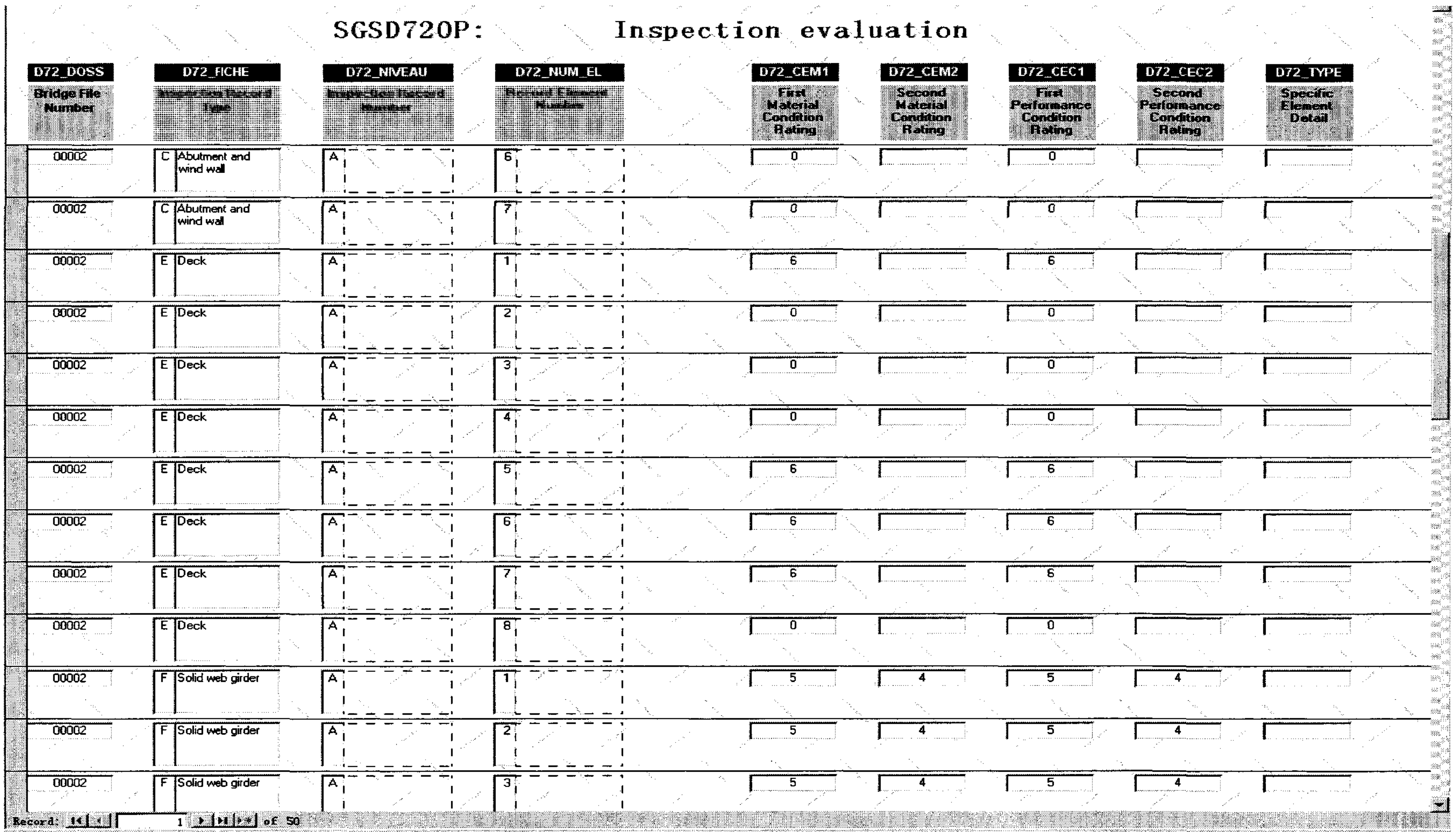


Figure 4.15 Information on the inspection card



SGSD720P: Inspection evaluation

D72_DOSS Bridge File Number	D72_FICHE [illegible]		D72_NIVEAU [illegible]	D72_NUM_EL [illegible]	D72_CEM1 First Material Condition Rating	D72_CEM2 Second Material Condition Rating	D72_CEC1 First Performance Condition Rating	D72_CEC2 Second Performance Condition Rating	D72_TYPE Specific Element Detail
00002	C	Abutment and wind wall	A	6	0		0		
00002	C	Abutment and wind wall	A	7	0		0		
00002	E	Deck	A	1	6		6		
00002	E	Deck	A	2	0		0		
00002	E	Deck	A	3	0		0		
00002	E	Deck	A	4	0		0		
00002	E	Deck	A	5	6		6		
00002	E	Deck	A	6	6		6		
00002	E	Deck	A	7	6		6		
00002	E	Deck	A	8	0		0		
00002	F	Solid web girder	A	1	5	4	5	4	
00002	F	Solid web girder	A	2	5	4	5	4	
00002	F	Solid web girder	A	3	5	4	5	4	

Record: 1 of 50

Figure 4.16 Inspection evaluation

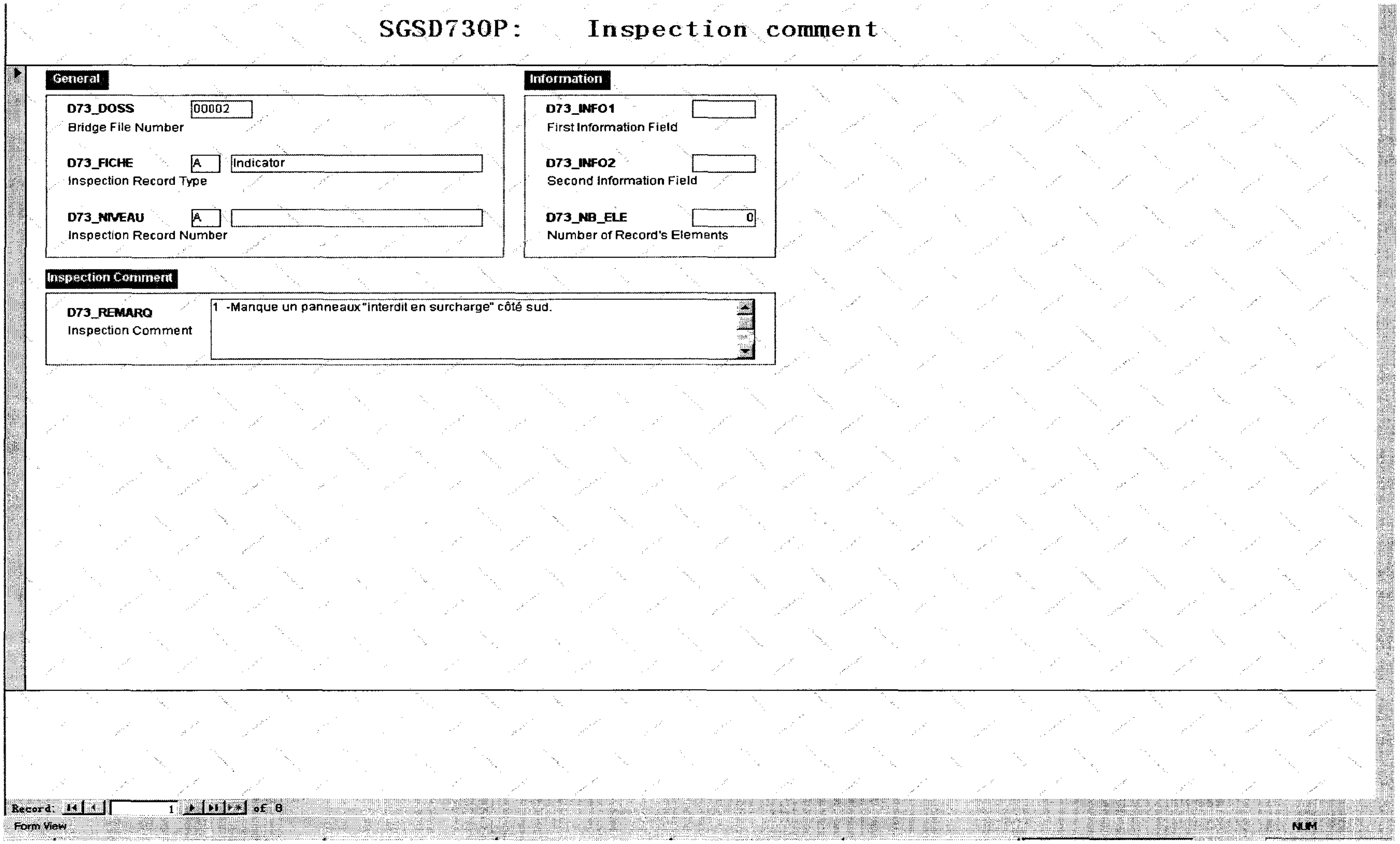


Figure 4.17 Inspection comment

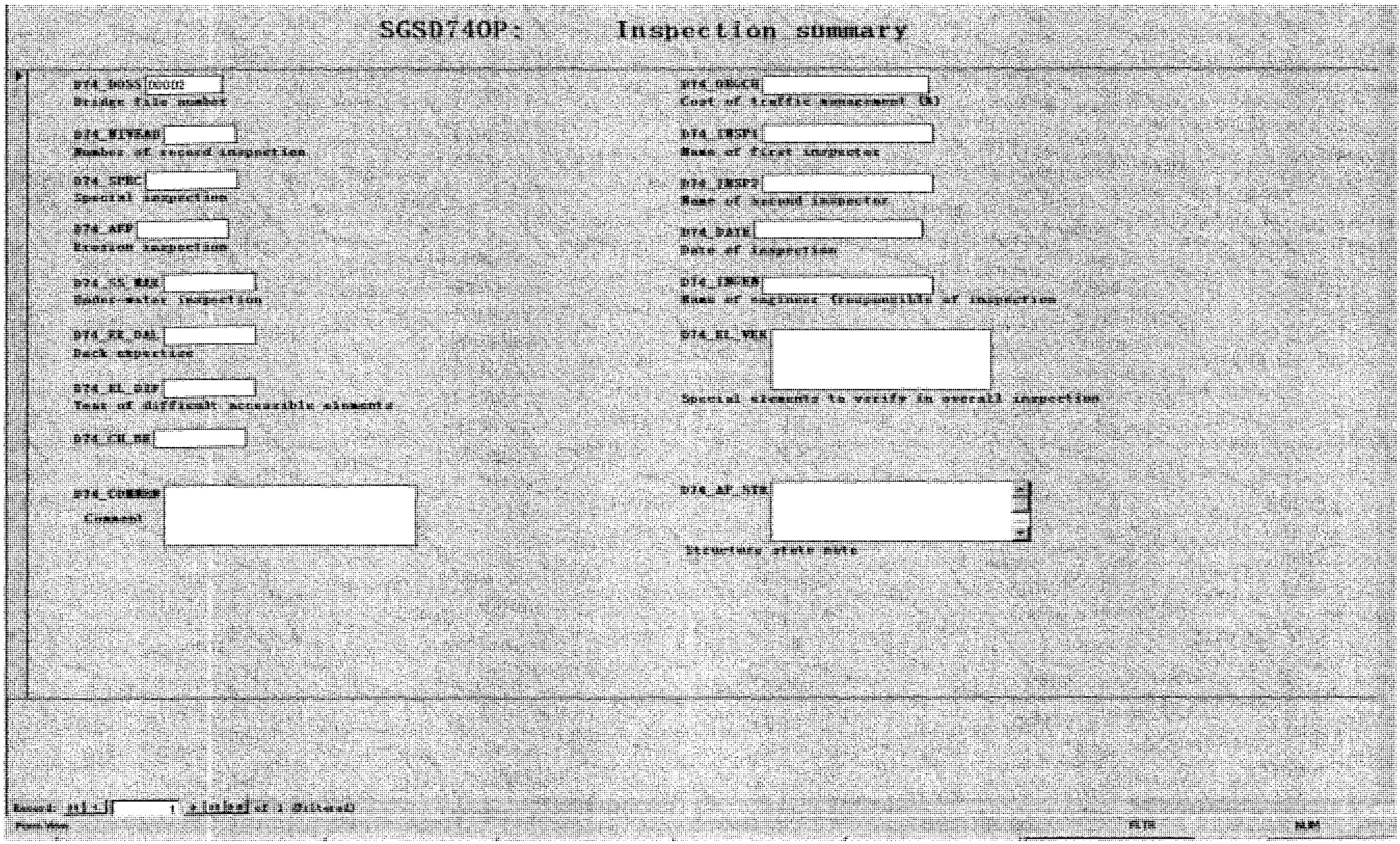


Figure 4.18 Inspection summary

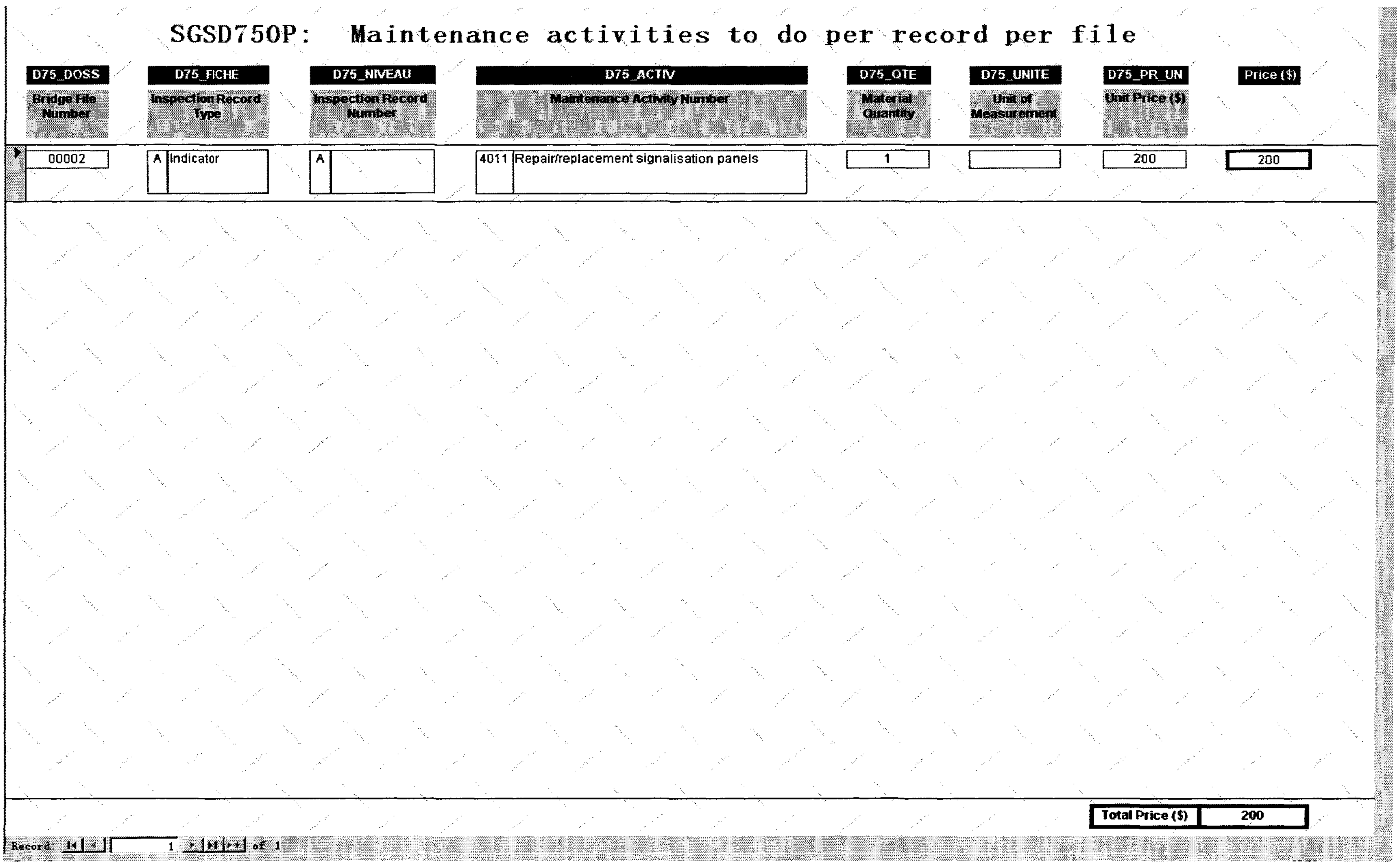


Figure 4.19 Maintenance activities to do per record per file

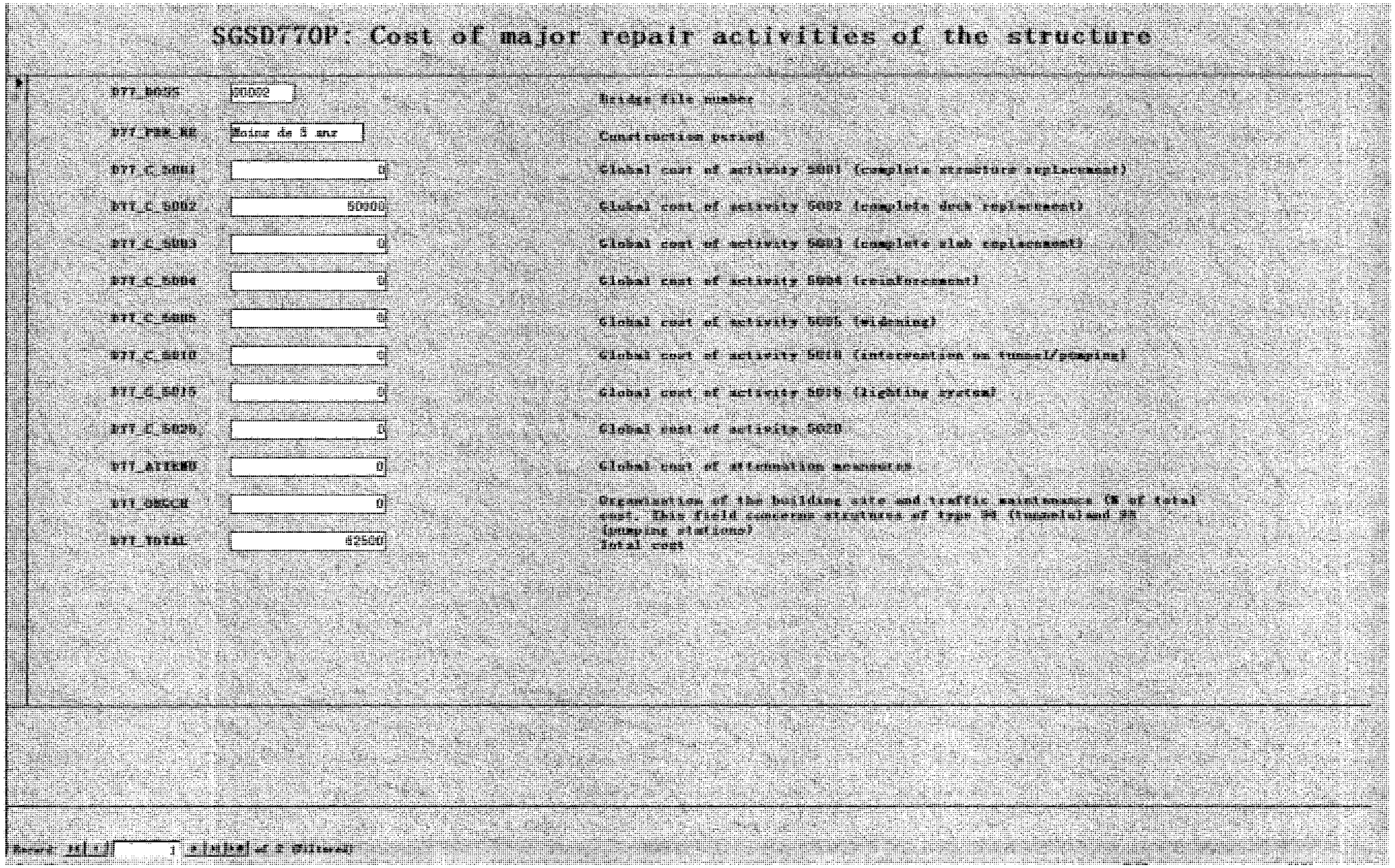


Figure 4.20 Cost of major repair activities of the structure

There are ten interfaces developed to link to the ten tables of the MTQ database. Bridge 00002 will be taken as an example to explain how the interfaces work. As was explained above, Figure 4.11 is an example of the main interface, which here displays general information about Bridge 00002. The Annual Average Daily Traffic (AADT) is 1250 and there are 2 lanes. Under the Bridge State Evaluation, the Structure Functional Index and the Structure State Index are 94 and 83, respectively. The *Comment* indicates that the upper part of pile foundation (1.3 meters) was replaced in 2002.

Figure 4.12 is the interface to Table SGSD 400P of the database and it gives the information about the obstacles in the section. From this figure, we can see that the obstacle name is "Affluent Riviere Harricana". Figure 4.13 is the interface to the SGSD 410P, and it gives the information on the foundations of the bride including the pile number, type and material, foundation type, and the right and the left bearing type. SGSD 420P (Figure 4.14) is the interface about the structural system. It tells us for example that the span length of Bridge 00002 is 19.8 m. The type of structure is I-beam under R.C. slab and it has 5 beams. Figure 4.15 shows interface SGSD700P, which displays the bridge inspection records types A-V.

SGSD 720P, SGSD 730P, and SGSD 740P (Figures 4.16, 4.17 and 4.18) show all record information related to inspection. Table 4.2 shows the element categories of bridges in Quebec (MTQ, 2004). Table 4.3 shows the eight elements of deck inspection evaluation (MTQ, 2004).

Table 4.2 Element categories of bridges in Quebec (MTQ, 2004)

Inspection Form	Form Description	No. of Inspected Elements
A	Signalistion	4
B	Water stream, approaches backfilling, and slope protection	5
C	Abutment and wing wall	7
D	Foundation and substructure	6
E	Deck	7
F	Solid web girder	7
G	Box girder	8
H	Truss beam	5
I	Arch beam	6
J	Arch with spanderal wall	9
K	Structure floor	7
L	Wind bracings	5
M	Deck joints	7
N	Curbs and side walks	3
O	Barriers	9
P	Approaches	7
Q	Retaining walls	6
R	Culverts	6
S	Covered bridge	11
U	Suspension bridge	7
V	Cable-Stayed bridge	3
		135

Table 4.3 Deck inspection evaluation (MTQ, 2004)

No.	Type	Element	MCR	PCR	Description
1	S	Wearing surface			
2	A	Drainage system			
3	P	Exterior surface 1			
4	P	Exterior surface 2			
5	P	End soffit 1 (under deck)			
6	P	Middle soffit (under deck)			
7	P	End soffit 2 (under deck)			
8	P	Above concrete deck			

The letters A, P, and S mean Auxiliary element, Primary element and Secondary element, respectively. MCR and PCR indicate the Material Condition Rating and the Performance Condition Ratings, respectively. Interface SGSD 720P shows Inspection

Record Type, Inspection Record Number, Record Element Number and so on. For instance, for Bridge 00002, one of the inspections is for the deck (Code E). There are eight categories of inspection elements: pavement surface, drainage system, exterior side 1 in R.C., exterior side 2 in R.C., end soffit 1 (under deck), middle soffit (under deck), end soffit 2 (under deck) and above concrete deck. Figure 4.21 shows the deck evaluation areas. Among those eight categories of inspection elements, Figure 4.16 shows the evaluation codes MCR and PCR (the value of a code is between 1 (critical) and 6 (excellent)). Four of the results are 6, which means excellent condition with reference to pavement surface, end soffit 1 (under deck), middle soffit (under deck), and end soffit 2 (under deck).

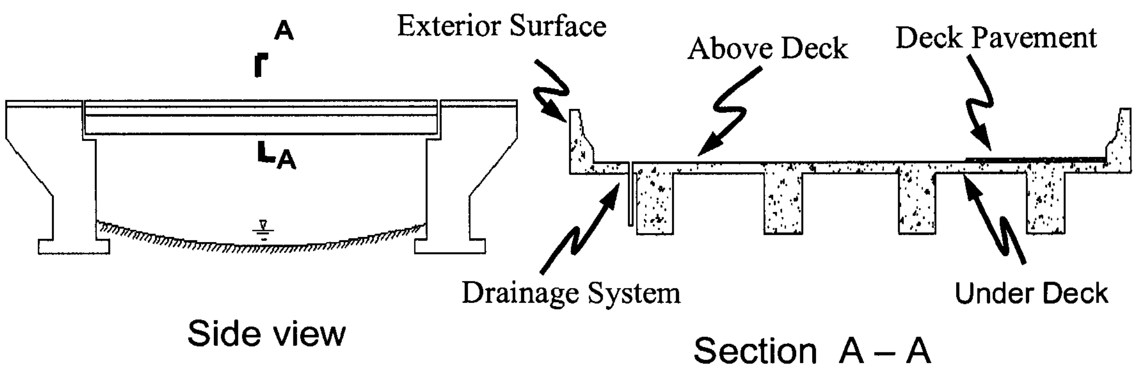


Figure 4.21 Deck evaluation areas

Interfaces SGSD 730P and SGSD 740P (Figure 4.17 and Figure 4.18) have more details about inspection results of Bridge 00002, such as comments about the inspection.

Interface SGSD 750P (Figure 4.19) records information about what kind of maintenance activities were undertaken for a bridge. For Bridge 00002, the repair or the replacement of signalization panels was done. The use of material quantity is 1 unit and unit price is $200. In interface of SGSD 770P, the major repair activities of the structure are displayed. We can see in Figure 4.20 that the construction period was less than 5 years and the replacement cost was $50,000. This is an approximate value. The replacement cost is based on historical costs and may be revised each year so that estimates are more accurate.

4.3 QUEBEC BRIDGE REPLACEMENT COST ANALYSIS

4.3.1 Introduction

The purpose of this analysis is to demonstrate the benefits of having a comprehensive database of bridges and how this data can be used for calculating average replacement cost as a simple case study. Like any structures, bridges need maintenance during every period of service after they are built. However, resources for maintenance are limited compared to the huge needs. Therefore, it is necessary to make optimal financial decisions about limited maintenance funds in order to balance economic resources and bridge safety. This section explores factors that should be considered in decisions about bridge replacement cost. Figure 4.22 shows replacement cost as one element of BMS cost data, as viewed within the context of the three current approaches: network-level agency costs, project-level agency costs, and user costs (Thompson, 1996).

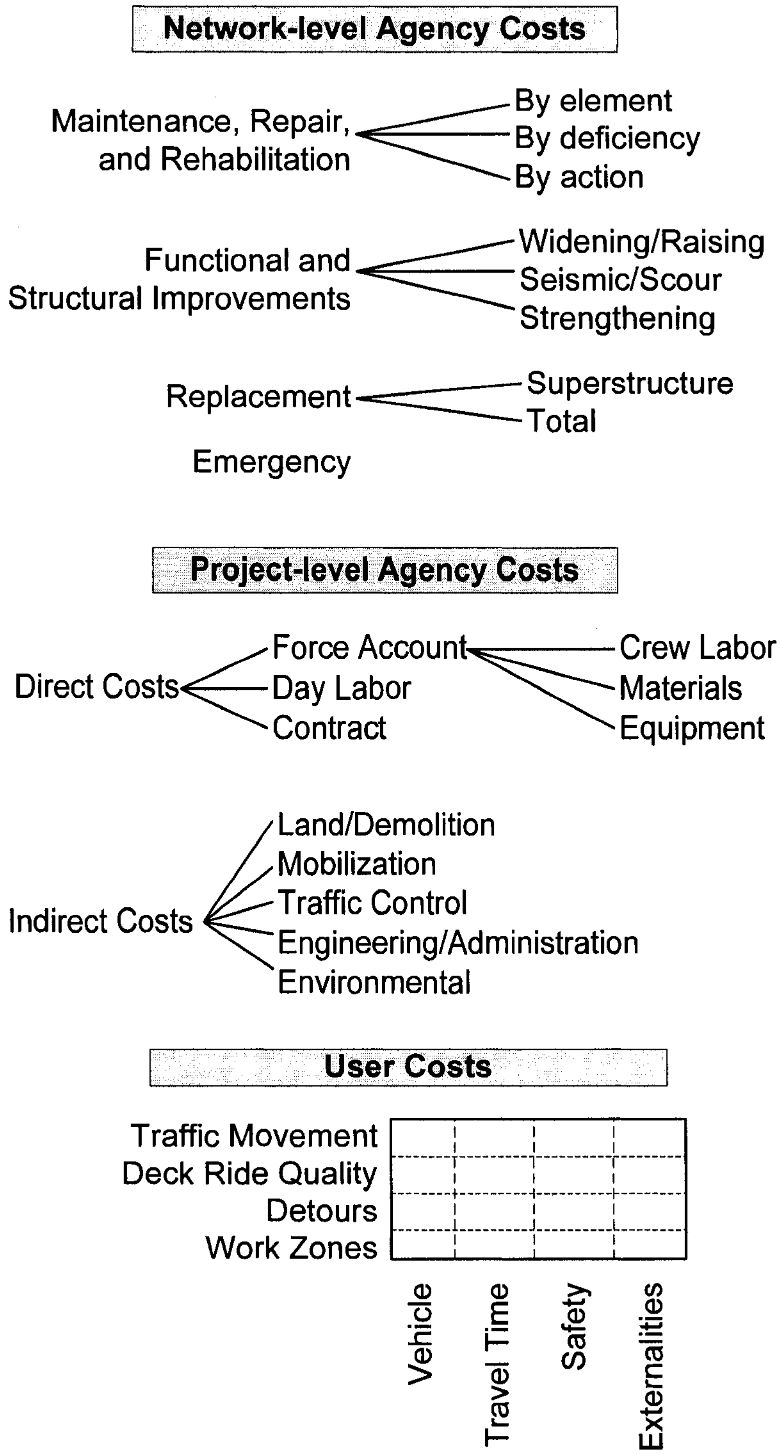


Figure 4.22 Structure of BMS cost data (Thompson, 1996)

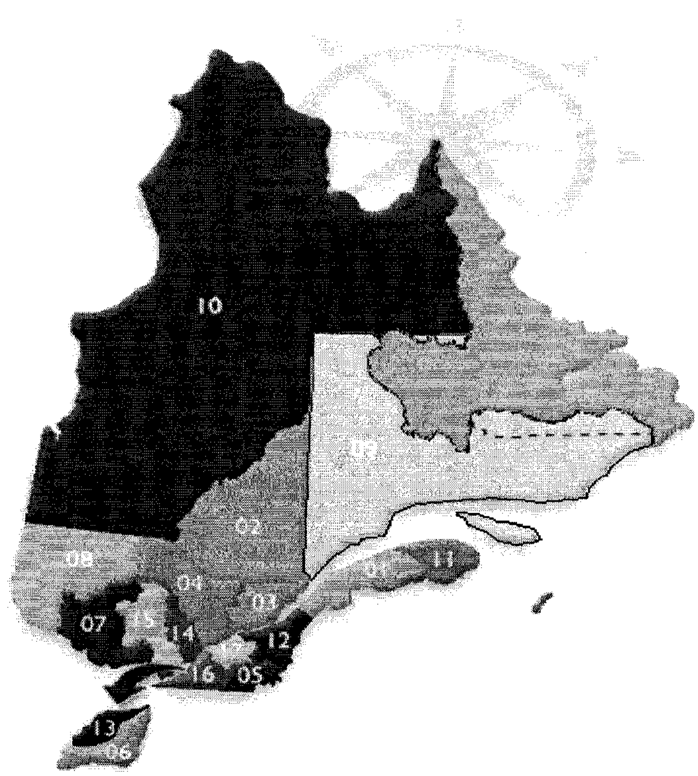


Figure 4.23Administrative regional divisions (Quebec Portal, 2008)

Before any detailed analysis of the replacement cost of Quebec bridges, an overview of Quebec bridge data will be helpful. In Quebec, there are about 8,700 bridges in total, which are recorded in the database of the Ministry of Transportation Quebec (MTQ). The MTQ divides the whole province into 17 administrative regions. Figure 4.23 shows the administrative regional divisions of Quebec (Quebec Portal, 2008).

The following factors are used to analyze the replacement cost of bridges in Quebec: construction year, structure type, and location. As for the type of structure, different types of bridge structures would have different replacement costs. These two factors have a very important effect on replacement cost. The third factor, location, involves the influence of weather conditions and the difficulty of work in isolated areas on the replacement cost.

In Analysis Part I, the first two factors, that is, construction year and type of structure will be discussed together. In Analysis Part II, the third factor – construction location – will be analyzed.

4.3.2 Data Used in the Analysis

The following data have been used in the analysis: (1) bridge type, (2) construction year, (3) length and width of bridge deck, (4) replacement cost, and (5) location of the bridge. The first three data items are extracted from Table SGAD010P. The replacement cost of the whole structure is taken from Table SGAD770P. The last data item is based on GIS. The database of MTQ has the data about replacement cost available only of 759 bridges. Furthermore, the GIS data have some of the bridges missing (103 out of 759). Therefore, our analysis is based on 759 and 656 bridges as a sample of all bridges in Quebec without and with considering the location, respectively. Figures 4.24, 4.25, and 4.26 show the distributions of the construction year, bridge type, and the location of the bridges of the sample. From these figures, it can be seen that the selected set of bridges (656) can be considered as a representative sample of bridges in Quebec.

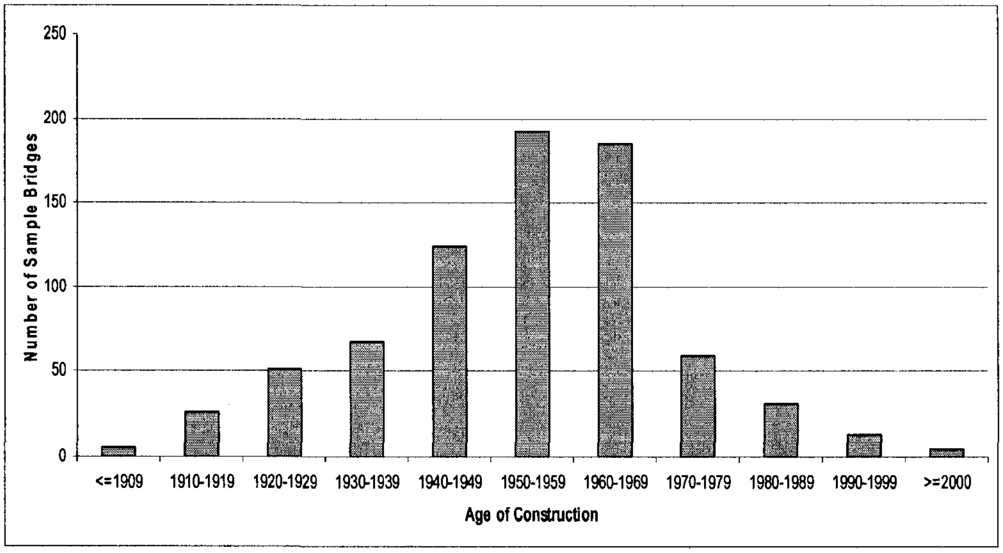


Figure 4.24 Distribution of construction year of sample bridges

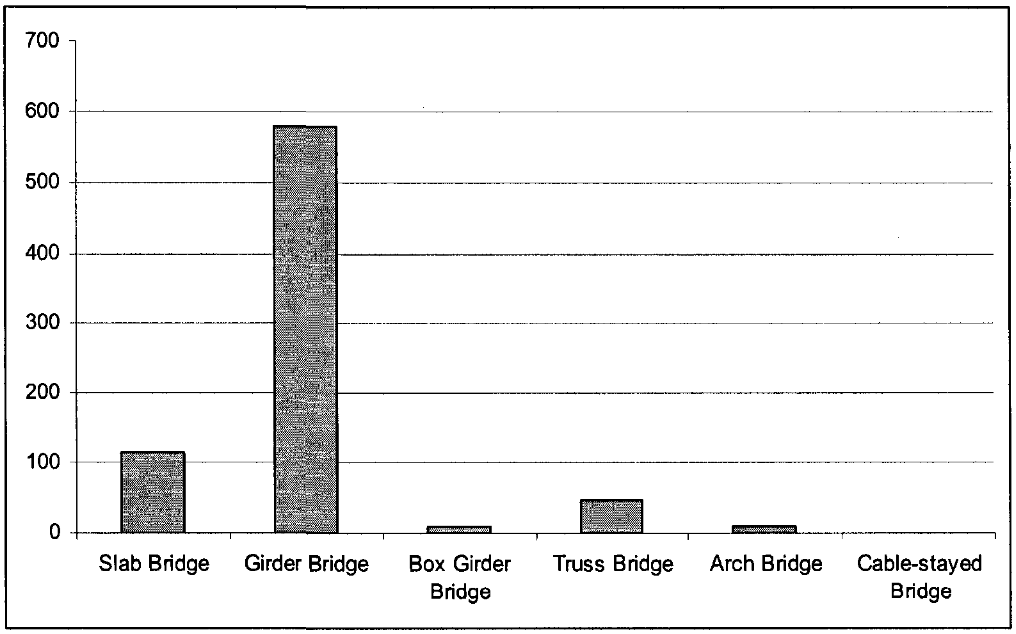


Figure 4.25 Distribution of bridge type of sample bridges

Figure 4.26 Distribution of location of sample bridges

Analysis Part I

Table 4.4 shows the average replacement cost (unit: $\$/m^2$) of the 759 bridges in Quebec. The table uses bridge structure type and construction period as determining factors in the calculation of this cost. The steps for getting Table 4.4 are: (1) calculate the replacement cost per bridge structure; (2) select all bridges of specific type and period of construction; and (3) calculate the average replacement cost for each category.

The first row shows six types of bridges: Slab Bridge, Girder Bridge, Box-girder Bridge, Truss Bridge, Arch Bridge and Cable-stayed Bridge. The first column shows the six categories of construction period. The average replacement cost during 1940-1944 is lower than other categories.

The average replacement cost based on type gives the average replacement cost for each type of bridge, irrespective of construction period. The last column indicates the average replacement cost of all bridges of a certain type irrespective of the construction period. It can be noticed from Table 4.1 that truss and arch bridges were built less frequently after the 1940s.

Among the six types of bridges, the average replacement cost of the truss bridge is the second highest ($\$3662/m^2$), just after that of cable-stayed bridges ($\$8169/m^2$). The truss bridge is the strongest and most stable structure types. However, because the truss bridge uses a great amount of steel, its cost is the highest. The girder bridge gradually became the main type of bridge structures, especially after 1950. As Table 4.4 indicates, girder bridges are more expensive than slab bridges.

According to MTQ (Bélanger and Gagnon, 2008), the replacement average costs (of bridge deck area) are very different from one bridge to another, even for the same bridge type. For example, for girder bridges (most of the 700 bridges are of this type), the average replacement costs is $\$ 2148/m^2$, but there are some bridges with replacement costs of more than $\$ 3500/m^2$. There may be several factors to explain such variation. First, the accuracy of the amounts varies depending on the progress of the project preparation. Secondly, some regions also include the cost of mitigation measures (construction of a temporary bridge, parking incentives, etc.). Finally, some provisions for contingencies would occur.

At the MTQ, cost estimates are made at various checkpoints in the project path (3 or 4 estimates to arrive at the final estimate at the step of plans and specifications. Some "default" estimates are used in the first step (and maybe sometimes in the second). Efforts are being made (and tools to facilitate the estimation are currently under development) to increase the accuracy of estimates at the point of control, applying adjustment factors to take into account the specificity of the bridge to rebuild (complexity of the site, piers in a river, type of foundation, time of year when the tender is launched, traffic control, fees, etc.)

Table 4.4 Average replacement cost of the bridges per type of bridge and remaining service life (unit: $\$/m^2$)

Structure Type / Construction Period	Slab Bridge	Girder Bridge	Box-girder Bridge	Truss Bridge	Arch Bridge	Cable-stayed Bridge	Average based on construction period
<=1929	1959 (4)	2531 (42)	0	4221 (33)	2287 (4)	0	3450 (83)
1930-34	2586 (1)	3427 (27)	0	3586 (3)	2569 (2)	0	3420 (33)
1935-39	1950 (8)	2701 (23)	0	2520 (2)	1910 (2)	0	2466 (35)
1940-44	586 (10)	2211 (23)	0	93 (1)	0	0	1447 (34)
1945-49	2912 (30)	2074 (59)	0	2358 (3)	2810 (1)	0	2246 (93)
>1950	3133 (62)	2011 (404)	3210 (9)	3108 (5)	0	8169 (1)	2571 (481)
Average based on type	2517 (115)	2148 (578)	3210 (9)	3662 (47)	2287 (9)	8169 (1)	*2569 (759)

Note:

- ( ) means the number of bridges of this category.
- * means the general average replacement cost for 759 bridges. Appendix H has the bridge construction unit cost per square foot in the U.S.A. for comparison.
- The cost data are based on year 1999 as reference year.

Analysis Part II:

Canada has long and harsh winters. The location of bridges ought therefore to have an important effect on the replacement cost. In this analysis, GIS is used to show the geographical location of bridges. Because records are missing for some bridges among the 759 bridges in the original data set, 656 bridges have been selected in this analysis. The bridges have been divided into two groups: North Bridges (Group A) and South Bridges (Group B). This division is based on the criterion that each group should contain about half of the available bridges. Access and ArcGIS are the tools used to identify and locate the bridges for which the necessary data is available. Finally, 656 bridges are divided into 334 bridges in Group A and 322 bridges in Group B. The last step is the calculation of the replacement cost. Figure 4.27 outlines the sequence of steps for replacement cost analysis based on location of bridges.

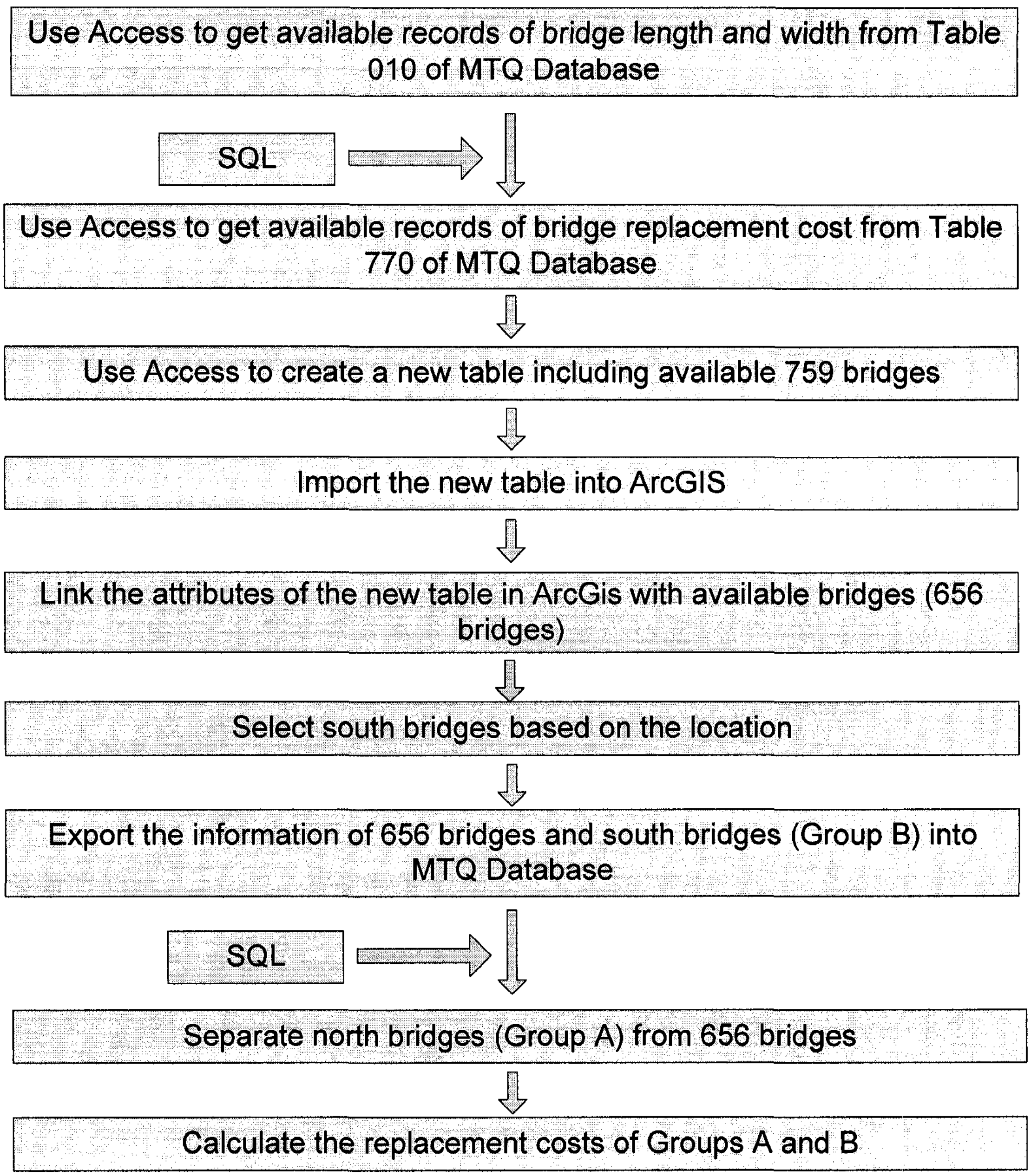


Figure 4.27 Flowchart of replacement cost analysis based on location of bridges

Figure 4.8 shows the 656 bridges in GIS in Quebec for which the necessary data is available. Figure 4.9 and Figure 4.10 show the bridges of Group A (large dots) and the ones of Group B (large dots).

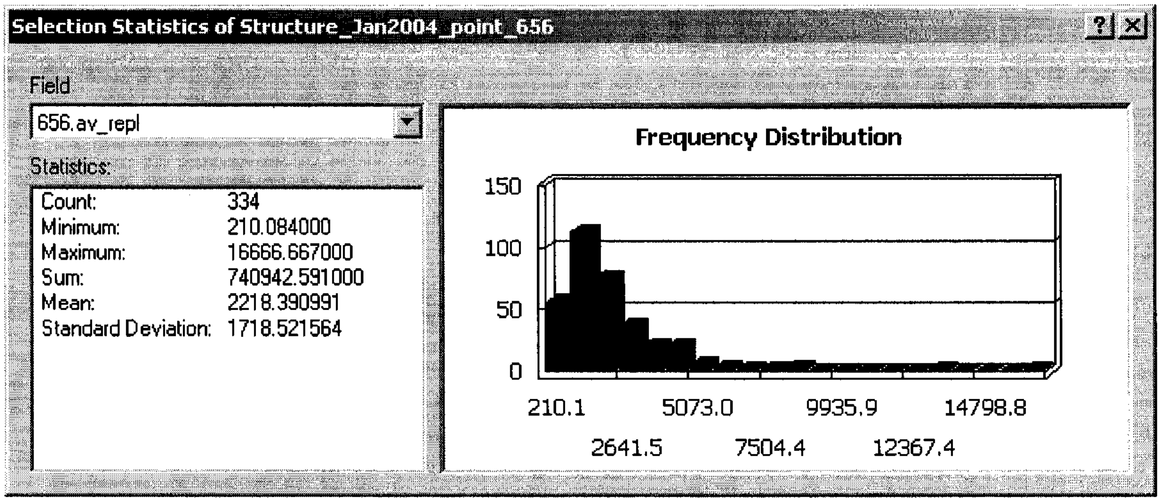


Figure 4. 28 Analysis result of Group A

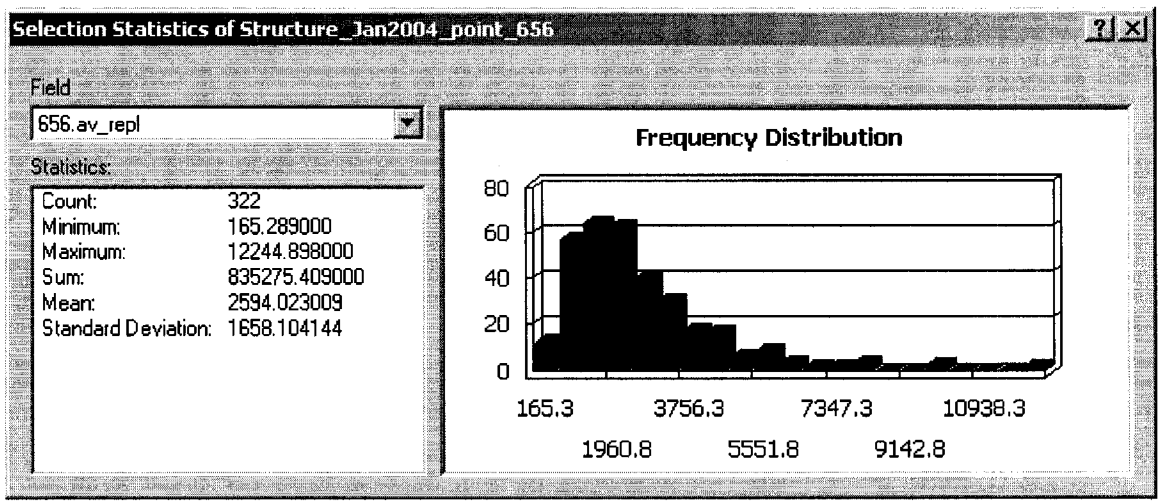


Figure 4. 29 Analysis result of Group B

From Figure 4.28 and Figure 4.29, the value for Group A ($2218/m2) is smaller than that of Group B ($2594/m2). In other words, the average replacement cost of bridges in North is less than that of in South. According to MTQ (Bélanger and Gagnon, 2008), there is no specific monitoring for costs related to bridges built in northern Quebec. However, lower costs for mitigation measures and traffic management in remote areas reduce the gap with work in urban areas.

In the past, having costs higher in remote areas was perhaps more observable. At present and the past few years, with the vast amount of projects and the huge demand for services in engineering and construction, this is less significant because costs have risen everywhere. In the future, multi-variant analysis could be used for analyzing this case in the future. Multivariate analysis of variance methods extend analysis of variance methods to cover cases where there is more than one dependent variable and where the dependent variables cannot simply be combined. In this case, more factors, such as bridge span and construction method should be considered together.

4.4 THE ASSESSMENT OF BRIDGES IN QUEBEC AND PROPOSED DEPRECIATION METHOD

4.4.1 Capital stock assessment of bridges in Quebec

As mentioned in Chapter 2, the owners of bridges need to know the current value of the bridges they own. Also, the bridge management agencies use the assessment of bridges as capital stock in the accounting of bridge assets. This section will explore the capital stock assessment of Quebec bridges. Figure 4.30 shows the flowchart for the assessment of Quebec bridges.

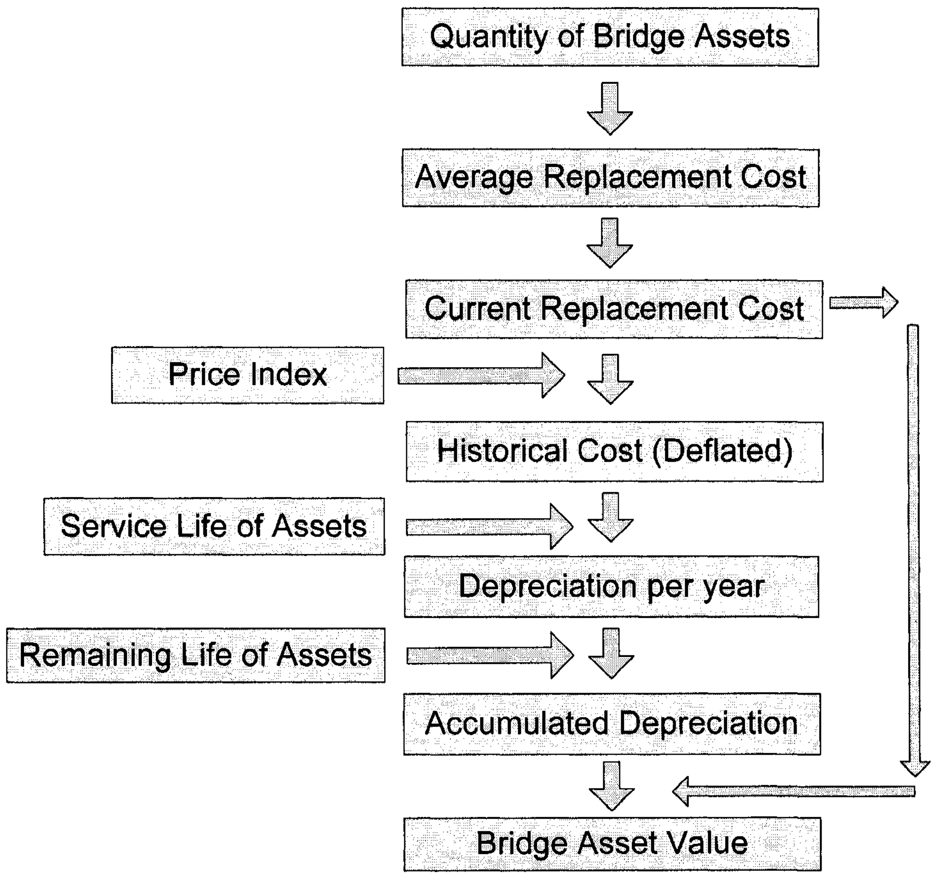


Figure 4.30 Flowchart for the assessment of Quebec bridges

As shown in Figure 4.30 Flowchart for the assessment of Quebec bridges, the assessment process of Quebec bridges is based on the application of asset depreciation accounting. In this case, bridge area and average replacement cost are used for calculating bridge asset value. As was explained in Section 4.3, the average replacement cost can be calculated. The average age can be calculated based on the construction year (assuming the reference year as 1999). The acquisition year is the average value of all construction years. Current Replacement Cost (CRC) is the multiplication of the sum of bridge structure area in Quebec by the average replacement cost.

The following represents the detailed calculation of the assets of Quebec bridges.

- Average age of assets (AA): 31 years
  - Acquisition year: 1968 Date of database: 1999
- Price Index (PI) relative to 1993 (RSMeans, 2008): for year 1968: 24.9%; for year 1999:117.6%
- Current Replacement Cost (CRC): $15,231,615,407
- Historical Cost (HC)(Deflated) = $CRC*PI_{1968}/PI_{1999}$
- Estimated Service Life (ESL): 75 years
- Depreciation per year (DPY) = HC/ESL
- Accumulated depreciation (AD) = DPY*AA
- Bridge Asset Value in 1999 (depreciated historical cost) = HC – AD = $1,892,036,025

The forgoing calculations include the use of the straight line depreciation method to determine annual depreciation.

From a reference from MTQ (Richard, 2007b), the value of bridges of MTQ is estimated as $11,292M. There is a gap of about $4 billion between our calculation and that of MTQ. The difference of two results is about 25.8%. MTQ (Bélanger and Gagnon, 2008) uses a concept called "value as new". This is the cost to rebuild a bridge that would be exactly the same type and exactly the same dimensions. The size of a deck is multiplied by a unit cost determined for each bridge type. As this is not a replacement value, the result is somewhat underestimated. This method does not take into account depreciation.

4.4.2 Proposed depreciation method based on traffic volume

Straight line depreciation method (SLDM) is one of several traditional depreciation methods usually used in accounting. In the future, having more data about bridges in the bridge inventory would provide the possibility to improve depreciation calculation. For example, traffic volume is the main factor that may affect the service life of bridges. Therefore, it may be used to calculate the rate of depreciation. The original formula of SLDM is (White et al., 2000):

$$D_t = \frac{P - F}{n} \qquad (4.1)$$

Where:
D_t: rate of depreciation
P : property cost
F : salvage value
n : years of depreciation

If the actual traffic volume in a given year is greater than the one estimated, then that bridge would depreciate faster. On the other hand, if the actual traffic volume is less than estimated, the rate of depreciation is less. In Equation 4.2, both actual and design traffic volumes are proposed as coefficients in the SLDM.

$$D_t = \frac{T_a}{T_d} * \frac{P - F}{n} \qquad (4.2)$$

Where:
T_a: actual traffic volume
T_d: design traffic volume

In this case, the value of bridge depreciation could be different every year. It depends on the value of T_a/T_d. In addition, the actual service life may be different from the design service life and should satisfy the condition: $P - \sum_n D_t \geq 0$. This method could be applied in the future if the required data (T_a and T_d) are available. As we proposed in Chapter 3, future BMS inventory should include life cycle data, which will make the proposed method more applicable.

Here is an example for this proposed depreciation method. According to straight line method, the bridge would be depreciated at the end of 75 years. However, if we use the proposed depreciation method proposed here, the time of depreciation is 43 years (assuming an annual increase of traffic volume of 5%). Table 4.5 shows the detail.

Table 4.5 Example of proposed depreciation method

End of Year (t)	SL Depreciation (A)	Designed Traffic Volume (B)	Actual Traffic Volume (C)	Actual Depreciation (D=A*C/B)	Present Cost (E)
0					75,000,000
1	1,000,000	100,000	50,000	500,000	74,500,000
2	1,000,000	100,000	52,500	525,000	73,975,000
...	...	...	...	...	...
42	1,000,000	100,000	369,599	3,695,994	7,384,124
43	1,000,000	100,000	388,079	3,880,794	3,503,331
44	1,000,000	100,000	407,483	4,074,833	-571,503
...	...	...	...	...	..
75	1,000,000	100,000	N/A	N/A	N/A

From Table 4.5, we can see that, in straight line depreciation, the depreciation is a constant ($1,000,000) every year. The bridge takes 75 years to depreciate. However, according to the proposed depreciation method, the depreciation is variable every year. This value changes with the change of traffic volume. In the end, the depreciation period is just 43 years. This method is maybe suitable for the assessment in the network level.

4.5 SUMMARY AND CONCLUSIONS

In this chapter, in order to better understand the Quebec bridge data, the data obtained from the MTQ as an Access file has been analyzed and a graphical user interface (GUI) has been developed to improve the usability of the data. The inventory part of this database is proposed as an example that can be modified in the future to be used as the base for the Canadian BNI.

Next, the database is used to perform some calculations related to replacement cost of bridges. The effect of three factors on the replacement cost of Quebec bridges are studied including the age of bridges, their structural type, and location. However, the current data are not enough to analyze the replacement cost. Therefore, personal records for each bridge to monitor bridge status from the design stage to the end of design service life should be included in bridge database.

Finally, a method for assessing Quebec bridges is explained. In addition, a new depreciation method is introduced based on the traditional straight line method and considering the effects of traffic volume. As the example demonstrated, the annual depreciation value and the depreciation period are related more closely to actual use. The proposed depreciation method would result in a more accurate assessment of bridge assets as capital stock.

CHAPTER 5 SUMMARY, CONTRIBUTIONS, AND FUTURE RESEARCH

5.1 SUMMARY

One major issue in BMSs in Canada is that each province has its own system and there is no standard way of describing the inventory data. This situation is different from the U.S. where there are major systems (i.e. Pontis and Bridgit) used by almost all states and the data are provided to the federal government using the NBI. Therefore, this thesis aims at reviewing the current state of BMSs in Canada and suggesting an initiative to build a Canadian National Bridge Inventory.

In the survey of bridge management systems in Canada, BEADS of Alberta and OBMS of Ontario are noted as influential in developing perspectives among other Canadian BMSs. For instance, the BMSs of P.E.I. and Nova Scotia closely follow OBMS. As for Quebec, MTQ has made efforts to create a more advanced BMS, but it is somewhat different in structure and function. Information has been gathered based on literature review, on-line survey, and direct communications (telephone calls and emails) with agencies and engineers related to BMSs, who are from Statistic Canada, Transportation Canada, Infrastructure Canada, and all provincial transportation agencies in Canada. in additional, information about the Quebec BMS has been obtained from the MTQ including the database of bridges of Quebec and the GIS data of bridges. Finally, the survey establishes the benefits of unified bridge inspection specifications in terms of better information communication and more uniform inspection standard.

In the case study, first of all, a set of graphical user interfaces for Quebec bridge database were developed. These GUIs are presented as a possible model for a Canadian National Bridge Inventory. Then, the three factors affecting bridge replacement cost are analyzed. Next, an assessment of Quebec bridges is done to calculate their value as capital assets in 1999. Finally, a new depreciation method based on the traditional SLDM and considering the effects of traffic volume is proposed to demonstrate the possible benefits of gathering more information in future BMSs.

5.2 CONTRIBUTIONS

The contributions of this research are grouped as follows:

(1) The data from the following surveys have been collected and analyzed: federal level, provincial level, and municipal level. Ontario is special because it has many municipal bridges and is the only province that has regulations about bridge inspection at both the provincial and municipal levels. From the survey about the status of bridges in Ontario, the results of the survey are: (1) On average, 28%, 48%, and 24% of municipality's bridges fall into the Now Needs category, 1-5 Year Needs, and 6-10 Year Needs, respectively; and (2) The average cost of repairs for each municipal bridge need is about $663,000 in the Now Needs, about $521,000 in the 1-5 Year Needs, and about $892,000 in the 6-10 Year Needs, respectively.

(2) From the recent survey of Transport Canada about the regulatory nature of bridge management at the provincial and municipal levels, the results are: (1) Only one province—Ontario— has a bridge inspection regulation in Canada. The rest of the

provinces have policies. (2) New Brunswick and P.E.I. assume all ownership responsibilities including inventory, bridge maintenance and bridge inspection for all public roadway bridges. (3) Alberta almost has a regulation for bridge inspection. In its regulation, it indicates that the Responsible Road Authority is required to perform management/maintenance of the road network under its jurisdiction. Proper management of a road network would include bridge inspection. (4) Quebec is responsible for bridge inspections for all municipal bridges for municipalities less than 100,000 inhabitants. The large municipalities inspect their bridges themselves. (5) Six provinces (Saskatchewan, Manitoba, Ontario, New Brunswick, Nova Scotia, and P.E.I.) are using the OSIM for inspecting their bridges.

(3) Chapter 3 also proposed developing a Canadian NBI to facilitate sharing the data and comparing performance measures as the user base in other provinces grows. Furthermore, the future Canadian NBI should expand the inventory data to include all life cycle data (i.e. design, construction, inspection, and maintenance) as suggested by Itoh et al. (1997) and Feek (2008).

(4) A GUI for managing and manipulating the Quebec bridge database was developed. This GUI provides a clear means for retrieving and processing this data. Extending this approach to a Canadian National Bridge Inventory would facilitate the sharing and use of bridge information throughout Canada.

(5) Three factors affecting bridge replacement cost have been analyzed using the MTQ database: construction year, structure type, and location. These factors could be crucial considerations in deciding how to allocate limited funds in the face of ever-expanding maintenance needs, as well as in controlling project cost during an entire life cycle of a bridge. According to the case study, current data are not enough to analyze bridge replacement cost. Therefore, personal records for each bridge to monitor bridge status from the design stage to the end of design service life should be included in bridge database.

(6) Finally, a method for assessing Quebec bridges is explained. In addition, a new depreciation method is introduced based on the traditional straight line method and considering the effects of traffic volume. As the example demonstrated, the annual depreciation value and the depreciation period are related more closely to actual use. The proposed depreciation method would result in a more accurate assessment of bridge assets as capital stock.

5.3 FUTURE RESEARCH

The present research identifies several limitations related to the requirements of the methods and techniques in bridge management to be developed in the future. In order to benefit from the unified bridge management specifications in Canada and develop a proper Canadian NBI, the following points need to be explored in future research:

(1) Identifying a common set of data which is available in all provinces and getting feedback from transportation ministries of provinces based on the common set.

(2) Comparing the inventory data of the BMS of each province and identifying and proposing potential improvement of BMSs based on the advantages already present in individual provincial BMSs.

(3) Identifying and examining additional factors, such as traffic volume, which would potentially improve the calculation of depreciated asset value.

(4) Developing more accurate and comprehensive accounting methods for considering bridges as tangible capital assets.

(6) Improving the GUI by creating additional tables in the database to explain the meaning of the codes used in the database (e.g., pile type, bearing type) and linking these tables with the GUI.

(7) Conducting a pilot study to collect the data based in the identified inventory specifications.

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APPENDIX A: SURVEY OF BRIDGE MANAGEMENT SYSTEM IN CANADA

The survey of Bridge Management in Canada consists of questions in the following categories: (1) Organizations and staff; (2) Bridge Management System; (3) Bridge number and structure types; (4) Inspection procedures; (5) Extension and integration with other systems, and (6) Recommendations about improving BMS.

For example, the Ministry of Transportation of Ontario is responsible for bridge management in Ontario. There are about 100 people working at the head office and Regional offices. The head office provides support to the regional offices in the form of manuals, standards and systems. The regional offices are responsible for operations including inspection, needs, priorities, planning, design, and construction management. The Ontario BMS design started in 1998 and was developed in 1999-2002. Initial release with local databases was in 2000 and production version with server in 2002. It is a fully developed BMS. The components of Ontario BMS include inventory, inspection, deterioration modeling, forecasting, budget allocation and optimization. However, deterioration modeling, forecasting, budget allocation and optimization are not fully used at present. These four parts should be improved in the future. In OBMS, Markovian model is its deterioration model. However, there is no asset valuation model. In addition, GIS will be linked to BMS in the future. In order to be compliant with PSAB, asset valuation is based on both management and financial accounting provided in financial statements. The key strengths of the OBMS are:

- Comprehensive inventory and inspection modules
- Local databases can be used in the field for data collection

- Central secure server with all data accessible over the network, and
- Ability to determine element needs

The weaknesses are:

- Analysis needs to be simplified/rationalized - too many models to maintain
- Need to link elements to improve overall bridge project prediction

There are 1854 concrete bridges, 752 steel bridges, and 14 timber bridges. Among all bridges, the numbers of slab bridge, girder bridge, box-girder bridge, truss bridge, arch bridge, and other type are 957, 1185, 235, 33, 17, and 193, respectively. The visual inspection of bridges is done every two years with four levels of the condition rating scale. Inspectors are responsible for making the condition rating, which is based on deficiencies. These components will be rated: deck, beams, piers, abutments, embankment, joints, wearing surfaces, bearing, cables, rails, welds, nuts, and bolts, drainage system, and lighting system. For these components, the following types of damages will be inspected: spall, corrosion, crack, fracture, fatigue, and scour. As for testing methods, MTO also uses NDT (divers inspect underwater piers and potential mapping) every five years or as required. Up to now, MTO does not have any continuous monitoring of the bridges. OBMS is an independent system. However, MTO is planning to develop an emergency management sub-system.

Bridge Management Questionnaire

Questions about the organization answering the survey

Q1: Please select your organization from the following list.

- O Alberta Infrastructure and Transportation
- O British Columbia Ministry of Transportation
- O Manitoba Infrastructure and Transportation
- O New Brunswick Department of Transportation
- O Newfoundland and Labrador Department of Transportation and Works
- O Northwest Territories Department of Transportation
- O Nova Scotia Department of Transportation and Public Works
- O Nunavut Department of Community Government and Transportation
- O Ontario Ministry of Transportation
- O Quebec Ministry of Transportation
- O Saskatchewan Highways and Transportation
- O Prince Edward Island Transportation and Public Works
- O Yukon Department of Highway and Public Works
- O Other (please specify)

Q2: What are your responsibilities in bridge management?(select all applicable)

- ☐ Budget allocation
- ☐ Bridge engineering
- ☐ General infrastructure management
- ☐ Other (please specify)

Q3: How many people are involved in bridge management at your organization and in which capacity?

Questions about the Bridge Management System (BMS)

Q4: Do you have a BMS?

- O Yes

O No

If yes, what is the name of your BMS?

Q5: What are the components of your BMS? (select all applicable)

☐ Inventory
☐ Inspection
☐ Deterioration modeling
☐ Forecasting
☐ Budget allocation
☐ Optimization
☐ Other (please specify)

Q6: Do you usually use all of the developed components of your BMS? Please specify the components of your BMS that are not fully used at present. Select all applicable.

☐ Inventory
☐ Inspection
☐ Deterioration modeling
☐ Forecasting
☐ Budget allocation
☐ Optimization
☐ Other (please specify)

Q7: Does the bridge inventory of your system include as-built drawings?

O Yes

O No

Please explain about any missing drawings (i.e., in the case of old bridges and foundations)

Q8: When did you start using your BMS? Please give a brief summary of the development history of your BMS.

Q9: Is your system fully developed or under development?

- O Fully developed
- O Under development

Q10: If it is under development, at what stage are you currently in developing the system?

Q11: What kind of deterioration models do you use?

- O Markovian deterioration model
- O Expert opinion Regression model
- O Other (please specify)

Q12: Is there a Geographic Information System (GIS) component in your BMS?

- O Yes
- O No

If no, have you thought about using it?

Q13: Do you use Health Index in your BMS?

- O Yes
- O No

If no, have you thought about using it?

Q14: Does your BMS have an asset evaluation model?

- O Yes
- O No

If yes, what kind of asset evaluation model do you use?

Q15: Public Sector Accounting Board (PSAB) has a new requirement for the recognition of Tangible Capital Assets which will be applied in 2009 (infrastructure management agencies should record and report their capital assets in their financial statements). How is your organization adapting to this requirement?

Q16: Which parts of your BMS should be improved? (select all applicable)

☐ Inventory
☐ Inspection
☐ Deterioration modeling
☐ Forecasting
☐ Budget allocation
☐ Optimization
☐ Other (please specify)

Q17: What are the key strengths and weaknesses of your system?

Questions about bridges managed by your agency

Q18: How many bridges do you have in each of the following categories based on construction material?

- O Concrete
- O Steel
- O Timber
- O Other

Q19: How many bridges do you have in each of the following categories based on structure type?

Slab
Girder
Box-girder

Truss Arch
Cable-stayed
Other

Questions about inspection procedures

Q20: How often is visual inspection of bridges done?

- O Twice a year
- O Annually
- O Every two years
- O Every three years
- O Other (please specify)

Q21: What is the condition rating scale?

- O 1-4
- O 1-5
- O 1-9
- O Other (please specify)

Q22: Who makes the condition rating?

- O Engineers
- O Inspectors
- O Other (please specify)

Q23: How do you determine condition ratings?

- O Based on deficiencies
- O Based on performance
- O Other (please specify)

Q24: What components for bridges do you rate? (select all applicable)

- ☐ Deck
- ☐ Beams
- ☐ Piers
- ☐ Abutments
- ☐ Embankment

☐ Joints
☐ Wearing surfaces
☐ Bearings
☐ Cables
☐ Rails
☐ Welds, nuts and bolts
☐ Drainage system
☐ Lighting system
☐ Traffic equipment
☐ other (please specify)

Q25: What types of damages do you inspect? (select all applicable)
☐ Spall
☐ Corrosion
☐ Crack
☐ Fracture
☐ Fatigue
☐ Scour
☐ Other (please specify)

Q26: Do you use Non-Destructive Testing (NDT)?

○ Yes

○ No

Q27: Which of the following NDT methods are often used at your agency? (select all applicable)
☐Acoustic emission monitoring
☐Divers inspect underwater piers
☐Eddy-current sensor
☐Ground Penetrating Radar
☐Impact-Echo
☐Infrared imaging
☐Laser Measurement Technologies
☐Liquid-penetration testing
☐Magnetic particle testing
☐Magneto-inductive for evaluation of cables and wires
☐Neutron scattering technique
☐Nuclear magnetic resonance
☐Potential mapping

☐Prompt Gamma Neutron Activation Analysis
☐Strain Transducers
☐Structural health monitoring using fiber optic sensors
☐Thermographic methods
☐Ultrasonic testing
☐X-ray computed tomography
☐Other (please specify)

Q28: How often are these methods used?

Q29: What is the function of NDTs in your system?

- ○ Preventing purpose; performed periodically on all or subset of bridges
- ○ Performed only in case of damage detected by visual inspection

Q30: Do you have any continuous monitoring for some of your bridges? (Select all applicable)

☐ Some bridges are instrumented with sensors Number:
☐Some bridges are continuously monitored by video cameras Number:

Q31: Are these continuous monitoring systems integrated with your BMS?

- ○ Yes, they are automatically linked to the BMS and fully integrated into our system
- ○ No, they are not automatically linked to the BMS but the results are used indirectly
- ○ No, they are done independently and collected data are not directly linked to the system
- ○ No, but we would like to integrate the monitoring system with our BMS in the future

(Please explain about your future plans related to this issue)

Questions about BMS extensions and integration with other systems

Q32: Do you have any other transportation asset management systems? (Select all applicable)

☐ Pavement management system
☐ Road signs management system
☐ Road management system
☐ Paint management system
☐ Others (Please specify)

Q33: Is your BMS an independent system or integrated/connected with other transportation asset management systems?

- ○ No connection; our different systems are functioning independently by different departments
- ○ Some connections but not fully integrated
- ○ Fully integrated; it is subset of our transportation asset management

Q34: Do you have any type of:

☐ Natural disaster risk management to have best functionality for your bridges in case of emergencies
☐ Terrorist attack plan aiming to prevent terrorist attacks or to mitigate their consequences
(Please specify)

Q35: Does your BMS provide any automated tool to permit vehicle routing for oversized and overweighted vehicles?

- ○ Yes, the system automatically does vehicle routing
- ○ No, the system does not automatically provide vehicle routing, but it provides the limitations of each bridge
- ○ No, oversized and overweighted vehicle routing is done by another department

Q36: Please give your recommendation about improving BMS.

Submit

Thank you for your participation!

APPENDIX B: ORGANIZATIONS IN CHARGE OF BRIDGE MANAGEMENT SYSTEMS IN CANADA

Provinces	Agency Responsible of BMS	Name	Position	Telephone	Email	www
Alberta	Department of Infrastructure and Transportation	Salim Hasham	Director, Programming Section	(780)427-2088	Sal.hasham@gov.ab.ca	www.trans.gov.ab.ca
		Tom Loo	Director Bridge Engineering	(780)415-4876	Tom.loo@gov.ab.ca	www.trans.gov.ab.ca
British Columbia	Ministry of Transportation	Kevin Baskin	Chief Bridge Engineer	(250)387-7737	Kevin.Baskin@gov.bc.ca	www.gov.bc.ca
		Gary Farnden	Engineer	(250)387-7728	Gary.Farnden@gov.bc.ca	
Manitoba	Department of Infrastructure and Transportation	Ron Richardson	Director	(204) 945-6831	RoRichards@gov.mb.ca	www.gov.mb.ca
New Brunswick	Department of Transportation and Public works	Ralph Campbell	Research Engineer	(506)453-7955	Ralph.Campbell@gnb.ca	www.gnb.ca
Newfoundland and Labrador	Department of Transportation	Minister's Office (Nancy)	Secretary	(709)729-3678	TenderingandContracts@gov.nl.ca	www.tw.gov.nl.ca
Nova Scotia	Department of Transportation and Public Works	Alan A. MacRae	Executive Director	(902)424-5687	macraeal@gov.ns.ca	www.gov.ns.ca
Ontario	Ministry of Transportation Ontario	Bala Tharmabala	Manager	(416)235-4686	bala.tharmabala@ontario.ca	www.mto.gov.on.ca
Quebec	Ministry of Transportation Quebec	Guy Richard	Director of Stuctures	(418)643-6906	Guy.Richard@mtq.gouv.qc.ca	www.mtq.gouv.qc.ca
Saskatchewan	Department of Highways and Infrastructure	Howard Yea	Director of Bridge Services	(306)787-4830	howard.yea@gov.sk.ca	www.highways.gov.sk.ca
Prince Edward Island	Department of Transportation and Public Works	Darrell Evans	Manager	(902)569-0578	djevans@gov.pe.ca	www.gov.pe.ca

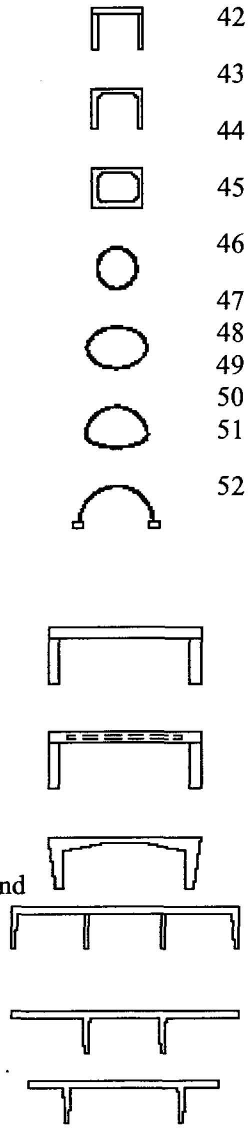
APPENDIX C: TYPES OF BRIDGE STRUCTURE

Culverts

11 Solid slab(R.C.)
12 Rigid frame(R.C.)
13 Box section(R.C.)
14 Circular section(R.C.)
15 Circular section(Steel)
16 Circular section (Thermoplastic)
17 Elliptic section(Steel)
18 Curved closed section (Steel)
19 Arc(R.C.)
20 Arc(Steel)

Slab Bridges

31 Solid slab(R.C.)
32 Solid slab(P.C.)
33 Hollow slab(R.C.)
34 Hollow thick slab(P.C.)
35 Portal frame(R.C.)
36 Portal frame below ground (R.C.)
37 Portal frame(P.C.)
38 Rigid frame(R.C.)
39 Rigid frame(P.C.)



Girder Bridges

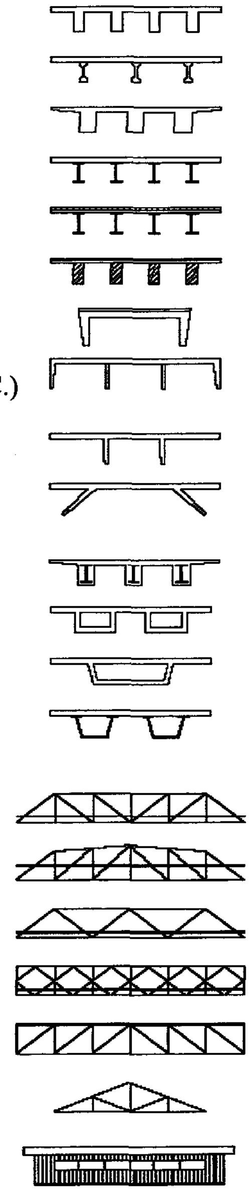
41 Rectangular beams(R.C.)
42 Precast beams(P.C.)
43 Rectangular beams(P.C.)
44 I-beams under R.C.slab(Steel)
45 I-beams under wood slab(R.C.)
46 Rectangular beams(Wood)
47 Portal frame (R.C.)
48 Portal frame below ground(R.C.)
49 Portal frame(Steel)
50 Rigid frame(R.C.)
51 Rigid frame(Steel)
52 Covered with concrete(Steel)

Box Girder Bridges

56 Two boxes(R.C.)
57 One box(P.C.)
58 Two boxes(Steel)

Truss Bridges

61 Through N truss(Steel)
62 Intermediate N truss(Steel)
63 Through W truss(Steel)
64 Through bailey truss(Steel)
65 Deck N truss(Steel)
66 Triangular truss(Wood)
67 Covered truss(Steel)



Arch Bridges

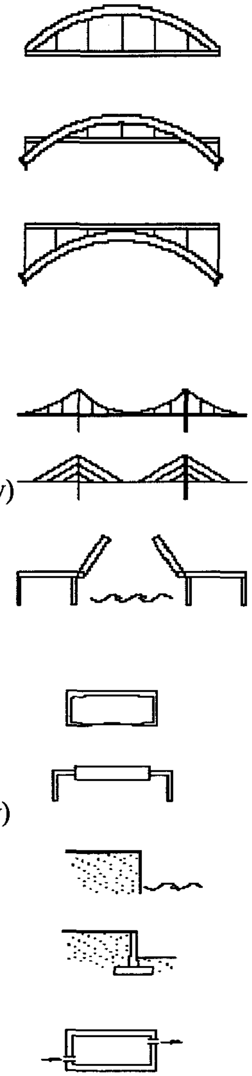
71 Through arch(R.C.)
72 Through arch(Steel)
73 Intermediate arch(R.C.)
74 Intermediate arch(Steel)
75 Deck arch(R.C.)
76 Deck arch

Cable Bridges

81 Suspension bridge(Any)
82 Cable-stayed bridge(Any)
83 Movable bridge(Any)

Others

94 Tunnel(Any)
95 Signals support(Any)
96 Platform(Any)
97 Retaining wall(Any)
98 Pumping station(Any)



APPENDIX D: NBI RECORD FORMAT IN THE U.S.A. (FHWA, 2007a)

With the conversion to metric and the addition of new items it is required to expand the size of the NBI record to 432 characters. The following format will be use to submit data to the FHWA.

ITEM NO	ITEM NAME	ITEM POSITION	ITEM LENGTH/TYPE
1	State Code	1-3	3/N
8	Structure Number	4-18	15/AN
5	Inventory Route	19 - 27	9/AN
5A	Record Type	19	1/AN
5B	Route Signing Prefix	20	1/N
5C	Designated Level of Service	21	1/N
5D	Route Number	22 - 26	5/AN
5E	Directional Suffix	27	1/N
2	Highway Agency District	28 - 29	2/AN
3	County (Parish) Code	30 - 32	3/N
4	Place Code	33 - 37	5/N
6	Features Intersected	38 - 62	25/AN
6A	Features Intersected	38 - 61	24/AN
6B	Critical Facility Indicator	62	1/AN
7	Facility Carried By Structure	63 - 80	18/AN
9	Location	81 - 105	25/AN
10	Inventory Rte, Min Vert Clearance	106 - 109	4/N
11	Kilometerpoint	110 - 116	7/N
12	Base Highway Network	117	1/N
13	Inventory Route, Subroute Number	118 - 129	12/AN
13A	LRS Inventory Route	118 - 127	10/AN
13B	Subroute Number	128 - 129	2/N
16	Latitude	130 - 137	8/N
17	Longitude	138 - 146	9/N
19	Bypass/Detour Length	147 - 149	3/N
20	Toll	150	1/N
21	Maintenance Responsibility	151 - 152	2/N
22	Owner	153 - 154	2/N
26	Functional Class Of Inventory Rte.	155 - 156	2/N
27	Year Built	157 - 160	4/N

28	Lanes On/Under Structure	161 - 164	4/N
28A	Lanes On Structure	161 - 162	2/N
28B	Lanes Under Structure	163 - 164	2/N
29	Average Daily Traffic	165 - 170	6/N
30	Year Of Average Daily Traffic	171 - 174	4/N
31	Design Load	175	1/N
32	Approach Roadway Width	176 - 179	4/N
33	Bridge Median	180	1/N
34	Skew	181 - 182	2/N
35	Structure Flared	183	1/N
36	Traffic Safety Features	184 - 187	4/AN
36A	Bridge Railings	184	1/AN
36B	Transitions	185	1/AN
36C	Approach Guardrail	186	1/AN
36D	Approach Guardrail Ends	187	1/AN
37	Historical significance	188	1/N
38	Navigation Control	189	1/AN
39	Navigation Vertical Clearance	190 - 193	4/N
40	Navigation Horizontal Clearance	194 - 198	5/N
41	Structure Open/Posted/Closed	199	1/AN
42	Type Of Service	200 - 201	2/N
42A	Type of Service On Bridge	200	1/N
42B	Type of Service Under Bridge	201	1/N
43	Structure Type, Main	202 - 204	3/N
43A	Kind of Material/Design	202	1/N
43B	Type of Design/Construction	203 - 204	2/N
44	Structure Type, Approach Spans	205 - 207	3/N
44A	Kind of Material/Design	205	1/N
44B	Type of Design/Construction	206 - 207	2/N
45	Number Of Spans In Main Unit	208 - 210	3/N
46	Number Of Approach Spans	211 - 214	4/N
47	Inventory Rte Total Horz Clearance	215 - 217	3/N
48	Length Of Maximum Span	218 - 222	5/N
49	Structure Length	223 - 228	6/N
50	Curb/Sidewalk Widths	229 - 234	6/N
50A	Left Curb/Sidewalk Width	229 - 231	3/N
50B	Right Curb/Sidewalk Width	232 - 234	3/N
51	Bridge Roadway Width Curb-To-Curb	235 - 238	4/N

52	Deck Width, Out-To-Out	239 - 242	4/N
53	Min Vert Clear Over Bridge Roadway	243 - 246	4/N
54	Minimum Vertical Underclearance	247 - 251	5/AN
54A	Reference Feature	247	1/AN
54B	Minimum Vertical Underclearance	248 - 251	4/N
55	Min Lateral Underclear On Right	252 - 255	4/AN
55A	Reference Feature	252	1/AN
55B	Minimum Lateral Underclearance	253 - 255	3/N
56	Min Lateral Underclear On Left	256 - 258	3/N
58	Deck	259	1/AN
59	Superstructure	260	1/AN
60	Substructure	261	1/AN
61	Channel/Channel Protection	262	1/AN
62	Culverts	263	1/AN
63	Method Used To Determine Operating Rating	264	1/N
64	Operating Rating	265 - 267	3/N
65	Method Used To Determine Inventory Rating	268	1/N
66	Inventory Rating	269 - 271	3/N
67	Structural Evaluation	272	1/AN
68	Deck Geometry	273	1/AN
69	Underclear, Vertical & Horizontal	274	1/AN
70	Bridge Posting	275	1/N
71	Waterway Adequacy	276	1/AN
72	Approach Roadway Alignment	277	1/AN
75	Type of Work	278 - 280	3/N
75A	Type of Work Proposed	278 - 279	2/N
75B	Work Done By	280	1/AN
76	Length Of Structure Improvement	281 - 286	6/N
90	Inspection Date	287 - 290	4/N
91	Designated Inspection Frequency	291 - 292	2/N
92	Critical Feature Inspection	293 - 301	9/AN
92A	Fracture Critical Details	293 - 295	3/AN
92B	Underwater Inspection	296 - 298	3/AN
92C	Other Special Inspection	299 - 301	3/AN
93	Critical Feature Inspection Dates	302 - 313	12/AN
93A	Fracture Critical Details Date	302 - 305	4/AN
93B	Underwater Inspection Date	306 - 309	4/AN
93C	Other Special Inspection Date	310 - 313	4/AN

94	Bridge Improvement Cost	314 - 319	6/N
95	Roadway Improvement Cost	320 - 325	6/N
96	Total Project Cost	326 - 331	6/N
97	Year Of Improvement Cost Estimate	332 - 335	4/N
98	Border Bridge	336 - 340	5/AN
98A	Neighboring State Code	336 - 338	3/AN
98B	Percent Responsibility	339 - 340	2/N
99	Border Bridge Structure Number	341 - 355	15/AN
100	STRAHNET Highway Designation	356	1/N
101	Parallel Structure Designation	357	1/AN
102	Direction Of Traffic	358	1/N
103	Temporary Structure Designation	359	1/AN
104	Highway System Of Inventory Route	360	1/N
105	Federal Lands Highways	361	1/N
106	Year Reconstructed	362 - 365	4/N
107	Deck Structure Type	366	1/AN
108	Wearing Surface/Protective System	367 - 369	3/AN
108A	Type of Wearing Surface	367	1/AN
108B	Type of Membrane	368	1/AN
108C	Deck Protection	369	1/AN
109	Average Daily Truck Traffic	370 - 371	2/N
110	Designated National Network	372	1/N
111	Pier/Abuntment Protetion	373	1/N
112	NBIS Bridge Length	374	1/AN
113	Scour Critical Bridges	375	1/AN
114	Future Average Daily Traffic	376 - 381	6/N
115	Year of Future Average Daily Traffic	382 - 385	4/N
116	Minimum Navigation Vertical Clearance Vertical Lift Bridge	386 - 389	4/N
	Federal Agency Indicator	391	
	Washington Headquarters Use	392 - 426	
	Status	427	
n/a	Asterisk Field in SR	428	1/AN
SR	Sufficiency Rating (select from last 4 positions only)	429 - 432	4/N
Status field:			
1 = Structurally Deficient;			
2 = Functionally Obsolete;			
0 = Not Deficient;			
N = Not Applicable			

APPENDIX E: INTERNATIONAL BRIDGES AND TUNNELS (VEHICULAR CROSSINGS) (CANADA GAZETTE, 2008)

Name	Location
Campobello--Lubec Bridge	Campobello, New Brunswick — Lubec, Maine
Clair--Fort Kent Bridge	Clair, New Brunswick — Fort Kent, Maine
Edmundston--Madawaska Bridge	Edmundston, New Brunswick — Madawaska, Maine
Forest City Bridge	Forest City, New Brunswick — Forest City, Maine
Thoroughfare International Bridge	Fosterville, New Brunswick — Orient, Maine
Milltown Bridge	St. Stephen, New Brunswick — Calais, Maine
St. Croix--Vanceboro Bridge	St. Croix, New Brunswick —Vanceboro, Maine
St. Leonard-Van Buren Bridge	St. Leonard, New Brunswick —Van Buren, Maine
St. Stephen--Calais Bridge	St. Stephen, New Brunswick — Calais, Maine
Ambassador Bridge	Windsor, Ontario — Detroit, Michigan
Baudette-Rainy River Bridge	Rainy River, Ontario — Baudette, Minnesota
Blue Water Bridge	Point Edward, Ontario — Port Huron, Michigan
Fort Frances International Falls Bridge	Fort Frances, Ontario — International Falls, Minnesota
International Rift Bridge	Hill Island, Ontario — Wellesley Island, New York
Peace Bridge	Fort Erie, Ontario — Buffalo, New York
Pigeon River Bridge	Pigeon River, Ontario — Grand Portage, Minnesota
Prescott --Ogdensburg Bridge	Prescott, Ontario — Ogdensburg, New York
Queenston — Lewiston Bridge	Queenston, Ontario — Lewiston, New York
Rainbow Bridge	Niagara Falls, Ontario — Niagara Falls, New York
Sault Ste. Marie International Bridge	Sault Ste. Marie, Ontario — Sault Ste. Marie, Michigan
Three Nations Crossing Bridge	Cornwall, Ontario — Rooseveltown, New York
Whirpool Rapids Bridge	Niagara Falls, Ontario — Niagara Falls, New York
Windsor — Detroit Tunnel	Windsor, Ontario — Detroit, Michigan
Glen Sutton — East Richford Bridge	Glen Sutton, Quebec — East Richford, Maine

APPENDIX F: TABLE SGSD010P IN MTQ BRIDGE DATABASE (MTQ, 2001)

RDT-5081 Rédaction de la documentation technique

Description des fichiers

No du système:5016	Date Modification :	1995-12-20
Nom du fichier:SGSD010P	Version :	1
Répertoire: C:\UTIL\SGS\	Suffixe :	1

Description: Description et localisation des structure

Field Name	Type	Length	Decimal digits	Format	French description	English translation	Attri bute
NO_DG	Caractère	2	0	99	Numéro de D.G.	?	Y
NO_REGION	Caractère		0	99	Numéro de D.T.	?	Y
NO_DIST	Caractère	2	0	99	Numéro de C.E.	?	Y
NO_CE	Caractère	2	0	99	Numéro de C.E.	?	Y
NO_SC	Caractère	2	0	99	Numéro de S.C.	?	F
NO_DOSSIER	Caractère	7	0	99999AX	Numéro de dossier de pont:	Number of file of bridge	Y
NO_IDENTIF	Caractère	15	0	999...15.... 999	Numéro d'identification du pont	I.D. of bridge	Y
JURIDIC1	Caractère	2	0	99	Première juridiction	First jurisdiction	Y
JURIDIC2	Caractère	2	0	99	Deuxième juridiction	Second jurisdiction	F
TYPE_STRU	Caractère	2	0	99	Type de structure	Type of structure	Y
SITE	Caractère	30	0	XXX...30.	Site de la structure	Site of structure	M
NO_MUNICIP	Caractère	7	0	9999999	Numéro de la première municipalité	Number of first municipality	Y
D01_N_MUN2	Caractère	7	0	9999999	Numéro de la deuxième municipalité	Number of second municipality	N
NO_CEP	Caractère	3	0	999	Numéro de la première C.E.P.	?	Y
D01_N_CEP2	Caractère	3	0	999	Numéro de la deuxième C.E.P.	?	F
DERN_MODIF	Caractère	8	0	99.99.99	Date de la dernière modification	Date of last modification	Y
RESEAU	Caractère	2	0	99	Numéro du réseau (classification fonct.)	Network number	M
D01_NOM	Caractère	30	0	XXX...30.	Nom de la structure	Structure name	S
D01_RESP	Caractère	2	0	99	Intervenant MTQ: (01-99)	Intervenient	S

D01_INTER	Caractère	1	0	9	Interprov.-Internat. (pont limitrophe) entre Québec et les zones limitrophes	Inter-provisional.-international between QC and close zone	F
D01_ROUTE	Caractère	30	0	XXX	No ou nom de la route si non numérotée	Number or name of road if no number	M
D01_LOC_P1	Caractère	14	0	XXX..14.. XXX	Première localisation. C'est la concaténation des champs RTE1+TRC1+SEC1+SRTE1	1st localisation	M
D01_RTE1	Caractère	5	0	XXXXX	Numéro de la première route	Number of 1st road	M
D01_TRC1	Caractère	2	0	99	Numéro du tronçon	Number of parcel	M
D01_SEC1	Caractère	3	0	999	Numéro de la section	Number of section	M
D01_SRTE1	Caractère	4	0	XXXX	Numéro de la sous-route	Number of under-road	M
D01_CHAIN	Caractère	6	0	999999	Numéro du chaînage de la route	Number of road chaining	M
D01_LOC_P2	Caractère	14	0	XXX..14.. XXX	Deuxième localisation. C'est la concaténation des champs RTE2+TRC2+SEC2+SRTE2	2nd localisation	S
D01_RTE2	Caractère	5	0	XXXXX	Numéro de la deuxième route	Number of 2nd road	S
D01_TRC2	Caractère	2	0	99	Numéro du tronçon	Number of parcel	S
D01_SEC2	Caractère	3	0	999	Numéro de la section	Number of section	S
D01_SRTE2	Caractère	4	0	XXXX	Numéro de la sous-route	Number of under-road	S
D01_CHAIN2	Caractère	6	0	999999	Numéro du chaînage de la route	Number of road chaining	S
D01_ORIENT	Caractère	2	0	XX	Orientation de la structure	Structure orientation	S
D01_PR_ORI	Caractère	30	0	XXX...30	Point de repère pour orientation route	Indication for road orientation	M
D01_FONDAT	Caractère	4	0	9999	Année de const. des élém. de fondation	Year of construction of foundation elements	M

D01_SYSTEM	Caractère	4	0	9999	Année de const. des syst. structuraux	Year of construction of structural systems	M
D01_PLATEL	Caractère	4	0	9999	Année de const. du platelage	Year of construction of deck	M
D01_MEMBR	Caractère	4	0	9999	Année de pose de la dernière membrane	Year of last membrane pavement	S
D01_REVET	Caractère	4	0	9999	Année de pose du dernier revêtement	Year of last covering placing	S
D01_EXP_DL	Caractère	4	0	9999	Année de la dernière expertise de dalle	Year of last expertise of paving stone	F
D01_REP_DL	Caractère	4	0	9999	Année de la dernière réparation imp. de la dalle	Year of the last repair of deck	F
D01_DJMA	Numérique	6	0	999999	Débit journalier moyen annuel (DJMA)	Annual average daily traffic (date,day,month,year)	Y
D01_V_LRD	Numérique	3	0	999	Pourcentage des véhicules lourds	Percentage of heavy vehicles	Y
D01_DETOUR	Numérique	5	1	999.9	Longueur du détour en km	Length of detour in KM	M
D01_CONCEP	Caractère	1	0	9	Type de chargement de conception	Design load type	M
D01_EVALUA	Caractère	1	0	X	Statut de l'évaluation	Status of evaluation	S
D01_P_EVAL	Caractère	4	0	9999	Année de la dernière évaluation du pont	Year of last evaluation of bridge	S
D01_OBSERV	Caractère	1	0	X	Inspections d'observation	Visual inspection	S
D01_FREQ_O	Caractère	2	0	99	Fréquence (en mois) des inspections d'observation	Frequency of visual inspection (in month)	F
D01_CA_EV1	Caractère	3	0	999	Capacité évaluée en tonnes (2 essieux)	Evaluated capacity (t) (2 axles)	S

D01_CA_EV2	Caractère	3	0	999	Capacité évaluée en tonnes (3 essieux)	Evaluated capacity (t)	S
D01_CA_EV3	Caractère	3	0	999	Capacité évaluée en tonnes (4 essieux)	Evaluated capacity (t)	S
D01_QS660	Numérique	4	2	9.99	FCSQS660, facteur de capacité de surcharge pour le QS660.	Overcharge capacity factor	Y/0
D01_AF_R_T	Caractère	1	0	9	Type d'affichage recommandé	Recommended display type	S
D01_AF_R_P	Caractère	1	0	X	Panonceau P-200-P-1 recommandé	Recommended sign	0/1
D01_CA_RE1	Caractère	2	0	99	Affichage recommandé (tonne) (2 essieux)	Recommended display (tons) (2axles)	F
D01_CA_RE2	Caractère	2	0	99	Affichage recommandé (tonne) (3 essieux)	« «	F
D01_CA_RE3	Caractère	2	0	99	Affichage recommandé (tonne) (4 essieux)	« «	F
D01_AF_P_T	Caractère	1	0	9	Type d'affichage sur place	Display type used	M
D01_AF_P_P	Caractère	1	0	X	Panonceau P-200-P-1 affiché sur place	Display sign used	M/0/1
D01_CA_AF1	Caractère	2	0	99	Affichage sur place (2 essieux)	Display used (2 axles)	F
D01_CA_AF2	Caractère	2	0	99	Affichage sur place (3 essieux)	« «	F
D01_CA_AF3	Caractère	2	0	99	Affichage sur place (4 essieux)	« «	F
D01_AF_S_T	Caractère	1	0	9	Type d'affichage de capacité souhaitable	Display type of desired capacity	M
D01_CA_SO1	Caractère	2	0	99	Capacité souhaitable (tonnes)(2 essieux)	Desired capacity (t) (2 axles)	F
D01_CA_SO2	Caractère	2	0	99	Capacité souhaitable (tonnes)(3 essieux)	« «	F

D01_CA_SO3	Caractère	2	0	99	Capacité souhaitable (tonnes)(4 essieux)	« «	F
D01_AF_M_T	Caractère	1	0	9	Type d'affichage de capacité minimum	Display type of minimum capacity	S
D01_CA_MN1	Caractère	2	0	99	Capacité min. souhaitable (2 essieux)	desired minimal capacity (2 axles)	F
D01_CA_MN2	Caractère	2	0	99	Capacité min. souhaitable (3 essieux)	« «	F
D01_CA_MN3	Caractère	2	0	99	Capacité min. souhaitable (4 essieux)	« «	F
D01_EAUX_H	Numérique	6	2	999.99	Hauteur eaux hautes extrêmes	Extreme high water height	Y/0
D01_EAUX_B	Numérique	6	2	999.99	Hauteur eaux basses extrêmes	Extreme low water height	Y/0
D01_ETUDE	Caractère	4	0	9999	Étude réalisée (année)	Year of study	S
D01_NAVIGA	Caractère	1	0	X	Eaux navigables	Navigable water	M
D01_AFFOUI	Caractère	1	0	X	Possibilité de problèmes d'affouillement	Possibility of undermining problems	M
D01_EMBACL	Caractère	1	0	X	Possibilité d'embâcle	possibility of Blockage	M
D01_INONDE	Caractère	1	0	X	Possibilité d'inondation	Possibility of Flooding	M
D01_LG_TOT	Numérique	7	1	99999.9	Longueur totale de la structure	Total length of structure	Y/0
D01_HM_MUR	Numérique	5	2	99.99	Hauteur moyenne du mur	Average height of wall	F
D01_LG_TBL	Numérique	7	1	99999.9	Longueur du tablier	Length of deck	Y
D01_VOIES	Numérique	1	0	9	Nombre de voies de circulation	Number of lanes	Y
D01_DEG_VS	Numérique	5	2	99.99	Dégagement vertical supérieur	Vertical upper clearing	F
D01_LAR_HT	Numérique	6	2	999.99	Largeur hors tout de la structure	Total width of structure	Y
D01_LAR_VC	Numérique	6	2	999.99	Largeur de la voie carossable	Width of vehicle lane	Y

D01_LAR_RE	Numérique	6	2	999.99	Largeur voie carr. recommendée	Recommended vehicle lane width	Y
D01_LAR_MS	Numérique	6	2	999.99	Largeur voie carr. min. souhaitable	Desired minimum vehicle width	Y
D01_H_REMB	Numérique	5	2	99.99	Hauteur du remblai	Filling up height	F
D01_BIAIS	Caractère	1	0	X	Biais: «G»auche, «D»roit, «N»ul	Sloping : G=Left, D=right, Null	Y
D01_YBIAIS	Numérique	5	2	99.99	Y de biais (angle)	Sloping angle	Y/0
D01_PHONE	Numérique	1	0	9	Téléphone:	Telephone	0/1
D01_ELECTR	Numérique	1	0	9	Électricité:	Electricity	0/1
D01_AQUEDU	Numérique	1	0	9	Conduite d'aqueduc:	Water pipes	0/1
D01_CON_VI	Numérique	1	0	9	Conduits vides:	Empty pipes	0/1
D01_GAZ	Numérique	1	0	9	Gaz naturel:	Natural gas	0/1
D01_CABLE	Numérique	1	0	9	Câblodiffusion:	Cables	0/1
D01_EGOUT	Numérique	1	0	9	Égoût:	Sewers	0/1
D01_AUTRE	Numérique	1	0	9	Autres utilités publiques:	Other public utilities	0/1
D01_C_REMP	Numérique	9	0	999999999	Coût de remplacement du pont ($)	Cost of bridge replacement ($)	S
D01_M_REMP	Caractère	1	0	X	Mode du coût de remplacement (Généré/saisi)	Mode of cost	
D01_CL_PNT	Caractère	1	0	X	Classe de pont	Bridge class	M
D01_R_SISM	Caractère	1	0	X	Renforcement sismique réalisé	Seismic reinforcement	M
D01_SURF_A	Numérique	6	0	999999	Surface d'acier	Metal surface	F
D01_TY_PRO	Caractère	2	0	99	Type de protection contre la corrosion	Type of protection against corrosion	F
D01 LAMBRI	Numérique	5	0	99999	Surface de lambris	Panelling surface	F
D01_ECL_GA	Numérique	3	0	999	Nombre d'unités d'éclairage à	Number of left lighting	F

					gauche	units	
D01_ECL_DR	Numérique	3	0	999	Nombre d'unités d'éclairage à droite	Number of right lighting units	F
D01_ECL_CE	Numérique	3	0	999	Nombre d'unités d'éclairage au centre	Number of center lighting units	F
D01_E_E_GA	Caractère	1	0	X	Éclairage entretenu par (à gauche)	Lighting maintained by (left)	F
D01_E_E_DR	Caractère	1	0	X	Éclairage entretenu par (à droite)	Lighting maintained by (right)	F
D01_E_E_CE	Caractère	1	0	X	Éclairage entretenu par (au centre)	Lighting maintained by (center)	F
D01_PIS_GA	Caractère	1	0	X	Piste cyclable existante à gauche	Existent left Cycle track	M
D01_PIS_DR	Caractère	1	0	X	Piste cyclable existante à droite	Existent right Cycle track	M
D01_PIS_CE	Caractère	1	0	X	Piste cyclable existante au centre	Existent center Cycle track	M
D01_NE_PIS	Caractère	1	0	X	Piste cyclable nécessaire	Needed Cycle track	M
D01_E_T_GA	Caractère	1	0	X	Trottoir existant à gauche	Existent left pavement	M
D01_E_T_DR	Caractère	1	0	X	Trottoir existant à droite	Existent right pavement	M
D01_N_T_GA	Caractère	1	0	X	Trottoir nécessaire à gauche	Left needed pavement	M
D01_N_T_DR	Caractère	1	0	X	Trottoir nécessaire à droite	Right needed pavement	M
D01_C_R_GA	Caractère	1	0	X	Chasse-roues existant à gauche	Existing Guard stone left	M
D01_C_R_DR	Caractère	1	0	X	Chasse-roues existant à droite	Existing Guard stone right	M
D01_C_R_CE	Caractère	1	0	X	Chasse-roues existant au centre	Existing Guard stone center	M

APPENDIX G: FLOWCHART OF SEARCHING BRIDGE DATA

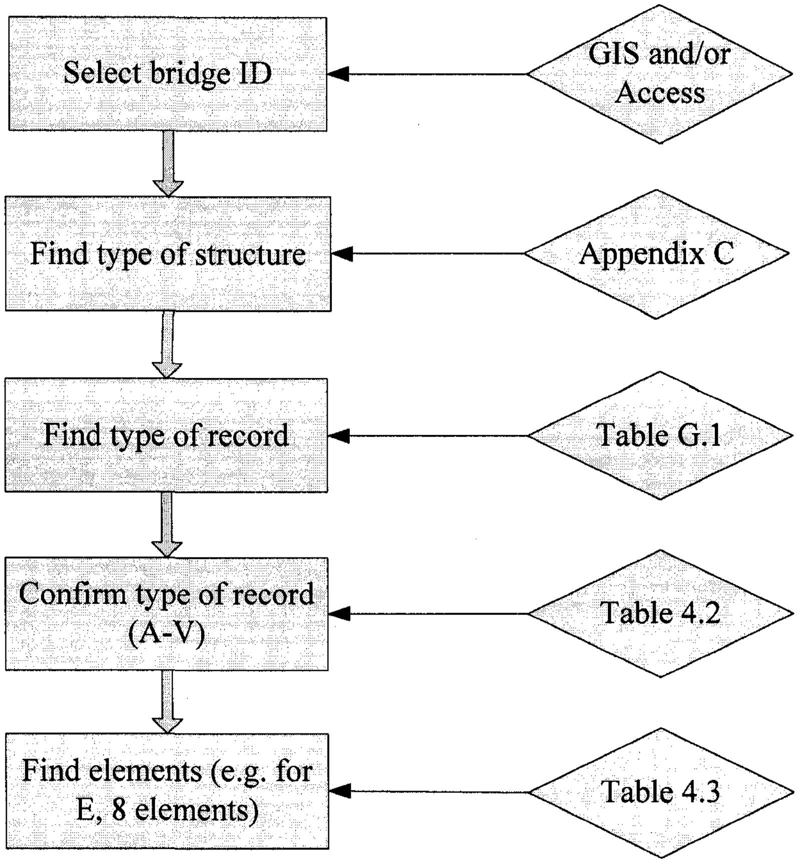


Figure G.1 Flowchart of searching bridge data

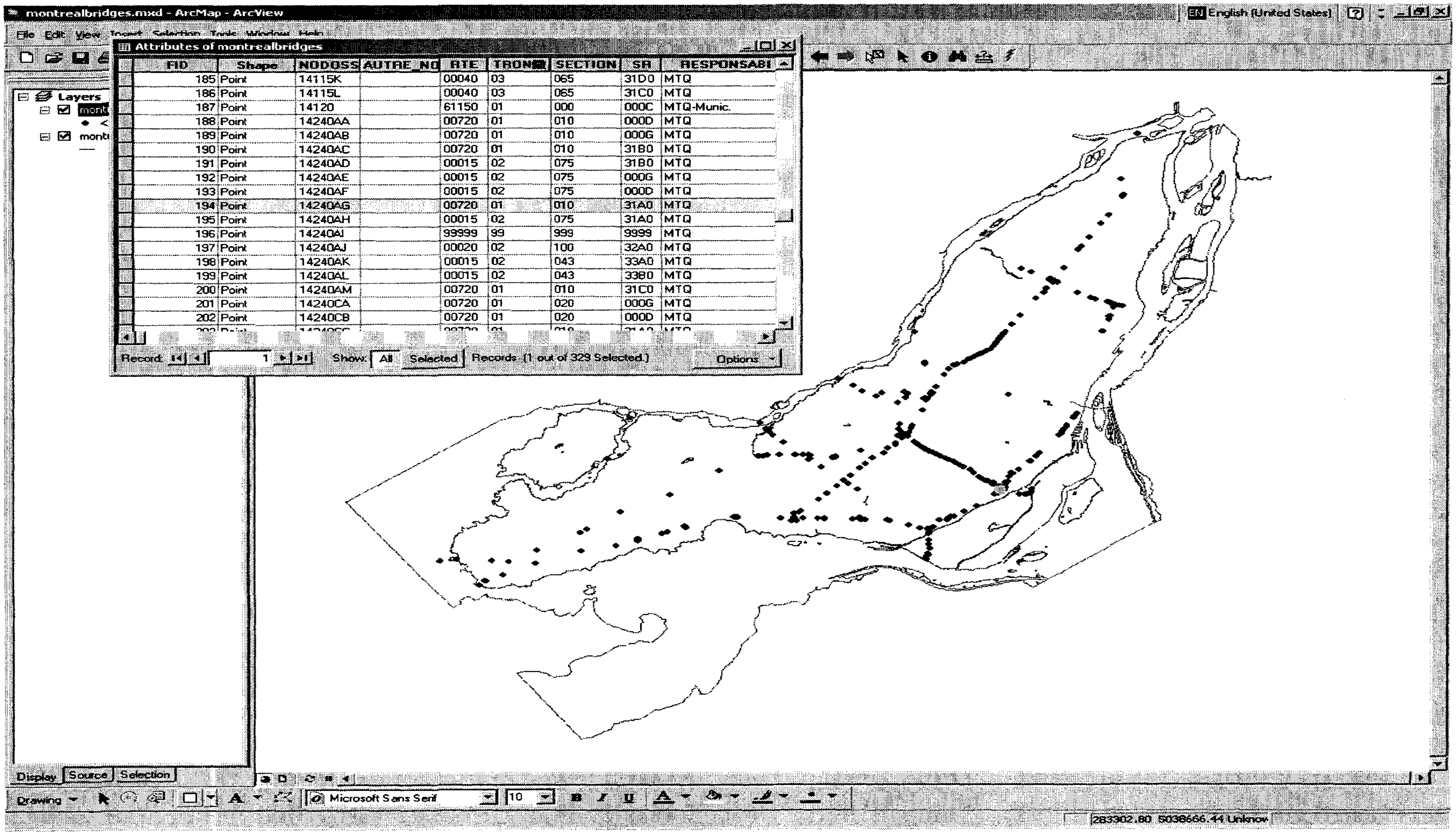


Figure G.2 Finding the attribute of bridges from GIS

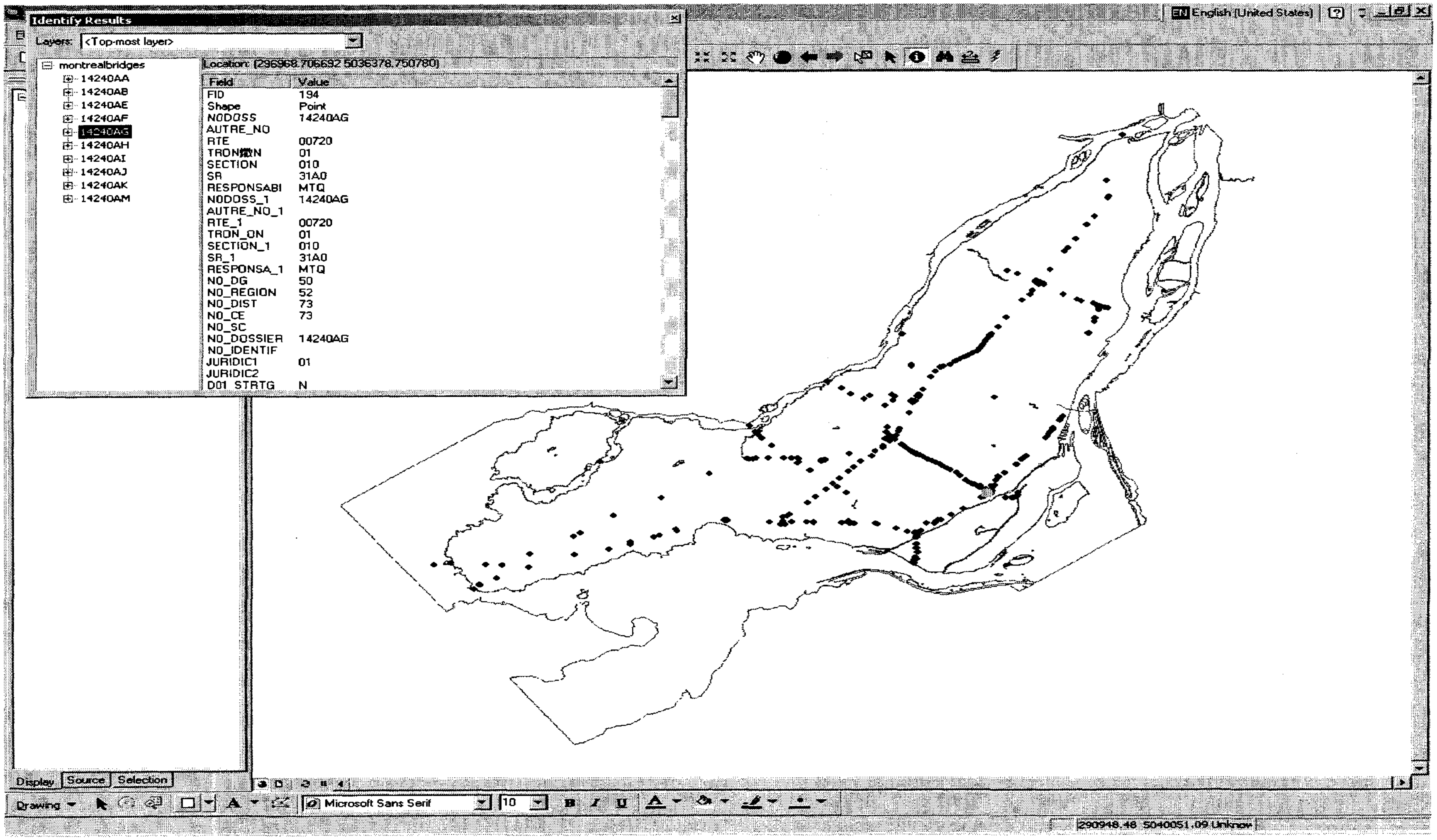


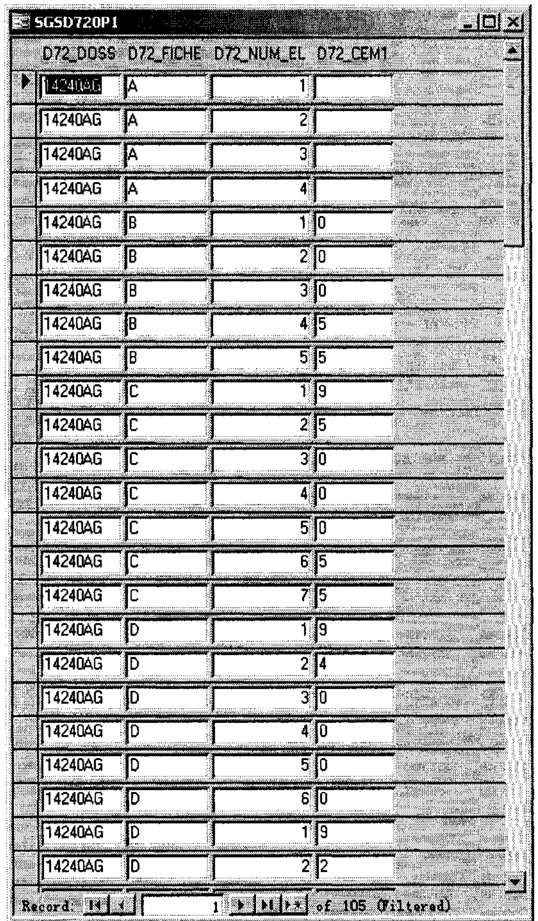
Figure G.3 Finding more detailed information from GIS

Table G.1 Finding type of records

TYPE DE STRUCTURE	TYPE DE FICHE																						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	Z
11	X	X														X		X		X			X
13	X	X			X									X	X	X		X		X			X
14	X	X														X		X		X			X
15	X	X														X		X		X			X
16	X	X														X		X		X			X
17	X	X														X		X		X			X
18	X	X														X		X		X			X
19	X	X												X	X	X		X		X			X
20	x	X														X		X		X			X
31	X	X	X	X	X								X	X	X	X				X			X
32	X	X	X	X	X								X	X	X	X				X			X
33	X	X	X	X	X								X	X	X	X				X			X
34	X	X	X	X	X								X	X	X	X				X			X
35	X	X	X	X	X								X	X	X	X				X			X
36	X	X	X	X	X									X	X	X				X			X
37	X	X	X	X	X									X	X	X				X			X
38	X	X	X	X	X								X	X	X	X				X			X
39	X	X	X	X	X								X	X	X	X				X			X
41	X	X	X	X	X	X							X	X	X	X				X			X
42	X	X	X	X	X	X							X	X	X	X				X			X
43	X	X	X	X	X	X							X	X	X	X				X			X
44	X	X	X	X	X	X					X		X	X	X	X				X			X
45	X	X	X	X	X	X					X			X	X	X				X			X
46	X	X	X	X	X	X								X	X	X				X			X
47	X	X	X	X	X	X							X	X	X	X				X			X
48	X	X	X	X	X	X								X	X	X				X			X
49	X	X	X	X	X	X								X	X	X				X			X
50	X	X	X	X	X	X							X	X	X	X				X			X
51	X	X	X	X	X	X							X	X	X	X				X			X
52	X	X	X	X	X	X							X	X	X	X				X			X
56	X	X	X	X	X		X						X	X	X	X				X			X
57	X	X	X	X	X		X						X	X	X	X				X			X
58	X	X	X	X	X		X				X		X	X	X	X				X			X
61	X	X	X	X	X			X			X	X	X	X	X	X				X			X
62	X	X	X	X	X			X			X	X	X	X	X	X				X			X
63	X	X	X	X	X			X			X		X	X	X	X				X			X
64	X	X	X	X	X			X			X		X	X	X	X				X			X
65	X	X	X	X	X			X			X	X	X	X	X	X				X			X
66	X	X	X	X	X			x			X	X		X	X	X				X			X
67	X	X	X	X	X	X					X	X				X			X	X			X
71	X	X	X	X	X				X		X	X	X	X	X	X				X			X
72	X	X	X	X	X				X		X	X	X	X	X	X				X			X
73	X	X	X	X	X				X		X	X	X	X	X	X				X			X
74	X	X	X	X	X				X		X	X	X	X	X	X				X			X
75	X	X	X	X	X				X	X	X	X	X	X	X	X				X			X
76	X	X	X	X	X				X		X	X	X	X	X	X				X			X
81	X	X	X	x	X			X			X	X	X	X	X	X				X	X		X
82	X	X	X	X	X	X	X				X	X	X	X	X	X				X		X	X
85	Selon le type de structure par travée																						
97																	X			X			X
LÉGENDE	1	1	1	4	3	2	2	2	2	2	2	2	5	1	1	1	1	1		1	1	1	1

LÉGENDE

1 : 1 fiche / structure
2 : 1 fiche / travée (max. 3 fiches)
3 : 1 fiche / 2 travées (max. 6 fiches)
4 : 0 fiche /1 travée
1 fiche / 2 ou 3 travées
2 fiches /4 ou 5 travées
3 fiches / 6 travées ou plus
5 : 1 fiche / 2 travées (max. 3 fiches)



SGSD720P1

D72_DOSS	D72_FICHE	D72_NUM_EL	D72_CEM1
14240AG	A	1	
14240AG	A	2	
14240AG	A	3	
14240AG	A	4	
14240AG	B	1	0
14240AG	B	2	0
14240AG	B	3	0
14240AG	B	4	5
14240AG	B	5	5
14240AG	C	1	9
14240AG	C	2	5
14240AG	C	3	0
14240AG	C	4	0
14240AG	C	5	0
14240AG	C	6	5
14240AG	C	7	5
14240AG	D	1	9
14240AG	D	2	4
14240AG	D	3	0
14240AG	D	4	0
14240AG	D	5	0
14240AG	D	6	0
14240AG	D	1	9
14240AG	D	2	2

Record: 1 of 105 (Filtered)

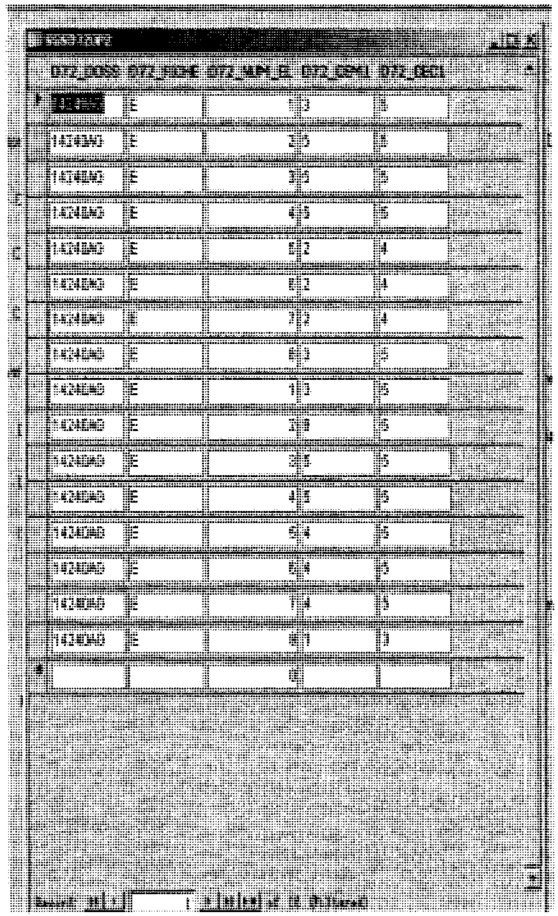


Figure G.4 More detailed information from Access

APPENDIX H: BRIDGE CONSTRUCTION UNIT COST PER SQUARE FOOT (FEDERAL-AID HIGHWAYS) (FHWA, 2007b)

Region	STATE	1997	1998	1999	2000	2001	2002
1	CONNECTICUT	183	151	192	162	346	77
	MAINE	98	96	100	160	141	143
	MASSACHUSETTS	109	109	148	110	195	140
	NEW HAMPSHIRE	142	142	150	159	222	152
	NEW JERSEY	141	123	157	137	169	144
	NEW YORK	117	130	134	179	145	155
	RHODE ISLAND	172	170	175	197	259	208
	VERMONT	86	N/A	113	113	176	165
	PUERTO RICO	66	85	74	N/A	65	116
3	DELAWARE	117	93	122	N/A	79	226
	MARYLAND	76	81	94	117	106	105
	PENNSYLVANIA	109	119	136	152	111	112
	VIRGINIA	75	81	74	80	89	87
	WEST VIRGINIA	114	78	103	127	122	129
	DIST. OF COLUMBIA	110	N/A	N/A	N/A	162	N/A
4	ALABAMA	44	49	68	55	59	58
	FLORIDA	56	65	55	80	76	83
	GEORGIA	39	53	54	49	51	56
	KENTUCKY	62	67	80	98	87	65
	MISSISSIPPI	39	41	54	54	42	50
	NORTH CAROLINA	64	60	64	65	75	73
	SOUTH CAROLINA	53	68	66	73	82	63
	TENNESSEE	55	64	51	62	52	46
5	ILLINOIS	69	84	86	96	114	90
	INDIANA	65	57	72	75	79	70
	MICHIGAN	79	93	94	91	118	108
	MINNESOTA	58	58	58	73	93	82
	OHIO	66	79	76	79	79	86
	WISCONSIN	45	41	44	49	60	55
6	ARKANSAS	49	53	58	57	63	62
	LOUISANA	36	33	39	40	39	44
	NEW MEXICO	56	66	63	73	57	67
	OKLAHOMA	43	54	59	55	61	41
	TEXAS	35	35	42	44	42	42
7	IOWA	40	43	50	54	54	58
	KANSAS	50	53	52	68	62	65
	MISSOURI	58	70	74	70	78	82
	NEBRASKA	53	56	56	55	66	57
8	COLORADO	52	59	65	72	58	56
	MONTANA	54	69	65	N/A	81	65
	NORTH DAKOTA	67	57	57	54	55	55
	SOUTH DAKOTA	49	57	68	47	58	57

	UTAH	64	98	61	N/A	99	73
	WYOMING	60	72	64	78	61	55
9	ARIZONA	62	56	50	57	58	61
	CALIFORNIA	71	68	74	81	110	100
	HAWAII	N/A	310	194	N/A	323	314
	NEVADA	102	126	30	88	64	131
10	ALASKA	141	106	104	104	132	187
	IDAHO	68	56	73	75	95	75
	OREGON	90	74	56	84	65	102
	WASHINGTON	98	98	68	97	119	114

APPENDIX I: STRUCTURE TYPES AND NUMBERS IN QUEBEC (Hu, 2006)

Category	ID	Material	System	Frequency	Total	
Culvert	11	R.C.	Solid slab	14	881	**9.3%**
	12	R.C.	Rigid frame	0		
	13	R.C.	Box section	392		
	14	R.C.	Circular section	1		
	15	Steel	Circular section	94		
	16	Thermoplastic	Circular section	0		
	17	Steel	Elliptic section	19		
	18	Steel	Curved closed section	244		
	19	R.C.	Arc	62		
	20	Steel	Arc	55		
Slab Bridge	31	R.C.	Solid slab	575	1749	**18.4%**
	32	P.C.	Solid slab	36		
	33	R.C.	Hollow slab	151		
	34	P.C.	Hollow thick slab	22		
	35	R.C.	Portal frame	445		
	36	R.C.	Portal frame below ground	353		
	37	P.C.	Portal frame	0		
	38	R.C.	Rigid frame	157		
	39	P.C.	Rigid frame	10		
Beam Bridge	41	R.C.	Rectangular beams	1483	5679	**59.8%**
	42	P.C.	Precast beams	722		
	43	P.C.	Rectangular beams	177		
	44	Steel	I-beams under R.C. slab	644		
	45	R.C.	I-beams under wood slab	2363		
	46	Wood	Rectangular beams	30		
	47	R.C.	Portal frame	28		
	48	R.C.	Portal frame below ground	1		
	49	Steel	Portal frame	0		
	50	R.C.	Rigid frame	50		
	51	Steel	Rigid frame	8		
	52	Steel	Covered with concrete	173		
Box-Girder Bridge	56	R.C.	Two boxes	55	139	**1.5%**
	57	P.C.	One box	48		
	58	Steel	Two boxes	36		
Truss Bridge	61	Steel	Through N truss	97	305	**3.2%**
	62	Steel	Intermediate N truss	2		
	63	Steel	Through W truss	78		
	64	Steel	Through bailey truss	12		
	65	Steel	Deck N truss	32		
	66	Wood	Triangular truss	4		
	67	Steel	Covered truss	80		
Arc Bridge	71	R.C.	Though arch	4	73	**0.8%**
	72	Steel	Though arch	12		
	73	R.C.	Intermediate arch	1		
	74	Steel	Intermediate arch	0		
	75	R.C.	Deck arch	51		
	76	Steel	Deck arch	5		
Cabled Bridge	81	Any	Suspension bridge	5	10	**0.1%**
	82	Any	Cabled-stayed bridge	5		
Others	91	Any	Movable bridge	1	664	**7.0%**
	92	Any	Foot bridge	36		
	94	Any	Tunnel	36		
	95	Any	Signals support	0		
	96	Any	Platform	0		
	97	Any	Retaining wall	566		
	98	Any	Pumping station	24		
	99	Any	Others	1		
				Total Number of Structures:	9500	**100%**