Plan for the Nova Scotia Transportation Management Information System

Paul D. Thompson, Lynne Cowe Falls, and Kent Speiran

Paul D. Thompson, Consultant, 2425 Hawken Drive, Castle Rock, CO 80104; 303-681-2425, fax 303-681-9439, pdt@pdth.com

Lynne Cowe Falls, Stantec Consulting Ltd., 300-1122 Fourth Street SW, Calgary, AB T2R 1M1, Canada; 403-716-8137, fax 403-716-8039, LcoweFalls@stantec.com

Kent Speiran, Nova Scotia Department of Transportation and Public Works, 1969 Upper Water St., Purdy's Wharf Tower II, P.O. Box 186, Halifax N.S. B3J 2N2, Canada; 902-424-3510, fax 902-424-0571, speirakd@gov.ns.ca.

ABSTRACT

The Nova Scotia Department of Transportation and Public Works (TPW) has engaged Stantec Consulting Ltd. to develop a plan for an integrated decision support system to serve four business areas: pavement management, bridge management, traffic, and safety. TPW intends to implement the plan using off-the-shelf software packages to the extent possible. Driving the plan is an ongoing effort to improve and streamline business processes across the Department. It is hoped that the new systems will strengthen and reinforce the improved organization.

At the foundation of the plan is a business process model describing responsibilities and procedures as they are envisioned for the future. The model identifies data collection, condition analysis, policy development, and treatment selection processes that are divided along disciplinary lines within the Department. Cross-disciplinary processes of planning, prioritization, budgeting, funding allocation, and work tracking are also identified and described. The procedures surrounding each individual process form the basis of subsystem requirements, and also help to focus the reengineering efforts.

Loosely holding the subsystems together will be a technical architecture that addresses the key ingredients of interoperability. These include a common use-case model, a set of core definitions of essential concepts and data items, a geographic referencing system, a core set of shared data, software interface standards, a framework for defining policy goals, a set of performance measures, a common accounting system, security and access control standards, and a business process for supporting and enhancing the system over time.

Key words: Management Systems, Interoperability, Integration, Use-Case Models, Performance Measures

BACKGROUND

The Nova Scotia Department of Transportation and Public Works (TPW) is responsible for the operation and management of 26,000 kilometers of public highways. Recently TPW realigned its core responsibilities to provide a decentralized delivery of construction, maintenance and operations services and programs from each of its four districts, while maintaining a centralized program development and monitoring service through its head office.

Operation and management of the provincial highway system has relied heavily on the experience and expertise of its managers and support staff, without the benefit of modern management systems to supplement acquired institutional knowledge. TPW senior management recognized the need for core management systems that would provide a basis for investment decisions, and initiated a project to develop and implement the Transportation Management Information System (TMIS), an integrated suite of computer based applications including bridge, pavement and highway safety management, and traffic census.

Lacking any existing management systems, TPW is in a unique position to take a fresh look at asset management system requirements, especially the potential for interoperability of asset management subsystems within a well-defined agency-wide framework.

BUSINESS PROCESS AND USE CASE MODELS

A Business Process Model is a forward-looking description of desired agency processes as they are envisioned to exist after implementation of the management systems. Successful implementation, by definition, changes and improves the decision-making processes in an organization. Information flows are modified, and the quality of information improves. The value of collected data is enhanced, making the agency more reliant on data collection processes. Improved information can better equip the agency to control its own future, and gives the agency a stronger basis to defend its decisions and its funding needs in the public and political arenas. Within the agency, each decision-maker is made more reliably aware of the implications of his or her actions on agency policies and performance. Delegation of authority and cooperative action are therefore enhanced. The Business Process Model helps to guide management system development so that the resulting systems will reinforce the desired organizational change.

To help accomplish these benefits, the Business Process Model describes the human decision-making processes to be supported by the system. This activity involves identifying the prospective users, describing processes that the users view as distinct activities, and listing the objectives and information requirements of the users as they conduct these processes. An example of a TPW business process is "inspection," which is conducted by different people within the department on different assets (i.e. pavements, bridges) and at varying levels of detail (i.e. surface distress versus deflection testing, or bridge element inspection versus walk-around inspection).

Based on the Business Process Model, the Use Case Model is a more specific, system-oriented description of the activities that might benefit from management system support (1). A use case is a single activity, normally conducted by one person at a time in one session, and viewed by the user as a whole task. An example of a use case in TPW is "needs identification". Each use case is still a human activity, not a computer activity, so it may be only partially supported by the management system. However, it should be possible to envision that all relevant information and features in the management system could be collected in a single self-contained screen (possibly with supporting screens if needed) focused on just that use case. Use case analysis is a tool of modern software design that helps to overcome certain persistent problems in early management systems:

- It provides an organizing framework for the software requirements, especially making it possible for the users of each use case to participate more effectively in the defining of requirements. It avoids complexity in a large software system by partitioning requirements into more manageable pieces that can be owned by each user group.
- It clarifies responsibilities and therefore acts as one tool to find and eliminate duplications of responsibilities (in the agency) and features (in the software).
- It helps to define whole tasks, helping to ensure that the management system reaches its full potential and helping to prevent a task from being unnecessarily divided between two or more dissimilar systems.
- More specifically, it provides an outline for product selection standards and user interface design, avoiding the past practice of organizing systems according to technical criteria or arbitrarily. Systems are easier to use when organized around the users' mental model of their business, especially if it means the user has to learn only a small part of the system to do his or her own job.

Business process and Use Case Models are most effective if their scope is intentionally broad, crossing the boundaries of traditional management system definitions and including processes which might be only indirectly affected by the system. This does not, however, imply designing huge monolithic systems that try to address the full scope of the Business Process Model. In fact, the objective is quite the opposite: to find a way to split up traditional, ill-fitting definitions into smaller modules that are more flexible and fit the organization better. This approach is analogous to the way an effective policy-making approach in an agency makes the agency better able to delegate authority and allow lower-level units to act autonomously.

TMIS provides TPW with a unique opportunity to develop a more integrated technical and planning architecture. This architecture, including performance measures, database standards, and geographic referencing, provides the glue to connect separately-developed modules into an integrated capability. The separate modules include tools specific to the defined business areas (pavement, bridge, traffic, and safety) where these fit the TPW well. In addition, TMIS will provide tools to assist in integration in the areas of prioritization, policy-making, budgeting, and resource allocation. This mature approach to system definition can help the Department maximize the effectiveness of its infrastructure decision support.

Use-Case Diagram

Figure 1 presents a simplified version of a general integrated use case model for the Transportation Management Information System (TMIS). The diagram uses symbols from the Unified Modeling Language, a graphic convention commonly used in software-related systems analysis (2). With the exception of the Safety Management Information System (SMIS), all of the use cases for the TMIS are for internal TPW functions. Safety requires national reporting and as such some of the use cases are confined by those requirements. All use cases in the diagram are shown as ovals, with use cases external to the TMIS having dashed borders. The full use case model, not shown in Figure 1, also indicates the users of each use case. In general, TPW has a decentralized structure with data collection, needs identification, and prioritization performed at the district level.

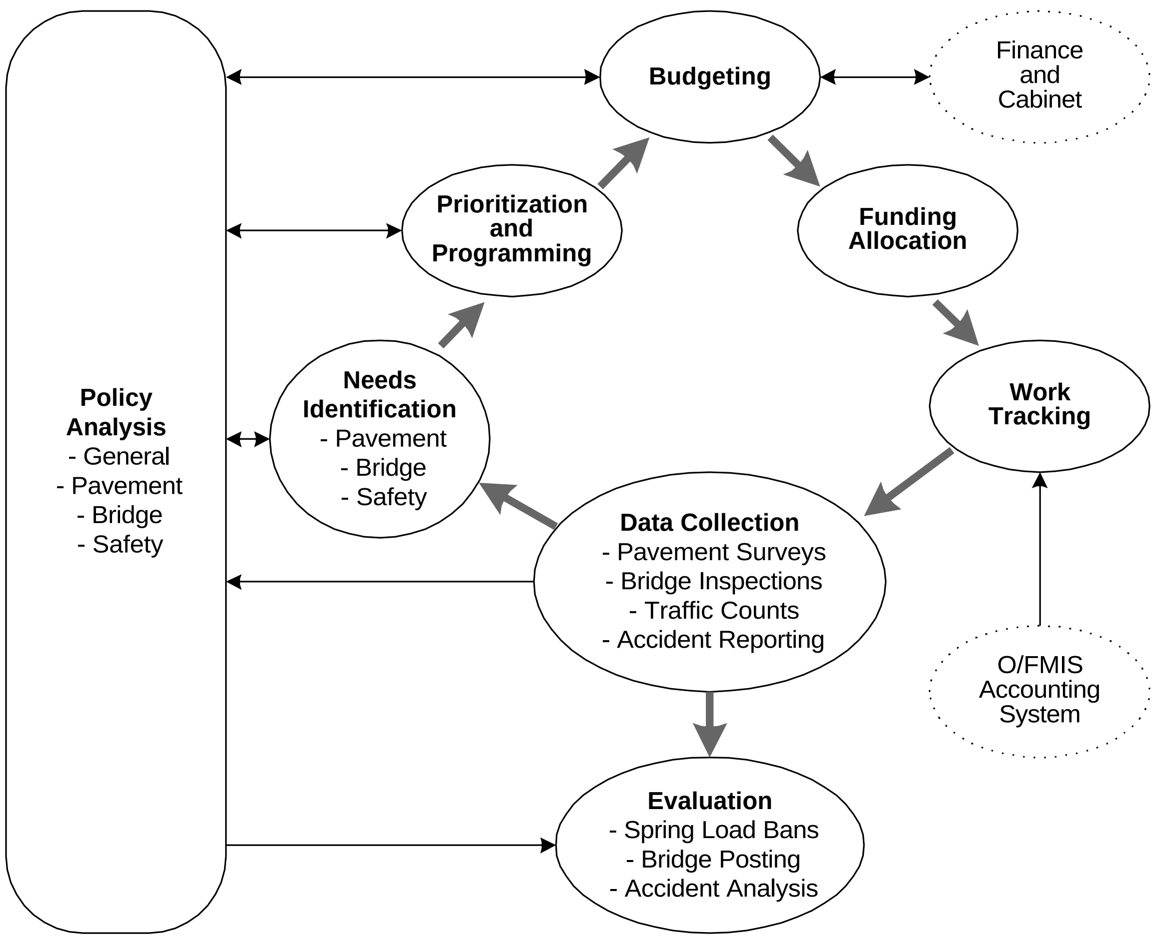

FIGURE 1. Use case model

Large arrows in the diagram show the normal sequence of events over the course of a year, which also correspond to the major data flows and the logical flow of analysis. Although there is a normal order to the use cases, there is no requirement that software decision support features be used in exactly this order. For example, bridge inspections occur continuously over the course of the year regardless of the status of other use cases.

The annual cycle begins with data collection activities at either the network or project level. Data collection can be a seasonal (as in the case of traffic counts and pavement surface condition rating) or an ongoing annual process (as in the case of bridge inspections and accident investigations). Implicit in this use case is quality control and assurance checks as well as uploading of the data into the TMIS database.

Using the data from the database, condition analysis determines the current condition and future performance using performance models and performance prediction models. The highway sections and/or bridges are compared to standards that are established by TPW business units, and identified as needs when they reach or exceed the minimum acceptable level. An example of a policy standard is the minimum acceptable pavement condition of highways, which can be set at different levels for each functional classification of the network. Treatment alternatives for identified needs are analyzed and selected using the treatment selection process, which is also affected by input from TPW business units. An example of this type of input to the process is in the consideration of changing a highway from uncontrolled to controlled access, or a department decision to replace all expansion joints on bridges currently scheduled for rehabilitation.

The policy analysis use case will benefit from the ability to analyze models and treatments through engineering feedback. In the condition analysis, this will involve analysis of the performance models and performance prediction, while in the treatment selection analysis, engineering feedback will be used to assess the effectiveness of one treatment over another. For example, analysis of the data may indicate that 50mm asphalt overlays produce the same life as 75mm overlays; therefore, cost savings can be made by using 50mm only.

Using the results of the needs identification analysis, projects are prioritized and a budget developed. For most purposes, priorities are developed and modified at the district level. The budget process is an iterative one that begins at the district level, and then is integrated at the head office level. A negotiation process with provincial bodies may result in changes in the budget proposal that have to be re-analyzed at the head office, and sometimes district, levels. District-level budget proposals are often subject to informal business-area targets, especially for pavement, bridges, and safety. However, this distinction is generally less relevant at the head office level, and not at all relevant to decision-making when presenting information to provincial budgeting authorities outside of TPW.

Once the budget is approved and funds allocated to the districts, the project lists can be traded between business areas, and the work is accomplished and monitored using the TPW accounting system, O/FMIS. All changes to the highway and bridge inventories are entered into the database, and the business process comes full circle.

Data Collection

The TMIS planning process has been an opportunity to improve and rationalize the various data collection activities across the Department. Data collection activities have traditionally been organized along disciplinary lines, which to some extent is unavoidable because of the specialized equipment and training required. However, a cross-disciplinary dialog on data collection issues can help to identify and fill gaps, and locate places in the process where resources can be used more efficiently. In general, data collection activities serve the following objectives:

- To maintain an accurate database of condition data about the asset, for all of the purposes described in the remaining use cases below.
- To discover maintenance opportunities in time to conduct inexpensive preventive actions to avoid more expensive safety problems.
- To discover safety problems in time to prevent injury or property damage.

- To collect the information necessary to support multi-year planning and budgeting of maintenance, repairs, functional improvements, and replacements. This includes early warning of deterioration that may soon benefit from preventive maintenance.

Since data collection is the most expensive element of the TMIS, and is critical to the success of the TMIS effort, special attention was given to the development and deployment of staff resources and equipment. Three levels of activity were identified for this purpose.

Level 1 data collection involves routine monitoring of all transportation assets by Area Operations Supervisors and quick network-wide surveys by automated equipment. For pavements, this involves the use of an Automatic Road Analyzer (ARAN) pavement survey vehicle, to measure pavement roughness and to videotape the status of pavement distresses and the condition of roadside features. For bridges, the level 1 process is a “walk-around” visual inspection to look for obvious signs of problems needing immediate attention, such as steel fractures, bearing displacement, or blocked drainage paths. Usually safety is the primary concern to be addressed in these inspections.

Since the Area Operations Supervisors are closest to the assets in their local areas and may visit each facility frequently, it makes sense to train them in level 1 data collection for all types of assets. Similarly, the TMIS should be designed to give the Area Operations Supervisor a single environment or screen to record problems with any type of asset. Level 1 generally records and uses data only on identified problems needing immediate resolution, and does not produce a systemwide condition survey that is tracked over time.

Level 2 data collection involves a scheduled visit to each facility to conduct a more comprehensive investigation of asset condition and needs. For bridges, this level includes the principal inspection, where a trained inspector (technician) or structural engineer spends 2-3 hours visually inspecting each bridge, normally once every two years. For pavements and safety features, this may involve a more comprehensive automated survey than was described for level 1 above. For all types of assets, the data collected by a level 2 process for any given asset is reviewed by an expert in that type of asset, to determine whether any safety or maintenance needs exist. Such experts are usually deployed in a more centralized District or Headquarters office, since there is neither the need nor availability of them at the Maintenance Area level.

Level 2 is the only level that produces a network-wide condition survey that is tracked over time. An ARAN vehicle may be used for combined level 1 and level 2 data collection, at least for pavements.

Level 3 data collection is conducted only on facilities where rehabilitation work is planned. Since it often requires specialized skills and equipment, level 3 is performed very infrequently. The collection and interpretation of level 3 data requires a high level of engineering skill within disciplinary lines.

This type of cross-disciplinary analysis is useful in identifying the high-level requirements of the TMIS. When planning a rehabilitation project, there is a clear need to be able to retrieve data from all three levels, since level 3 provides the necessary technical detail, level 2 provides the progression of damage over time, and level 1 provides the most recent information on evident problems. All three levels of data should be keyed to the same facility inventory description, and the same geographic referencing system.

Within the level 1 process, there is only one type of user and one process for all types of assets. It is not helpful at this level to have to enter bridge-related data into one system, pavement-related data into another system, and safety-related data into a third system, all with different user interfaces and capabilities. Here is one of many examples where the data entry requirements of TMIS are organized differently from the data retrieval requirements.

Maintenance management systems (MMS) provide level 1 data entry capabilities in many agencies (though not in Nova Scotia). However, MMS have almost never been effectively integrated with level 2 and level 3 data, often because of inconsistent facility inventory data or incompatible technical architectures.

In the level 2 process, data are entered separately along disciplinary lines, and are also often retrieved and analyzed along the same lines. This is where traditional capabilities of pavement and bridge management systems have been especially effective.

Senior management and public officials often have a need for a network-wide view of facility condition and trends over time. Level 2 is the only level of data collection that can satisfy this need. Unfortunately, the same engineering detail that provides a strong technical analysis for each type of asset also makes it impossible to compare asset condition across different types of facilities. This leads to the need for standardized definitions of performance measures, as discussed in more detail below.

Evaluation and Level of Service

Using the data provided in the inspection and inventory process, along with department standards, evaluations are made to determine the level of service for the asset. In the case of bridges, this would involve posting of the bridge to lower weights. In the case of pavements, this would involve spring load bans. In safety, this would involve reducing speed limits.

Evaluation always involves a decision, implicit or explicit, about the tradeoff between safety and public convenience. When this discretion is given to the individual engineer or determined separately by type of asset, it is applied non-uniformly across the agency, making it more difficult for the public to understand level of service decisions. Excessive legal risk may be placed on the agency or individual engineer in this situation. This is why nearly all state and provincial transportation agencies establish policies and enforce them by more detailed evaluation. The threshold of safety is firmly established by policy, and engineers can then conduct these activities without worrying as much about legal liability or job security.

In order to develop a consistent set of level of service standards, it is necessary to establish quantitative measures of the quality of service delivered to the public. For example, to analyze the tradeoff of safety and convenience, it is important to have ways of measuring "safety" and "convenience." Every decision the agency makes about treatment selection and priority has an implicit message about the relative values (economic or otherwise) of various attributes of the transportation system. One of the most valuable contributions of a management system to the decision-making process is to make these relative values explicit and objective.

Quantitative level of service standards are an essential tool for delegation of authority, either internally from the provincial level to geographic subdivisions, or externally from the Department to private contractors. This delegation is rarely specific to any one asset type. All of the management systems, regardless of asset type, should have the ability to relate a common set of level of service standards to budgetary requirements.

Needs Identification

Needs identification entails comparison of the current condition of the bridge or roadway to a department standard. The comparison results in the identification of a current or future need and further analysis produces a set of alternatives that are tested and evaluated during the development of a proposed work program and budget.

Needs and project alternatives are characterized by a cost, or budgetary requirement, and a predicted outcome, or benefit. Estimation of the cost of a project and the direct physical outcome are generally considered to be engineering activities using discipline-specific methodologies. For example, the means of predicting the change in condition of a bridge bearing due to rehabilitation would generally be much different from the means of determining the added pavement life due to crack sealing. The identification of feasible and preferred treatments also tends to be asset-specific.

For this reason, the needs identification process in Nova Scotia is divided along disciplinary lines, and may be well served by traditional off-the-shelf pavement and bridge management systems. However, many of the subsequent use cases, such as prioritization and budgeting, are not divided in this way. The conceptual gap this represents is reflected in Nova Scotia, as in many other places, by a handoff from engineers to managers and planners in the project development process. An extremely important requirement of the TMIS is to translate project costs and predicted outcomes, in engineering terms, into generic budgetary requirements and benefits, usable by non-engineers and understandable to elected officials and the public. These latter outputs of the system must be defined consistently across all types of assets.

To satisfy this requirement, the TMIS must at least be able to express project outcomes in terms of more generic performance measures, reflecting transportation system values such as economy (long-term agency and user cost), mobility, safety, travel time, travel distance, reliability, comfort/convenience, and preservation of the environment (3). Whenever possible, these must be related to level of service standards.

It is important that more than one alternative strategy be defined for each facility (bridge or road section), whenever possible. The strategy with greatest long-term benefit or lowest life cycle cost should be one of them, but less expensive alternatives with lower benefits should also be selected. The less expensive alternatives might address the elements or road sections with most urgent needs, deferring other needs until after the end of the planning horizon. The decision as to which alternative will be programmed should be made based on funding availability and the relative benefits and costs of competing projects. This happens during the prioritization and budgeting use cases.

Policy Analysis

Policy analysis is the process by which the agency develops and maintains level of service standards, performance measures, and treatment selection rules. Policy analysis also has a substantial effect on the Department's delivery capability, affecting the types of equipment and training to procure, and the rules governing the use of contractors vs. in-house forces. Like the evaluation and needs identification processes, policy analysis in the TMIS involves developing predictions of policy outcomes in terms of performance measures.

Some aspects of policy development are specific to asset types (e.g. the effect of treatment selection on asset condition), while others are not (the establishment of level-of-service standards). Reflecting this fact, current discipline-specific management systems typically provide a means of developing projects or programs to satisfy a given level of service objective, but do not provide a complete means of choosing or optimizing a level-of-service objective.

The TMIS system design will take advantage of the ability of off-the-shelf systems to perform discipline-specific policy analysis. However, the ability to analyze level of service standards across asset types does not yet exist in any off-the-shelf system, so it will eventually have to be developed.

Prioritization and Programming

The prioritization process begins in the District for all business areas. At present there are two major priority lists produced annually: one for capital projects and one, in each District, for maintenance.

Decision support for priority-setting for both the maintenance and capital programs will be most useful to TPW if it can provide both a single integrated priority support tool, and separate tools for bridges, pavements, and safety projects. By providing these tools, TMIS will support priority decisions both at the individual business area level for use by the Structural Engineers, Construction Managers, Area Managers, and District Traffic Supervisors, as well as integration of the individual business area priorities for use by the District Directors, Head Office Infrastructure Management, and the Executive Directors. In order to accomplish this, relevant data from the bridge, pavement, and safety systems can be gathered together by using performance measures, database referencing, and geographic referencing which are the same for all types of projects.

This integration will be extremely valuable in support of the budgeting and resource allocation processes, described next, because costs, benefits, and system performance can be computed for any level of total maintenance investment or any allocation of funding among Districts. District Directors and Head Office staff can immediately see the tradeoffs among all types of projects, and arrange the integrated priority list accordingly. Database queries and map displays of relative priorities would be simple to produce, without complications arising from the details of each type of project.

Budgeting

Based on project needs as stated by the Districts, the TPW Director of Finance presents budgetary needs to the Priorities and Planning Committee, a separate body under the Provincial government, and to the Provincial Finance Department. The Provincial Finance Department ultimately develops a budget that is approved by the Provincial Cabinet by means of the Priorities and Planning Committee. In principle, this is meant to be a negotiated process, though it has not been perceived as such in the past. In the most recent budget, the negotiation aspect of the process was improved by the Finance Department's request for three alternative budget proposals and their implications. Implications were stated in terms of transportation system performance and not in terms of individual projects.

Budgeting is viewed as a competitive process where TPW competes with other agencies for its share of limited Provincial revenue. The Department is viewed as having a weak negotiation position because the budget scenarios and their implications are not presented with strong quantitative justification, as is done by other Provincial Departments.

The Provincial government is encouraging Departments to develop budgetary justifications in terms of "outcome measures" describing the effects of the expenditure on the general welfare of the people of Nova Scotia. TPW, and particularly the Policy and Planning Division, would like to develop transportation system performance measures which respond to this need. One of its objectives is to improve the Department's competitive position by providing more understandable and accountable information to management on the implications of large-scale policy and budget decisions. It is clear that the ability of a management system to distill detailed engineering data into high-level management information, in the form of performance measures, would be an indispensable asset to the Department in accomplishing this objective.

Under the improved Business Process Model, TPW is able to provide defendable predictions of budget outcomes in the form of performance measures achievable for any given level of total funding. Performance would be expressed in terms of economic benefits (avoided agency and user costs) as well as safety, travel time, and other relevant indicators that the public can directly experience. The TMIS should provide information on the size and composition of the maintenance backlog under any budget scenario.

Also under the improved model, budgeting will entail a multi-year commitment of funds by the Province to maintenance of the existing transportation infrastructure. As a budgeting tool, TMIS will help the agency to create a more reliable programming process, by supporting a 5-10 year maintenance budget. More reliable longer-term programming may help to alleviate the problems the Department has experienced with project readiness. Multi-year funding also makes it credible for TPW to analyze the affordability of policies, helping the agency to set realistic goals and work efficiently to reach those goals. Nothing about this vision of decision support for budgeting is specific to any particular kind of infrastructure.

Funding Allocation

For the maintenance budget, funding is allocated among Districts to allow work orders and contractual commitments to be executed. Under the improved Business Process Model, the Head Office can distribute funding according to the overall maintenance priority list rather than using historical formulas. The priority list is the same one that was used for budgeting, except for any changes in conditions or project readiness that may have occurred during the time required by the budgeting process.

It is possible, by extending the budgeting tool, to analyze alternative ways of allocating funds among districts or other subsets of the highway network, such as functional classes. The tool could report the predicted performance measures for any given allocation, and could indicate which projects would be selected for any given set of allocation constraints.

Another level of integration is that of integrating the capital program priority lists with the maintenance list to explore alternative allocations between these two budget categories. This could be done on a district by district or province wide basis. TMIS will provide this capability. Like the budgeting tool, the funding allocation tool is completely generic, so only one tool is needed to cover all types of infrastructure and maintenance projects.

Work Tracking

To maintain the long-term usefulness and credibility of the decision support capabilities of the TMIS, it is necessary to be able to analyze the Department's ability to implement the programmed work, and the effectiveness of that work in delivering the predicted change in performance. This feedback loop begins with the effective recording of work accomplishments, both by in-house forces and by contractors.

TPW is in the process of implementing a new accounting system, called O/FMIS, which uses an off-the-shelf accounting package called SAP. O/FMIS has a system for identifying facilities that are the objects of maintenance and capital expenditure, including bridges and their elements. All labor and expenditures by in-house forces on work are recorded in O/FMIS with a unique bridge/road segment identifier. When a contractor is tasked with work on a single bridge, this also is recorded in O/FMIS with a bridge identifier. Each District and Area office has at least one O/FMIS terminal. Certain refinements will be needed in order to accurately track individual work tasks performed on more than one facility.

Since O/FMIS will provide tracking of work accomplishments, this will likely provide the input necessary to all the management systems for determining the work done. This will require some coordination to ensure that the types of activities tracked are recorded by location and meet the requirements for use in the TMIS. A common set of activity codes and cost/resource factors must be established in order to make the TMIS and O/FMIS data compatible with each other.

TECHNICAL ARCHITECTURE

When viewed from the perspective of a use case model, the TMIS is a large collection of modules that are inter-related in various ways, serving the decision support needs of a significant fraction of the Department. Regardless of the technical approach chosen, the scope of the problem is similar to the efforts of many states in the USA, to implement the management system requirements of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (4). A variety of approaches chosen by a number of states to implement these requirements and manage their complexity, are described in (5).

One possible approach to the development of such a system is to create a large database and software package that satisfies the full set of requirements of the whole system. However, this is viewed as too complex and expensive to be undertaken in Nova Scotia. TPW desires to minimize the cost of developing new software and, at the same time, wants to take advantage of the advanced state of development of several off-the-shelf systems. An alternative vision of the system is a loose collection of separately-developed modules organized by use-case, connected by a separate technical architecture. This vision can be implemented in stages, using off-the-shelf software for certain use cases where it is available, and developing the missing modules as time and resources permit. When off-the-shelf software is used, it is either modified to make it compatible with the technical architecture, or an adapter module is developed to move data between them. Software industry standards are relied upon whenever possible to avoid technical incompatibilities that generate unnecessary work.

A well-defined technical architecture is very important to the realization of this vision. The architecture must be just large enough to serve the fundamental interfaces among the use cases, and no larger. Just as in any successful software development effort, it is essential to exercise a stingy discipline with regard to “nice-to-have” but non-essential features.

One useful tool for finding the essential interfaces is the domain model, a concept borrowed from software design (6) that is also very useful in general systems analysis. Where the Use Case Model describes the verbs of the problem domain (activities which the users do that may be supported by the system), the Domain Model describes the nouns (things or concepts which the users want to manipulate). In terms of software design the Use Case Model forms the basis for organizing the user interface of the software, while the domain model organizes the internal structure of the software and the database. When used as a systems analysis tool, a domain model provides a stable means of organizing data and finding the overlaps and communication points among separate business processes. Most importantly, a domain model provides an organized way of finding and resolving differences in terminology and assumptions among different parts of an agency that must cooperate in order to accomplish the agency’s mission.

After the definition of the domain model, several additional parts of the technical architecture can be developed:

- A common system of geographic referencing, to make mapping and geographic analysis functionality as efficient and flexible as possible.
- A common logical data model, to make it possible to perform integrated ad hoc queries using SQL-based tools. This will assist the Department to efficiently manage the database, to gain reliability and security. A common logical schema does not always mean a common physical

schema: data may be distributed among multiple locations for performance and data management purposes. The common data model applies only to the data items that must be shared among use-cases. In general, raw condition and engineering data are not widely shared, though the performance measures developed from level 2 data may be.

- A common set of policy objectives to govern all project-level needs identification, especially level of service standards for physical roadway characteristics.
- A common set of performance measures to interface between the engineering-oriented project level parts of the system, and the management-oriented network-level parts of the system. All projects, regardless of the type of infrastructure they act upon, should be described according to a common set of cost and performance definitions in the network-level prioritization, budgeting, and funding allocation use cases, when brought together into an integrated program.
- A common convention for interaction with the O/FMIS accounting system, including a common set of facility identification and activity codes, to record and retrieve work accomplishment data.
- Common technical standards for new software development, especially the use of Microsoft's Component Object Model (COM) specification to govern interactions among software modules, and the use of a common database architecture for storage of shared data. Such standards are most important for new software modules that must participate in interactions with other use cases. They are less important for off-the-shelf or completely stand-alone software.
- Consistent system maintenance and access control policies for shared components of the system.
- A business process for defining, supporting, and enhancing all shared features of the system, through negotiation and consensus-building.

The last of these ingredients may be the most important for successful implementation. In TPW so far, this process has been conducted by informal working groups that meet as needed to resolve architectural issues, using consultant assistance in small assignments. The lack of a large organizational unit to serve this need has kept costs low and may help to avoid the analysis paralysis that sometimes occurs on large system design efforts.

CONCLUSIONS AND NEXT STEPS

TPW has commenced the implementation stage of the plan, involving the selection and implementation of a core suite of integrated management systems. Over the next twenty months, TPW plans to select, acquire, customize, develop and install a bridge management system, pavement management system, highway safety management system, traffic census system and network management system.

The TMIS demonstrates an important concept in asset management, that use-case analysis can be valuable in organizing the many data-sharing opportunities and interdependencies among the components of a full-scale asset management system.

REFERENCES

1. Jacobson, I. *The Object Advantage: Business Process Reengineering with Object Technology*. Addison-Wesley, New York, 1995.
2. Fowler, M., *UML Distilled: Applying the Standard Object Modeling Language*. Addison-Wesley, New York, 1997.
3. Poister, T.H. *Performance Measurement in State Departments of Transportation*, NCHRP Synthesis 238, TRB, National Research Council, Washington, DC, 1997.
4. General Accounting Office. *Transportation Infrastructure: States' Implementation of Transportation Management Systems.* Report GAO/RCED-97-32. US General Accounting Office, Washington, DC, 1997.

5. Management Systems Integration Committee. *The Integration of Transportation Information: Final Report of the Management System Integration Committee.* FHWA, US Department of Transportation, Washington, DC, 1998.

6. Booch, G. *Object-Oriented Analysis and Design with Applications.* Addison-Wesley, New York, 1994.