Design and Implementation of a New Bridge Management System for the Ministry of Transport of Québec

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ABSTRACT: In its continuing effort to ensure a safe, efficient transportation infrastructure for the people of Québec, the Ministry of Transport of Québec (MTQ) has been developing a new bridge management system. Known as Système de Gestion des Structures (SGS), the system has a number of novel features designed to meet the specific needs of MTQ.

This paper highlights the design of the Système de Gestion des Structures (SGS) and presents some of the challenges faced by the Ministry of Transport, and gives an overview of the analytical features of the system's analytical engine, the Strategic Planning Module.

1 INTRODUCTION

The Ministry of Transport of Québec (MTQ) owns and maintains an asset inventory of over 9000 structures, of which 4,300 are provincial bridges, 4,400 are municipal bridges, and the remaining are retaining walls and other miscellaneous structures. These structures are managed in a largely decentralized process by the Head Office and 14 Regional offices.

As is the case with other agencies, the bridge inventory in Quebec is aging and the average bridge condition constantly challenges the financial and human resources of the Ministry. In its continuing effort to ensure a safe, efficient transportation infrastructure for the people of Québec, MTQ has been developing a new bridge management system. Known as Système de Gestion des Structures (SGS), the system has a number of novel features designed to meet the specific needs of MTQ:

- A decentralized software architecture, using Microsoft's .NET framework, for maximum sharing of inventory and inspection data across the province, with more controlled access to the strategic planning analysis;
- A graphic user interface provided primarily in French with certain bilingual and localizable features;
- Support for a detailed bridge inspection methodology that is span-by-span, but has elements and condition states similar in concept to the Ontario Structure Inspection Manual, with separate inspection of protection systems.
- Strategic planning analysis featuring several levels to fit MTQ business processes: Network-level budgeting and performance analysis; priority programming; automated project scoping and treatment selection; and a digital dashboard for interactive design of the scoping and timing of projects.

- The model framework handles preservation, functional improvements, and replacement; provides explicit control of the element and project alternatives to be considered; and has features to update deterioration models based on new inspection data.

Begun in Fall 2005, the SGS has an Inventory and Inspection Module, which was delivered in early 2007, and an advanced Strategic Planning Module (MPS) due to be released in early 2008. The SGS combines lessons learned from the Ontario Bridge Management System (OBMS), also developed by Stantec, (MTO 1999, Thompson, Ellis, et al 2003) and recent research/preliminary design projects (Stantec 2003, 2006) into a new system that will be highly responsive to the Ministry's needs. The SGS is the first French language BMS of its kind.

2 OVERVIEW OF SYSTÈME DE GESTION DES STRUCTURES - SGS

The Système de Gestion des Structures (SGS) is a new state-of-the-art bridge management system that will replace an older system that handled inventory and inspection data. The SGS will provide a new inventory and inspection system and add analytical capabilities to enable MTQ perform bridge level and network level analyses.

2.1 *Revisions to Inspection*

The previous inspection system was based on a numerical rating and inspection manual that was originally developed based on the original Ontario Structure Inspection Manual (MTO 1985). MTQ rated the material condition of each bridge component using a scale from 1 to 6 with 6 being an element in new condition. The numbers on the scale represented a combination of severity of defects and their extent.

In order to modernize the inspection method and to meet the needs of the new SGS, MTQ made significant revisions to their bridge inspection manual. In the new manual, specific bridge elements are defined and the element condition is recorded as severity and extent separately. The inspector is required to record the quantity of defects in each of four (4) condition states for each bridge component. These condition states are Excellent or 'A', Good 'B', Fair 'C' and Poor 'D'.

Each condition state defines defects on the basis of their severity. For example, the Good condition state refers to an element (or part of an element) where the first sign of "Light" (minor) defects is visible. Material specific condition state tables are used to describe the severity of defects and assign this to the appropriate condition state. For example, concrete components might have "No Observed Defects" (Excellent), "Light Scaling" (Good), "Medium Scaling", or "Severe to Very Severe Scaling" (Poor). This explicit recording of quantities is necessary to allow estimation of types of repairs and their costs by the SGS and it provides the fundamental data needed for deterioration models..

2.2 *Inventory and Inspection Module*

The inventory and inspection module of SGS is deployed to all users of the SGS and is the primary tool for entering, viewing, editing and reporting structure and inspection information. This module was delivered in early 2007.

2.3 *Database organization and deployment*

MTQ maintains an enterprise Oracle database for its structure inventory and inspection data, which also includes structural evaluation results and data on features intersecting the roadway network at bridge sites. This secure database supports the entire inspection workflow process, including acceptance and review of inspection reports received from outside consultants.

Periodically data from the Oracle database are replicated to a Microsoft SQL Server database for use in reporting and analytical support modules, including the Strategic Planning Module

(MPS). The replication process offers an added measure of security from unintended database updates, and provides a readily configurable interface to major downstream functionality whose development cycle may be independent of the main database.

2.4 *Decision making process*

MTQ is moderately decentralized in its decision making processes. Bridge-level maintenance and repair decisions are made in regional offices from operational funding. However, most structural expertise is resident in the headquarters office in Quebec City, where major bridge level decisions and all program level and network level decisions are made.

With this organizational structure, bridge inventory and inspection data must be shared with regional offices, but strategic planning data and analysis software are used mainly in headquarters.

3 STRATEGIC PLANNING MODULE - MPS

All analysis in the SGS is performed in the Strategic Planning Module or MPS. The MPS is deployed to a limited number of users who perform bridge project planning and network level budgeting and priority setting.

3.1 *Desktop organization*

The MPS launches from within SGS and the user is able to select a particular bridge to analyze, or to work with the entire network or a subset of bridges. For a specific bridge the user may examine element level results or project results. At the network level the user may select the entire network or filter to a subset of bridges that depends on specific inventory, inspection, or even analysis results. Eg select all bridges of a particular type with a certain range of condition, of a certain age which are load capacity deficient, and older than 1970, and have projects greater than $100,000. This subset can be stored and analyzed in more detail.

3.2 *Performance measures*

The SGS reports several management indices. These indices are the bridge condition index BCI (or in French IES), IFS (a functionality index), IVS (seismic vulnerability/adequacy), and ICS (a combined index of the others). Although each of these indices could be used as a performance measure and analyzed in MPS, only the BCI (IES) is actually used in the analysis. Possible future enhancements to MPS include being able to set budgets based on the target performance measures based on the other indices.

3.2.1 *Bridge condition index – BCI (IES)*

The MPS uses the BCI (IES) as the principal performance measure index. The MTQ bridge condition index is based on the same concept as the OBMS BCI which has its roots in the Bridge Health Index used in the United States (Johnson and Shepard 1999). The BCI is a weighted average of the condition state distribution for the various elements that make up a given structure. The element replacement cost is used as the weighting factor so that elements that have a higher replacement cost have a higher weighting in the BCI.

The BCI is calculated as soon as an inspection is saved and is forecasted in the MPS analysis for each element treatment. The MPS calculates the resulting BCI for the various strategies for each bridge. The network average BCI is also calculated for each budget scenario so that network performance can be compared for different funding levels.

3.3 *Life cycle cost analysis framework*

MPS provides a family of decision support tools to assist in bridge project planning and program planning, as a part of the agency's overall asset management processes. All of the tools work within an integrated engineering-economic framework based on the concept of life cycle costs.

The analyses are organized into three levels of detail, as shown in Figure 1. The levels are:

- Element level, which focuses on a selected structural element of one bridge. This tool uses a Markovian deterioration 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. Functional improvements are also included at this level.
- Project level, which combines Element Alternatives into Project Alternatives, each of which represents a possible multi-year strategy to maintain service. The tool uses models of initial costs and life cycle costs to evaluate the Project Alternatives.
- Network level, which combines the Project Alternatives on multiple bridges into Program Alternatives, each of which is a multi-year plan for work on all or part of a bridge inventory, designed to satisfy budget constraints and performance targets while minimizing life cycle costs.

Each level of analysis in this framework provides a set of evaluated alternatives to feed the broader-scale tool to its left. All three levels are designed to stay consistent with each other, so if a change is made at one level, the remaining levels will adjust appropriately.

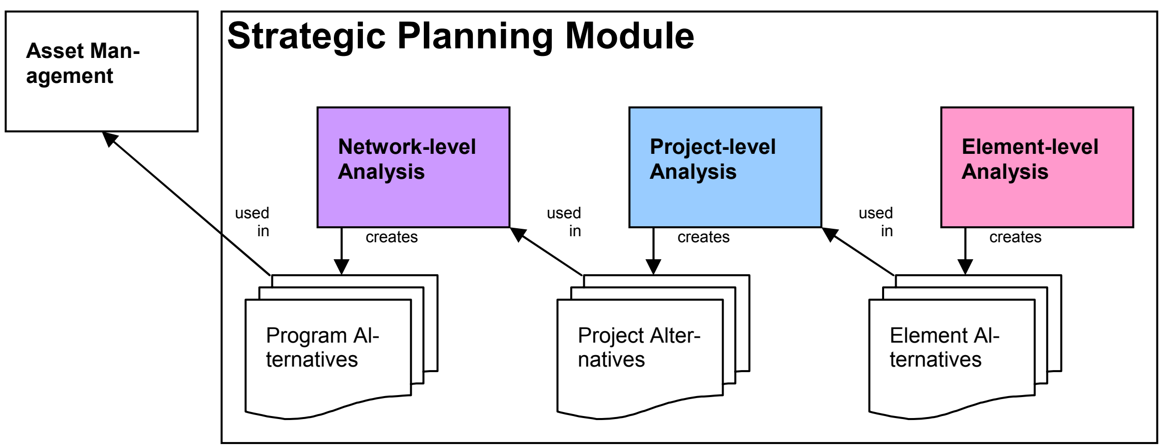

Figure 1. Levels of Analysis

On the other hand in going from left to right in the Figure, network-level analysis provides a context for the project level, because the network-level budget constraint affects which Project Alternatives can be programmed. For example, in a very constrained funding scenario many bridges will have to select the Do-Nothing alternative.

Similarly, the project-level analysis provides a context for the element level, influencing the cost-effectiveness of individual element treatments such as in the case when element treatments are combined at the same time to minimize traffic control costs.

For each treatment, the MPS generates two Element Alternatives, one for each implementation period, each with a life cycle activity profile. An additional one is created for the Do-Nothing alternative. A typical lifecycle profile is shown in Figure 2. This profile consists of zero or one treatment action applied during the 10 yr. detailed program horizon, followed by an annual average preservation expenditure after the end of the horizon which continues to end of analysis period, usually 50 years.

The treatment is modeled to occur in either year 0 or year 5, causing an immediate change in condition according to the treatment effectiveness model. Before and after the treatment, conditions change according to the deterioration model. Because bridge elements deteriorate slowly, and because the actual implementation year is uncertain, the fact that treatments may actually occur at any time during the planning period makes very little difference to the results, so it is ignored. The tactical planning tool, described below, is used for evaluating fine-grained changes in scheduling.

For the calculation of life cycle costs and benefits, the treatment cost is calculated from a benchmark unit cost, and discounted to year 0. It is assumed that no other costs are incurred during the 10 yr. program horizon.

Following the end of the program horizon, all further work is collapsed into a simplified long-term cost model. This model performs a generic life cycle cost analysis for each condition state over 50 years, to compute the average annual cost. On a given bridge element, the condition state probabilities forecast for the end of the program horizon become the basis for calculating an expected value long-term annual cost. This is discounted to year 0.

The benefit of an Element Alternative is computed by subtracting its total life cycle cost from that of the Do-Nothing Element Alternative. The Element Alternative with the lowest life cycle cost is selected for the first round of the project level optimization.

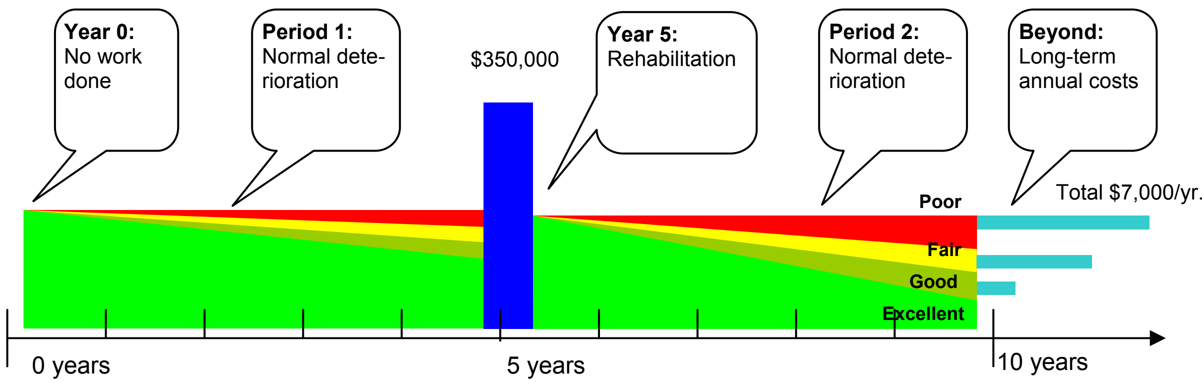

Figure 2. Lifecycle Profile for Typical Element or Bridge.

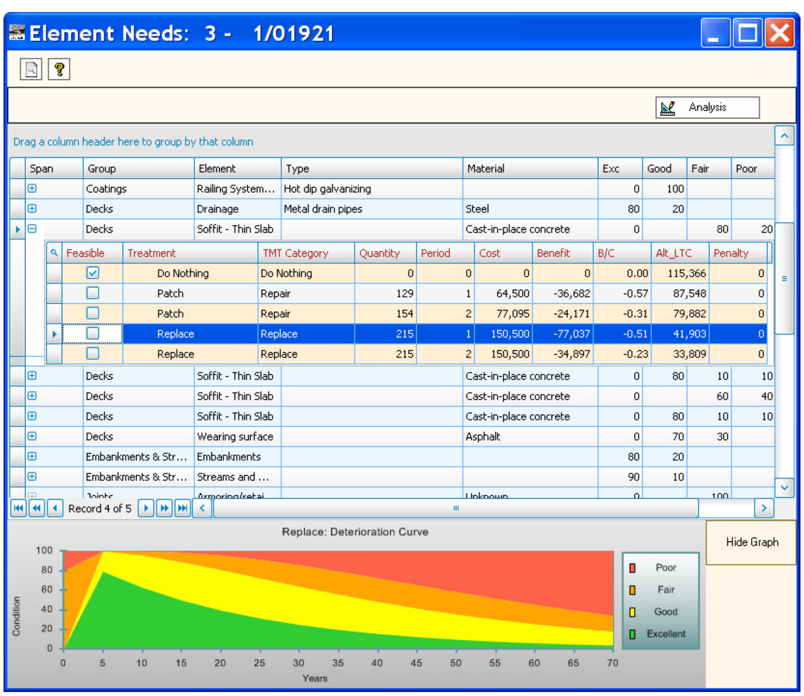

Figure 3. Element Needs.

3.4 *Program planning tools*

The MPS analysis supports three levels of program planning tools, providing a quick user-friendly way for MTQ engineers to evaluate strategic and tactical decisions for any bridge or for an entire inventory. At the Element Level, treatment cost effectiveness is shown with corresponding lifecycle cost and resulting deterioration curve displayed as shown in Figure 3. System recommended or user selected element treatments can be used.

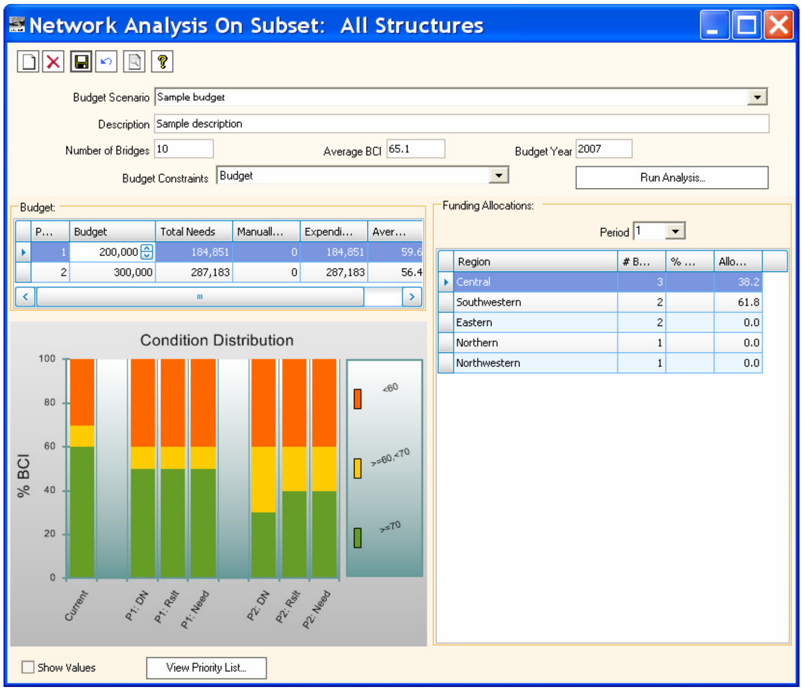

Figure 4. Budgeting and Setting Target Performance Measures.

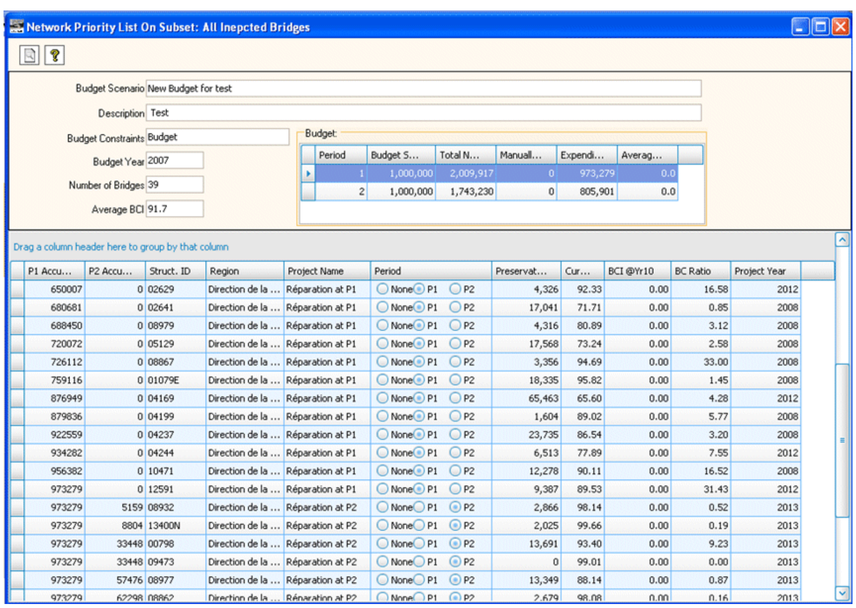

Figure 5. Project priorities.

3.4.1 *Budgeting and network level tradeoff analysis*

For a selected network subset, budgets are set in the budgeting screen (Figure 4). This can be done for the inventory as a whole, or a subset of it. Budgeting results are displayed across administrative subsets of the inventory. In addition, target performance measures (BCI) can be set and required budgets determined. The network level analysis screen shows graphically the tradeoff between funding and performance. Performance can also be summarized across geographical or administrative subsets of the inventory.

3.4.2 *Priority setting screen*

The priority-setting screen (Figure 5) lists all the projects that are identified for possible funding, and indicates how many of them can be funded under the available budget. Additional projects available within a specified margin of budget uncertainty are identified with a different colour. The analyst can use the mouse to rearrange priorities and view the effect on performance measures.

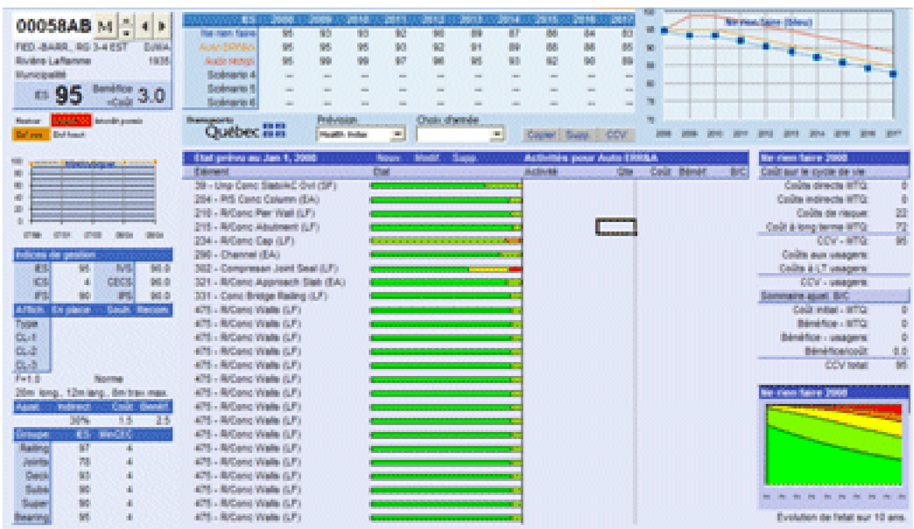

Figure 6. Tactical Planning Dashboard

3.4.3 *Tactical planning digital dashboard*

A unique and innovative feature of the MPS is the Tactical Planning Dashboard. The Tactical Planning Dashboard complements the Strategic Planning Module by adopting a purely bridge-level perspective on the planning of future work and enabling detailed study of project analysis. While the analysis is similar to MPS and relies on the same input data, the Dashboard fills an important gap in several ways:

- Element and Project Level information, as well as bridge inventory and inspection information is brought together in one window, whereas in the BMS this information is displayed in many different screens.

- MPS necessarily focuses on the uniform processing of groups of bridges, maintaining consistency across the inventory so projects can be prioritized and budgeting decisions can be made. The Digital Dashboard is more concerned with near-term considerations of project readiness and local conditions that might require adjustments to the program plan for individual bridges.

- MPS uses decision rules, budget constraints, and benefit/cost analysis to drive the prioritization and scheduling of work. The Digital Dashboard uses the same tools, but in an evaluative way to show the effect on performance measures when practical considerations modify the circumstances under which a project may have been planned.

- The network level analysis of MPS is based on a simulation of network-level processes and how every bridge in the inventory responds to these processes, including how bridges affect each other in the context of funding constraints. The Digital Dashboard does not rely on simulation but instead considers a wide variety of options for each bridge by itself.
- The information presented in the digital dashboard about individual bridges is more detailed than what is needed for program planning, and the decision variables are more fine-grained.

Project level decision making using the Digital Dashboard is likely to include a wider variety of information that what is provided in the MPS. Such information includes the engineer's personal knowledge of the site, design plans, various kinds of testing, and engineering judgment. The engineer's own mental processes are what integrate these information sources.

CONCLUSIONS

The Ministry of Transport of Québec's new bridge management system, Système de Gestion des Structures (SGS) is the first French BMS of its kind. SGS includes an advanced Strategic Planning Module (MPS) which incorporates a set of three analysis levels which are designed to stay consistent with each other, so if a change is made at the element level, the project and network levels will adjust appropriately. The budgeting and performance measure setting that is done at the network level has an immediate effect on selected projects and the results of project selection can be viewed in tabular or graphic form. The MPS incorporates an innovative digital Tactical Planning Dashboard which complements the MPS by providing a purely bridge-level perspective on the planning of future work and enabling detailed study of project analysis results and other information only available in several different screens in MPS.

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