Managing the Risk of Aging Pavement Infrastructure in New Brunswick Through Innovative Decision Making

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Abstract

In the mid-2000's, the New Brunswick Department of Transportation (NBDoT) was faced with aging and deteriorating pavement infrastructure, resulting in escalating maintenance costs and substantial rehabilitation demands. In response, the Department initiated an Asset Management Business Framework to transform its management of pavement infrastructure with the objective to more effectively manage its risks through improved decision in its rehabilitation planning. Guided by a well defined and integrated framework, a more strategic approach to long term, sustainable investment planning and program management has been implemented. This enables better decision-making by identifying the appropriate timing for the most effective and economical treatment based on long term, least life cycle costs to achieve optimal performance within annual budgets. Innovative decision making tools were introduced to build upon and expand the Department's existing capabilities. Performance modelling and linear programming-optimization are now used to develop strategic investment plans with tactical and annual programs that integrate a wide range of supporting information to enhance decision making. In 2007, the Department's efforts were recognized with a three-year commitment of sustained pavement rehabilitation funding from the Provincial Government, which was the highest level in New Brunswick's history. This has resulted in not only immediate improvements in the level of service being provided to road users, but through optimized decision making and targeting investments in the right place at the right time, has provided the Department a strategy to manage infrastructure assets with a long term sustainable outlook.

Introduction

The provincial paved highway system forms the backbone of New Brunswick's land transportation network. The network includes over 16,300 km of provincially designated paved asphalt and chipseal surfaced highways and local roads that interconnect neighbouring jurisdictions, municipalities, airports, ports and railways. The majority of goods are shipped via the highways, thereby directly supporting primary industries such as agriculture, forestry, fishery and mining as well as contributing to the growth of tourism within the province.

In the early 2000's, the New Brunswick Department of Transportation was faced with aging and deteriorating pavement infrastructure, resulting in accelerated maintenance costs and the need for substantial rehabilitation. This at a time of reduced operating budgets and competing funding demands. Figure 1 displays the surface age class distribution for all asphalt and chipseal surfaced roads as of 2005, excluding P3 sections (Route 2 and 95). As shown, the annual quantities of pavement resurfacing has varied with significantly higher levels in the mid to late 1990's followed by reductions in the early part of this decade..

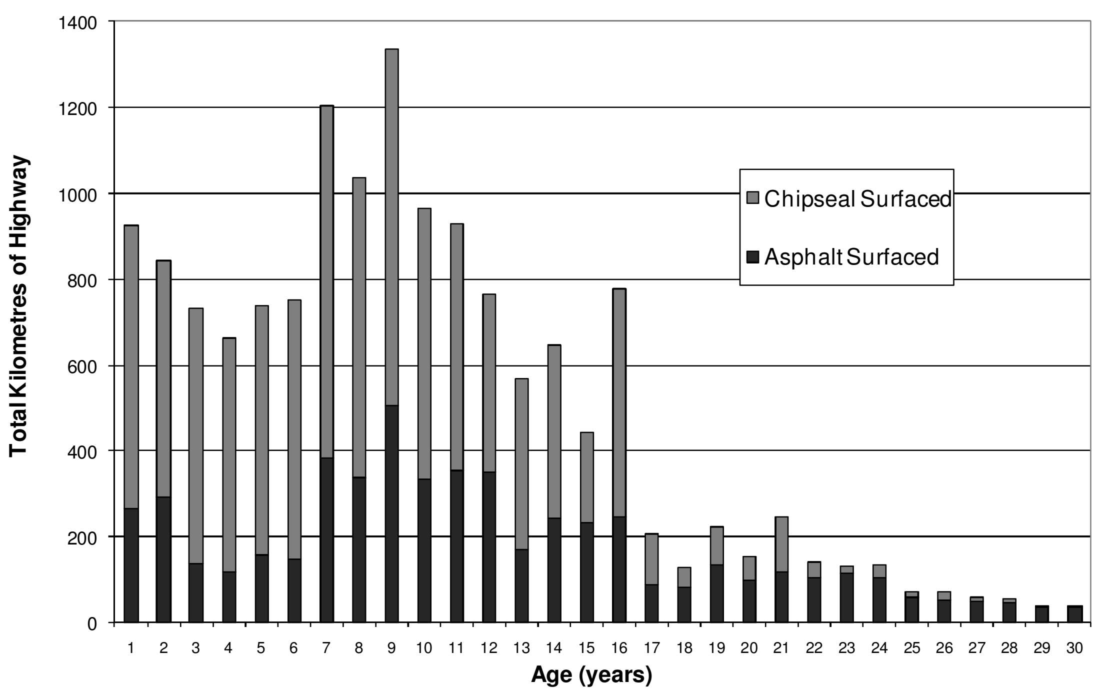

Figure 1: Pavement Infrastructure Age Distribution (2006)

Faced with the challenges of maintaining this mature infrastructure, the Department recognized the need to find a more effective way to manage its risks. In response, the

Province initiated the Asset Management Business Framework (AMBF) project with the goal to transform the management of its highway infrastructure (1).

AMBF Project

The AMBF was implemented to provide a more integrated and strategic approach to the long term, sustainable investment planning and program management of its transportation infrastructure. It underpins the Department's vision of ensuring a safe and sustainable transportation network to support the economic and social goals of the province and shapes its Strategic Plan. The key objectives of the AMBF were to:

- Provide a strategic approach to long-term investment planning and program development;
- Provide a more efficient means of allocating funds between assets;
- Allow for better decision-making by identifying the appropriate timing for the most effective and economical treatment of assets thus minimizing life-cycle costs;
- Use information and software tools necessary to support short and long-term planning in order to sustain optimal performance of the transportation network within our budget;
- Provide the opportunity to deliver an acceptable standard of performance for a growing network of transportation assets while maintaining expenditures within financial limits; and
- Support the Department's efforts in building the case for greater budget allocation and managing risks.

The ABMF is built upon the principles of sound asset management and encompasses the four key functional areas shown in Table 1 (2).

Table 1: AMBF Project Functional Areas

Functional Area	Details
1) Fundamental Asset Management Information	Asset inventory, condition assessments, projected deterioration, service levels and rehabilitation options
2) Planning and Program Development	A strategic, tactical and operational approach to long term management of assets utilizing linear programming and program development
3) Performance Measures	A cost effective approach for assessing asset condition
4) Continuous Improvement	Incorporating data analysis / feedback, lessons learned, best practices and innovations

The AMBF is being implemented by the Department in progressive stages based upon gaining a better understanding of asset management requirements, procedures and outputs. Pavement and bridge infrastructure, which account for majority of province's asset base in terms of value and funding demands were initially targeted, followed by other infrastructure including drainage systems, buildings and facilities.

Paved Highways and Roads AMP Planning Framework

Management of the paved highways and roads is guided by a well defined and integrated framework (3) that is comprised of several key components (See Figure 2).

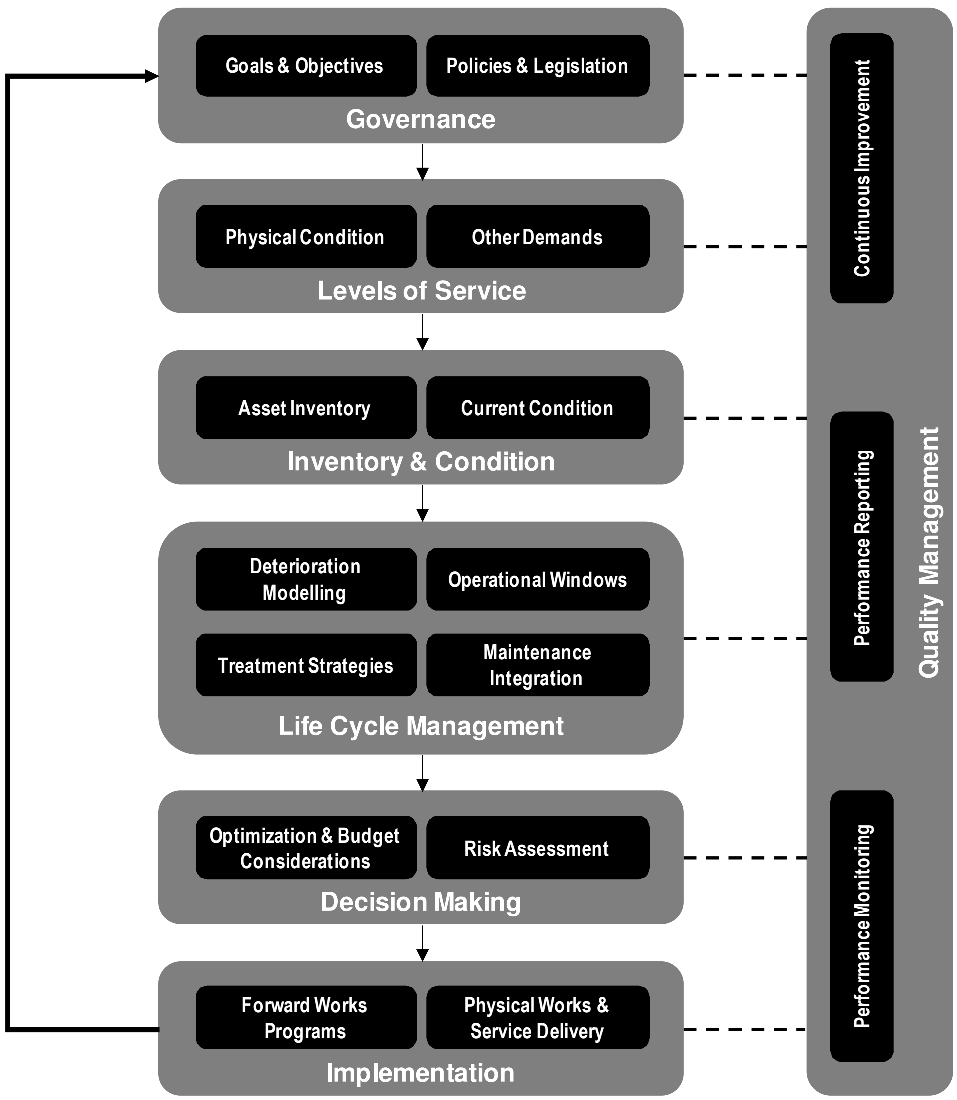

Figure 2: Pavement Infrastructure AMP Framework Components

Governance

The AMP framework for pavement infrastructure is guided by overarching government objectives, policies, plans and legislation. This included the Department's Strategic Plan along with key policies such as the Action Plan to Be Self Sufficient in New Brunswick and the Rural Road Infrastructure Plan. Aligning the AMP with these key governance directives was important to ensure that asset management processes and activities were focused. By doing so, has a significant impact on the ability to manage risk by resulting in the ability to make the right investment decision, in the right infrastructure assets at the right time.

Levels of Service

Levels of Service describe the quality of services to be provided by the pavement infrastructure for the benefit of road users. They are underpinned by performance indicators that are measured and evaluated according to physical condition, management and demand criteria.

The performance measures used to define the initial levels of service for highway pavements were based largely on physical and management criteria. This decision was intentionally made at the onset of the AMBF project as the Department had established measures in place and to narrow the scope in the early stages. The initial level of service criteria applied for the physical integrity of the pavement infrastructure included:

- Ensuring the condition profile for each functional classification does not decline over the three year planning period; and
- Elimination of all roads in very poor condition over a 12 year period.

In 2008 the Asset Management project was elevated to a Departmental Program under the Planning and Land Management Branch. Just prior to this time the Department established a number of management measures and targets related to the implementation of key asset management systems as well as the completion of continuous improvements (4). Non-condition based performance measures will be considered in time as continuous improvements.

Inventory and Condition

Asset inventory is the very foundation on which asset management processes are based and requires a robust data inventory combined with condition information in order to make informed investment decisions and effectively manage risk.

Historically the Department has maintained several types of asset inventory attribute data including length, surface age, surface type, rehabilitation treatments, functional classification, district and county. Traffic and pavement strength segment themes have also been recently introduced to support improved deterioration modelling.

A formal assessment of the coverage, reliability, confidence and accessibility of the asset inventory was carried out to target key areas where additional work was necessary (3). For example, initially the paved Local Road functional class inventory and associated attributed data was limited and now over the past few years, has largely been completed. Table 2 provides a brief synopsis of the current asset management systems and processes used for pavement condition data collection and storage.

Table 2: Pavement Infrastructure Corporate Applications and Processes

Component	Description
Current Pavement Management System	Pavement performance data is stored and managed in a series of MS Excel spreadsheets by individual routes and data type. The condition data is referenced to a defined version of the control section manual. Neither network wide assessment nor historical data analysis comparing previous year's data are easily undertaken, without a significant amount of manual manipulation.
Expedient Tables	Relational database tables that combined all of the individual spreadsheets for a single cycle of performance data on a province-wide basis have been created periodically to support pavement deterioration modelling research.
Transportation Related Attribute Management System (TRAMS)	Exor by Highways application is used as the primary inventory asset register and network manager for managing the provincial linear referencing system. The system enables the Department to integrate other spatial data with its Corporate Reference Network for use in other GIS applications. It is currently being implemented.
Operational Management System (OMS)	Hansen (Version 8) application is used to record all expenditure and operational information regarding the daily and seasonal/yearly management of NBDoT's personnel, equipment, and materials required for highway pavement asset operations and maintenance activities. Once fully operational, historical data will be used to track trends in pavement maintenance activities and associated costs, as well as support long term strategic planning.
Geographic Information System (GIS)	Corporate GIS based on an ESRI platform (Version 9.2) to support departmental activities by implementing a standardized, departmental approach for the collection, storage, maintenance, and use of spatial data.

Since the late 1980's, the Department has undertaken pavement condition assessments through its internal provincial pavement data collection program. The program has been developed and expanded over time to support both pavement management and design activities. It includes measuring:

- Pavement Roughness;
- Surface Condition;
- Rutting; and
- Structural Capacity.

The Department owns and operates a number of data collection vehicles and measuring devices (See Table 3). High speed network level surveys using a multi-function pavement evaluation vehicle equipped with laser sensors, an accelerometer and distance measuring instrumentation are used to collect pavement roughness and rutting data for numbered highways.

Table 3: Pavement Data Collection Program Components

Component	Data Collected	Source	Details / Processes
Surface Roughness	International Roughness Index (IRI)	High speed MDR Class II laser profiler	• Arterial/Collector/Local asphalt surfaced highways • 3-year cycle coverage • Data recorded at 50m intervals by wheel path • Sensor calibration procedures (prior, during, after) • Accuracy verification using 2 test sites • Field operation procedures – MDR manuals
Surface Condition	Surface Distress Index (SDI) and Individual Distress Ratings	Visual windshield surveys	• Arterial/Collector/Local asphalt surfaced highways • 3-year cycle coverage • 7 distress types (3 levels severity / 4 levels density) • Data recorded at 500 m intervals for both lanes • Field data collection rating manual
	Visual Inspection Rating (VIR)	Visual video based survey	• Chipseal surfaced roads • Cycle not established yet • Coarse rating (scale 10 – 0) • Data recorded at 500 m intervals for both lanes • Data collection rating manual
Rutting	Rut Depths	High speed ICC 5 laser sensor rut bar	• Arterial/Collector asphalt surfaced highways • 3-year cycle coverage • Data recorded at 50m intervals by wheel path • Sensor calibration procedures (prior, during, after) • Field operation procedures – MDR manuals
Structural Capacity	Measured Deflections	Dynaflect with 5 sensors	• Arterial/Collectors asphalt surfaced highways • 3-year cycle coverage • Data recorded at 200 m intervals • Right hand wheel path • Weekly calibration procedures and daily checks
Digital Images	Supporting	Geo-3D high speed survey	• Arterial/Collector/Local highways • Continuous images by direction • Forward, side and rear view • High resolution images • GPS referencing • Images converted to digital videos

Pavement surface deterioration is rated visually in the field using sampling techniques and according to a defined surface distress rating methodology. Local roads are rated in the office using high quality digital video. Pavement strength is measured using a Dynaflect (See Figure 3).

Figure 3: NBDoT Data Collection Units – High Speed MDR and Dynaflect Unit

Survey data obtained from the Department's pavement condition data collection program is used to generate a range of performance indicators as described in Table 4. All of these indicators measure the functional adequacy of the pavement.

Table 4: Pavement Performance Indicators

Component	Performance Indicator	Process	Source
Pavement Roughness	International Roughness Index (IRI)	ASTM E1926 Quarter Car Model	High speed ICC Class II laser profiler
Surface Condition Rutting	Surface Distress Index (SDI)	Mathematical model that incorporates severity and density ratings for 7 distress types into a single score from 10 to 0.	Visual field windshield surveys
	Distress Scores	Individual distress scores calculated from SDI model	Visual field windshield surveys
	Visual Inspection Rating (VIR)	Coarse rating from 10-0	Visual video based survey
Rutting	Rut Depths (mm)	Measured by laser profiler	High speed ICC 5 laser sensor rut bar
Structural Capacity	Equivalent Benkelman Beam Rebound Value (mean + 2 times standard deviation)	Seasonally adjusted value according to defined procedures	Dynaflect – based on single (#1) sensor reading
	Seasonally adjusted value according to defined procedures	Calculated based on defined procedures	Dynaflect – based on five sensor readings

Life Cycle Management

A suite of business processes are applied by the Department to support life cycle management of pavement assets. This includes long term deterioration modelling to determine future needs by identifying the gap between current and desired performance, applying operational windows to identify the most cost-effective timing for rehabilitation and ensuring it is integrated with operational maintenance.

Overall Approach

The framework for managing the risk of aging pavement infrastructure is built upon a strategic, tactical and operational approach. Each is critical in the decision making process to ensuring the right outcomes and must be inherently linked together. Guided by the Department's desired levels of service as discussed previously, performance modelling is performed at the strategic level to develop a 20 year optimized pavement asset investment plans that identify potential candidate sections and targeted rehabilitation strategies. These strategies are defined based on life cycle costing analyses that take into account the full range of pavement asset costs to determine the most appropriate timing for rehabilitation intervention. At the Tactical Level, a short term (i.e. 3 to 5 year) forward works program is generated and tools used to incorporate non-condition factors (i.e. safety, project specific requirements, etc.) into the project prioritization process.

Decision making for pavement infrastructure is now based upon Least Lifecycle Cost Analysis (LLCA) methodology. It provides an objective comparison of different pavement preservation strategies that can have different service lives, performance and associated costs. Implementing a LCCA approach to managing pavement infrastructure represented a fundamental shift from prior practices. In the past, it was not uncommon to allow pavements to deteriorate with significant reactive maintenance applied to the point where major rehabilitation was the only feasible option. The introduction of a LLCA approach has resulted in a significant change in practice. Deficient pavement sections were being targeted earlier in their life cycle to allow for less costly rehabilitation strategies to optimize performance and costs and purposely delaying rehabilitation for some more deteriorated pavement sections until the more appropriate time.

Performance Modelling

Pavement deterioration models describe the change in condition of the pavement infrastructure over time and is performed at the strategic level with the Department's planning framework. Developing these models was largely an exercise in determining how various road condition indicators changed with time and translation of these time-series relationships into a form that could be executed for assessing long term pavement preservation needs (5).

The deterioration modelling methodology required a sound understanding of the factors that influence pavement deterioration within the provincial highway system. The premise being made that road segments with similar pavement structures, function and environmental characteristics should exhibit similar deterioration over time. Due to a lack of time-series performance data, the surface age of the road segment was used as a proxy for time. The current set of key themes include:

- Surface Type;
- Highway Functional Classification;
- Urban / Non-Urban;
- Traffic Utilization; and
- Pavement Strength.

Pavement sections have been classified into common schemas and network level deterioration curves developed for each using statistical trend analyses. Dynamic segmentation was used to create datasets of homogenous road sections for specific combinations of themes and performance measures. Figure 4 provides an example of the deterioration curves considered.

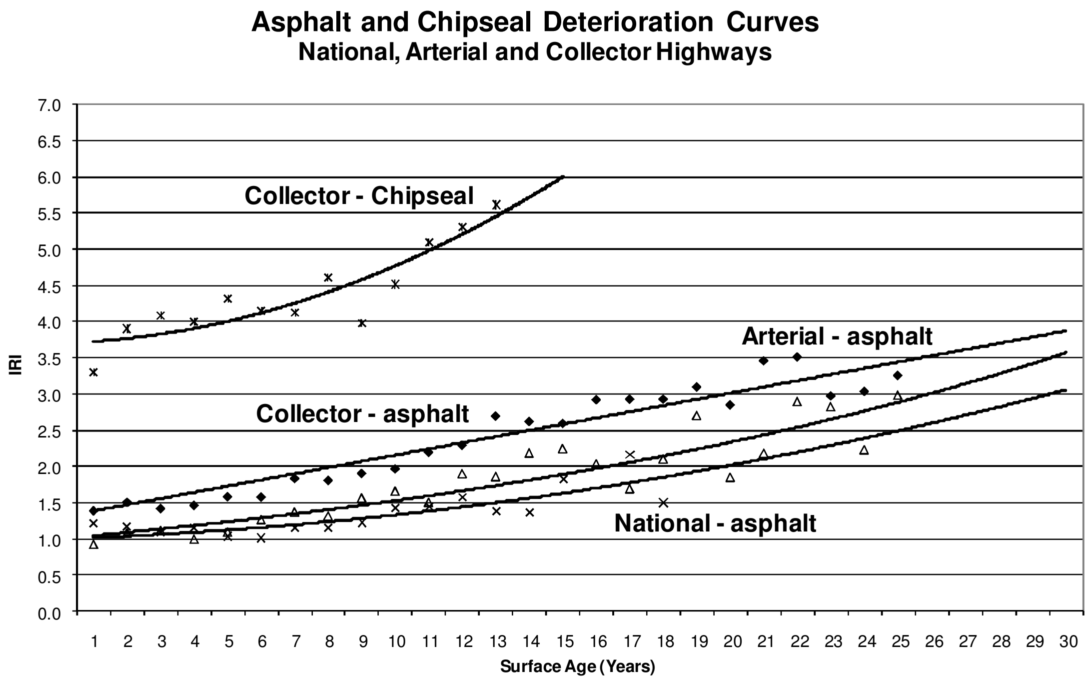

Figure 4: Example of Pavement Roughness Curves

Selection of the initial series of curves was influenced by the differentiation in pavement performance of asphalt versus chips sealed surfaces, current NBDoT treatment selection process and understanding of performance measures. For asphalt surface roads roughness and surface condition are the primary measures used modelling deterioration. Rutting was not found to be a significant driver in decision making as tends to be more a localized factor. Similarly, structural adequacy is not directly used in the strategic deterioration models, but is a theme for the other models in terms of establishing homogenous sections (5). Chipseal surfaced roads have been modeled based on the Visual Inspection Rating (VIR) approach.

Treatment Strategies and Operational Windows

Least life cycle strategies for paved highways and roads are largely defined by operational windows. These indicate when specific rehabilitation treatments are viable candidates based on the defined performance indicators. The rehabilitation strategies are “families” of treatments that have similar service lives, treatment outcomes and costs. This includes:

- Preservation;
- Minor rehabilitation;
- Major rehabilitation; and
- Reconstruction.

The overarching goal for identifying rehabilitation strategies within the modelling process is to ensure that the appropriate scope of rehabilitation is selected for each candidate section. Operational windows for preservation are not definitive at this time. The current set of deterioration curves is not able to accurately identify specific candidate sections and in most cases, the decision is made at the project level when more detailed information is available (6).

Decision Making

Various approaches can be used to assess long term rehabilitation needs and development of strategic and tactical forward works rehabilitation programs. In the past, the Department has largely followed a “worst-first” approach and with the implementation of the AMBF, linear programming- optimization is now used to develop strategic investment plans.

The Long Term Investment Management Program (LTIMP) linear program modelling tool is used to generate optimized investment management plans based on maximizing life cycle costs while meeting defined performance targets and / or other predefined constraints (6). The system generates a multi-periodic linear programming matrix which describes every potential choice over the entire planning horizon and then solves for the mathematical optimal solution based on management criteria, an objective function and constraints. Virtually any management objective or constraint can be formulated, including but not limited to condition states or indices, annual and planning horizon costs, carbon emissions, vehicle operating costs or geographic activity quotas. Figure 5 describes the inputs and outputs associated with the strategic decision making process.

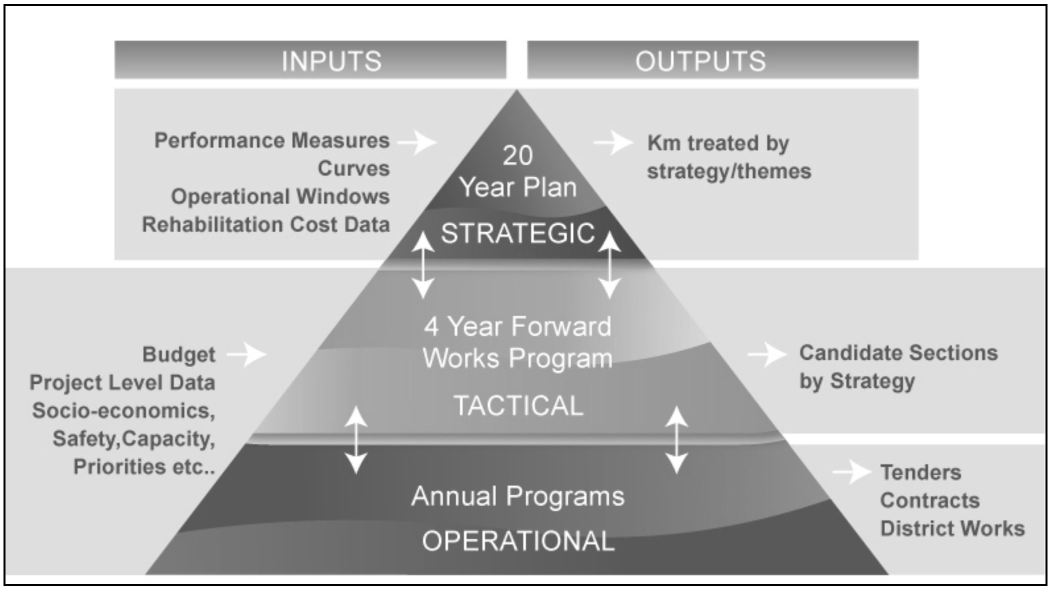

Figure 5: Hierarchical planning at NBDOT

Reporting functionality is customizable to meet user's specific needs including the ability to incorporate spatial analyses within the optimization process. For instance, a group of pavement sections within the same geographical area but with different optimized treatment years can be selected and the optimization process rerun to assess the effect of perhaps advancing the rehabilitation. The modelling is very robust / scalable and provides the Department with a powerful tool as it moves forward incorporating additional transportation assets.

Continuous Improvements

The AMBF is structured to support a process of continuous improvement. A key output of the AMP for paved highways and roads was the preparation of a Continuous Improvement Plan (CIP). The CIP focused on those areas within the planning framework that would strengthen and improve existing business processes to support the continued growth of pavement asset management practices and systems.
The CIP's included improvements in strategic, tactical and operational asset management across a number of areas as identified by the Department to be undertaken in the short term (i.e. less than three years) and longer term. Many of the

shorter term improvements were targeted to enhance the strategic modelling for the next cycle of program planning in 2011 as illustrated in Figure 6.

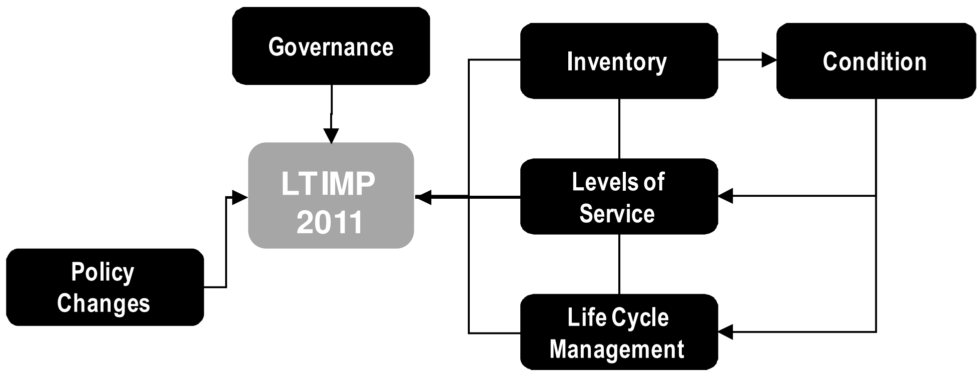

Figure 6: 2008-2011 CIP Focus

The CIP was developed in an open and collaborative manner to determine short and long term priorities to take forward for the next 3 years.. Nearly 50 specific CIP work tasks were identified, scoped out and scheduled across each of the pavement infrastructure AMP framework components as described in Figure 2. Examples of CIPS included completing the local roads inventory, assessing the potential to incorporate pavement strength within the deterioration models, improving the accuracy of the LTIMP modeling in the early years by introducing additional themes to conducting research on crack sealing, microsurfacing and surface treatment decision support policies.

Asset Management Plans

The development of formalized Asset Management Plans (AMP) is a key component of the Department's new infrastructure management. The AMP is a cornerstone tactical planning document that demonstrates a comprehensive understanding of the way the Department's physical assets are performing and being managed. It links the strategies and levels of service to operational day to day practices based on a long term least life cycle cost approach and disciplined asset management planning. The main purposes of the AMP within the Department are to:

- Demonstrate responsible management;
- Communicate and justify funding requirements; and
- Identify areas of continuous improvements.

The AMP outlines the Department's practices, processes and systems that are used to manage infrastructure assets. The AMP also transparently communicates the level of service and performance criteria for these assets, key management strategies, budget forecasts and risk mitigation. Taken collectively, this leads to a better understanding and ability to articulate the impacts of investment decisions.

Figure 7 illustrates how the AMP's are structured within the Department. Functional AMP's are prepared by the respective business units responsible for major asset groups (i.e. pavements, bridge structures, culverts, buildings, etc.). The individual functional AMPs are then rolled up into an overall corporate highway infrastructure plan spanning all assets.

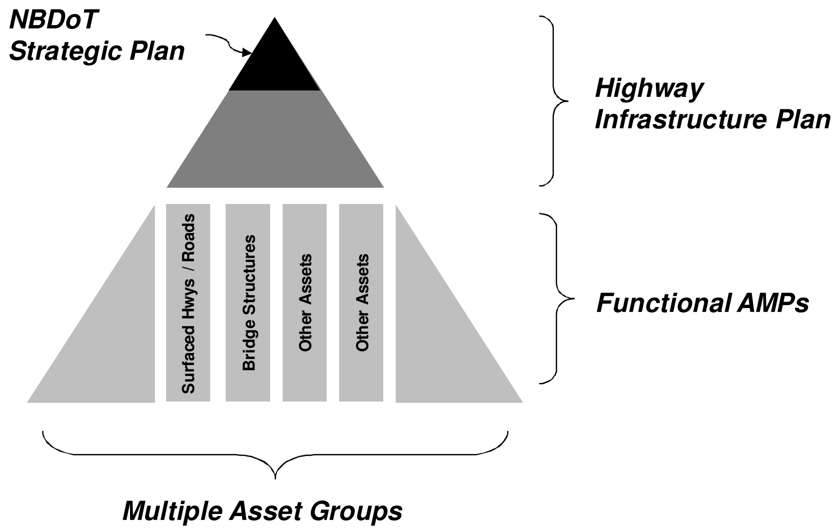

Figure 7: Strategic and Functional AMP Linkages

Initial AMP's have been prepared for pavements and bridges that are focused on documenting asset management practices and policies with a key scheduled improvements identified for moving forward. AMPs for other major asset groups will be developed in due course.

Value and Impact

As a result of implementing the AMBF, the Department has been able to develop and confidently defend a fact and goal based, long-term strategic infrastructure plan that outlined the funding levels needed to rehabilitate its pavement assets. The Department has estimated discounted savings of $1.4 billion over the 20 year planning horizon (i.e. $70 million annually) for pavement infrastructure. (7). These savings were calculated by subtracting the projected cost of the optimal least-lifecycle approach from the projected cost to attain the desired condition of the road network using the traditional.

Following implementation of the AMBF for pavement infrastructure in 2007, the Department halted the growth of road kilometres classified as “poor” (see Figure 8). To date, there were 1200 fewer kilometres of poor paved roads than projected under the traditional funding and approach, with continued reductions anticipated in following years (7).

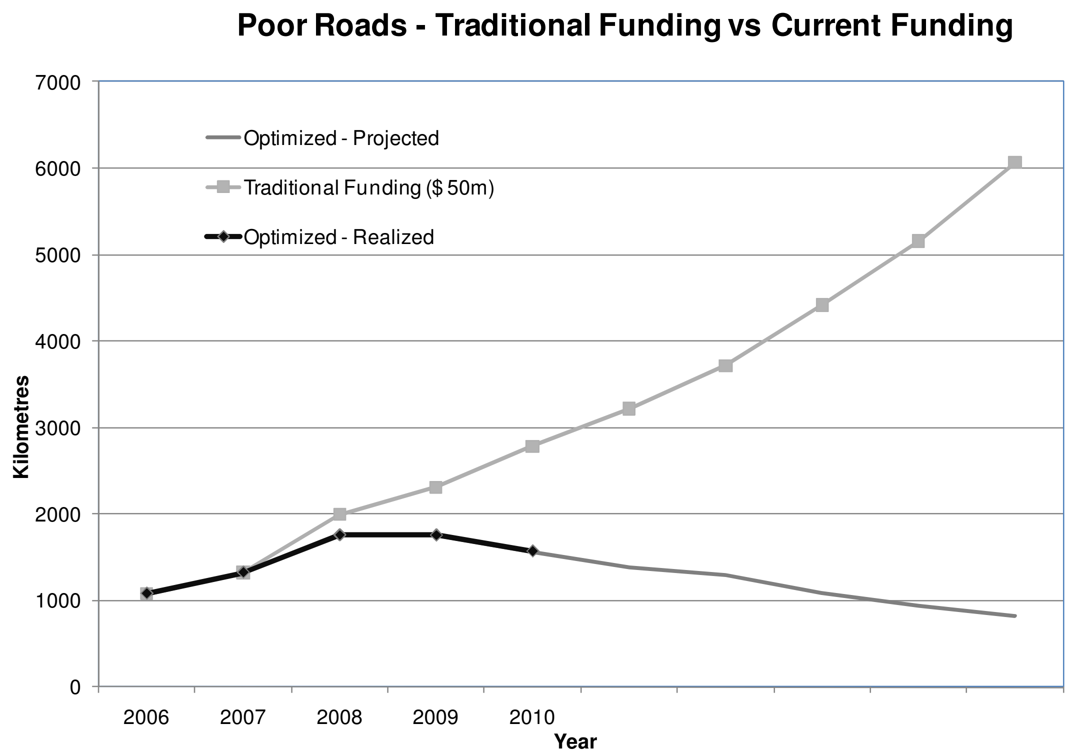

Figure 8: Comparison of Traditional vs. Optimized Decision Making Approach

The AMBF represented a fundamental shift in thinking and practice for the Department. It created organizational challenges that were much more difficult to accomplish than the technological challenges. Like most large public sector organizations, there were a number of information silos operating at NBDoT prior to implementation and consequently this impacted the ability to effectively manage its infrastructure assets. Shifting from a bottom-up to the top-down approach also required all employees to surrender the familiar way of doing things and embrace this new planning model and decision-making process. In response, the Department developed a change management plan to address them (7). The shift in planning approach is summarized in Table 5.

Table 5: Change Management Initiatives

Pre-Optimization Decision Making Approach	Post-Optimization Decision Making Approach
Worst First	Least Lifecycle Cost
Program Focus (Silos)	Network Focus
Event & Consumption Focus	Asset Focus
Short-Term Budget Management	Long-Term Asset Management Planning
Budget Cycle Planning	Ongoing Planning
Network-Level Data Collection	Performance Measurement
Budget Measurement	Managerial Valuation
Financial Evaluation	Continuous Improvement Process

Implementation of the AMBF and optimized decision making has transformed the way the NBDoT manages its pavement infrastructure. Key outcomes to date have included:

- Ability to effectively plan over long planning horizons while considering a full range of alternatives;
- Improved decision making with clearly-defined goals and objectives, strategies and plans that are more transparent and defendable;
- Providing the Department with the capability to make long term decisions with more confidence and commitment;
- Providing a more efficient means of allocating funds among the valued and competing needs of NBDoT's transportation network;
- Being able to quantifiably demonstrate the consequences of deviating from the optimized plan thereby reducing the influence of other factors;
- Helping to break down communication barriers within the Department and creating new levels of collaboration across the organization; and
- Allowing department managers and executives to pose what-if questions and explore multiple scenarios in a timely manner to ensure all relevant decision-making avenues are considered.

Summary

Through this work, the NBDoT has become a leader in the field of asset management, and the agency's success has attracted the attention of transportation officials around the world. In 2007, the Department's efforts were rewarded with a three-year commitment of sustained pavement rehabilitation funding from the Provincial Government, which was the highest level in New Brunswick's history for any government department – over 300 percent increase in funding from previous years.

In 2009, the Department was selected as a semi-finalist for the renowned Franz Edleman Award for Achievement in Operations Research and the Management Sciences. Future plans will see the AMBF and optimized decision making expanded to other infrastructure including bridges, buildings and ferries.

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