Migrating the City of Calgary from a Static Road Network Definition to a Dynamic Road Network Definition

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Abstract

The concept of pavement management has been around since the late 1970's. While the pavement management concepts remain the same, advancements in technology have been made in area of commercially-available pavement management software, including sophisticated user interfaces, linking with the latest GIS software, and web-enabled products.

Since 1987, the City of Calgary (City) has been using pavement management products to effectively manage their paved road network. As computer technology evolved and the pavement management need of the City changed, the migration from the Municipal Pavement Management Application (MPMA) to state-of-the-art client/server and web (browser-based) Highway Pavement Management Application (HPMA) seemed like a natural transition. HPMA is implemented and used by the Provinces of British Columbia, Alberta, Ontario, and Nova Scotia. Nevertheless, Calgary would be the first municipality in North America to implement HPMA.

One of the key reasons motivating the City to move from MPMA to HPMA was the software's capability to handle dynamic segmentation. Migrating the City's data from a static block-to-block segmentation database to a dynamic segmentation database tied to the City's GIS network presented some challenges. This paper presents the challenges encountered during the migration process and how the project team worked together to overcome these challenges. The paper also presents a comparison of results between the MPMA and HPMA databases, including the updated decision trees, the effect of the trees on the pavement network performance, and how the number of pavement sections changed due to dynamic segmentation. The paper also presents the GIS capabilities of displaying the condition of the pavement network.

1.0 INTRODUCTION

The City of Calgary (City) is responsible for the administration of a roadway network consisting of Arterial, Collector, Local, and Industrial roads totaling over 9,000 lane-kilometers. This network forms a valuable asset to be managed in a cost-effective manner in order to provide a desirable level of service to the stakeholders of the network.

Since 1987, the City of Calgary has been using Stantec Consulting Ltd.'s (Stantec) pavement management products to effectively manage their paved road network. As computer technology evolved and the pavement management need of the City changed, the migration from the Municipal Pavement Management Application (MPMA) to state-of-the-art client/server and web (browser-based) Highway Pavement Management Application (HPMA) seemed like a natural transition. As such, in 2011, Stantec was contracted by the City of Calgary to migrate the City's MPMA software database to a customized version of Stantec's HPMA software database.

The software configuration for the implementation of the HPMA involves the use of both the HPMA-C/S (client/server) and HPMA-web (browser-based). The HPMA-C/S provides complete pavement management system functionality. The HPMA-web currently provides data viewing and reporting capabilities similar to the HPMA-C/S, including graphing of data, viewing of data with images, and graphing and reporting optimization analysis results.

This paper presents the challenges encountered during the migration process and how the project team worked together to overcome these challenges. The paper also presents a comparison of results between the MPMA and HPMA databases, including the updated decision trees, the effect of the trees on the pavement network performance, and how the number of pavement sections changed due to dynamic segmentation. The paper also presents the GIS capabilities of displaying the condition of the pavement network.

2.0 IMPLEMENTATION CHALLENGES

HPMA is a commercial-of-the-shelf (COTS) pavement management system, which is implemented and used by the Provinces of British Columbia, Alberta, Ontario, and Nova Scotia as well as other state and federal agencies in the United States. Nevertheless, Calgary was the first municipality in North America to implement HPMA.

The development and implementation of the Calgary HPMA involved defining the City's street network in the HPMA and then importing the attribute data, including traffic, geometric, jurisdiction, and historic performance data from the City's MPMA database into the HPMA. This task required examining different sources of data, customizing data loading modules, populating code tables in the HPMA, and finally loading the required data into the software. In this section, the process of defining the code tables and loading the attributes and historic performance data is described.

With any new implementation, there are challenges that must be addressed. This section presents the challenges encountered during the migration process and how the project team worked together to overcome these challenges.

2.1 NETWORK DEFINITION

The HPMA street database is dependent on the definition of the street network in terms of street definitions. This is the main table that has to be first populated in the system prior to loading other data attributes. No data can be loaded to a street segment that has not been previously defined in the Street Definition table.

A street definition is defined as a street name along with a begin and end distance. Each street must be unique. If a street has a physical break in continuity, an additional definition segment is created. This can be done using the same street name with a different begin and end distance, or using an additional sequence number, or with a modification of street name. For physically divided roads, a street definition is created for each side. This can be done using either an additional direction indicator, or a modified street name including the direction.

In the City's MPMA database, street sections were defined based on a street, from, and to description. However, these sections were not tied directly to the City's GIS system. Furthermore, these sections in the MPMA were static. It was important for the City that their new pavement management system be tied to the City's GIS and that the street database was dynamically sectioned. Prior to this project, street definitions or routes had not been developed to be used as part of a pavement management database. As such, creating street definitions became a significant task in the MPMA to HPMA migration project.

To create unique street definitions, the following steps were undertaken:

- Process the data using Feature Manipulation Engine (FME) software to generate a single polyline for each unique continuous street segment,
- Generate lengths for unique street definitions,
- Calculate start and end distances for each unique street definition,
- Create sequential connectivity of multiple arcs in each unique street definition,
- Create additional definition segments at physical breaks in continuity, and
- Generate sequence of reference intersections along street definition.

Following data processing and street definition development, a thorough assessment of street definition routing and sequencing was undertaken to ensure completeness and continuity. The following items were verified:

- Sequence of multiple arcs within each street definition,

- Start and end distance accuracy,
- Inclusion of all required road class definitions (Arterial, Collector, Local, Industrial, Deerfoot Trail, Unknown/Undefined),
- Proper naming convention for divided and non-continuous street segments, and
- Sequence of reference intersections.

It should be noted that the street definitions went through several iterations prior to meeting the City's approval. Since the City has such a large network of roads, there were over 15,000 routes or street definitions to be developed and reviewed. It was important that the street definitions were unique and that City staff could identify the location of the routes based on the street name, from, and to descriptions. This presented a challenge as unique and easily identifiable events were not always available from the GIS. As such, new rules had to be created to account for situations of routes with dead ends, cul-de-sacs, or routes that started/ended at private roads and ramps.

After completing the above quality control/assurance/linkage steps, several issues were observed in the MPMA correspondence to the GIS database, which required manual intervention. Stantec manually fixed all the MPMA correspondence to GIS database issues and the final street definitions table was created and used throughout the project. A sample of the street definitions is provided in Figure 1.

As noted above, it was important for the City that the street database was dynamically sectioned; however, routes had not been developed to be used as part of a pavement management database. Therefore, as part of street definition creation, a linkage (Link ID) was created between the City's GIS Geo-Database and the HPMA. The Link ID was imported from the City's GIS Geo-Database into the HPMA Street Definition table. This allows individual sections to be displayed in ArcGIS ArcMap.

2.2 NEW DATABASE MANAGEMENT

One of the major differences between the MPMA and the HPMA is the database structure. MPMA is a one-tier database structure, where all performance and attribute data is tied to a given section. The HPMA has a two-tier database structure: a detailed street database and a de-normalized sectional data view (SDV). The source data are loaded and/or maintained in the detailed street database. The section data views are created within the system through the use of dynamic sectioning using user-defined sectioning parameters and/or predefined section definition overrides.

The HPMA detailed Street database includes database table for each type of roadway data (geometrics, projects, traffic, roughness, distress, etc.) and provides for storage of historical data for traffic, pavement structure and performance data. This database approach allows different data types to be stored based on their respective representative segments, rather than forcing a common segmentation approach to fit all data. Loading of data from various sources and maintenance of data is done in the Street level database.

The database tables include tables encompassing the following types of data:

- Street definitions (Street names, start and end kilometer points, etc.),
- Street landmarks or events (bridges, railroad crossings, intersections, etc.),
- Street attributes (jurisdiction, administrative, environment, geometrics, shoulders, etc.),
- Traffic data (AADT, ESAL, growth rate, etc.),
- Construction history data (project limits, treatments, layers & materials),
- Performance data (roughness, distress, deflection, friction),
- Images,
- Additional construction related tables (cores, Ground Penetrating Radar (GPR) data), and
- Additional tables (documents, programmed work, segment unit costs).

As part of the implementation process, the MPMA sections had to be linked to the HPMA street definitions so that historical performance and data attributes could be migrated from the MPMA to the HPMA. Stantec also worked with City staff to create new data loading routines to be able to load new performance and attribute data into the HPMA that would be tied to the new street definitions.

2.3 STAFF RE-TRAINING

One of the key challenges from the City's perspective was training and, in some cases, re-training staff on a new software package. While the basic pavement management concepts did not change, the database structure and interface were completely new to City staff. Therefore, training City staff was an essential component of the implementation process. City staff received initial/preliminary training at the onset of the project, which was followed-up with basic training for most users once most of the database had been figured. During this follow-up training, a general overview of the system and its results was also presented to Senior Level Management. More comprehensive training was provided to the advanced users once the system was fully implemented. Some additional web-based training with focused topics, such as data loading, were also made available during the implementation phases.

These training sessions helped City staff to learn the new software, familiarize themselves with the new screens, allow them to navigate through the different modules and learn about the database structure and management.

3.0 MPMA VS. HPMA RESULTS

As part of the validation process, the results from the HPMA were compared to the results of the MPMA. The following sections present some of the comparison results between the two data sets. It should be noted that other checks and balances were completed as part of the validation process, including, but not limited to, record counts and completeness checks. However, comparing the results between the data sets provides not only a comparison of the data itself, but a comparison of the models and parameters as well.

3.1 PRESENT STATUS/CURRENT CONDITION RESULTS

The City's GIS was used as the basis for the street definitions for the segments in HPMA; whereas, the MPMA sections were not previously linked to the GIS. As such, a one-to-one comparison of the two datasets was not possible. In order for some of the data to be migrated from MPMA to HPMA, some of the MPMA sections were either split or merged to match the GIS. As a result, there are slight variations between the two systems. Bearing in mind the differences between the two databases, the overall results at the network level for each functional class between the two systems are comparable as shown in Table 1.

The results indicate that the HPMA network average results are all within 5% of the MPMA results. The slight variations can be attributed to difference in lengths between the MPMA sections and the GIS. The difference in length can also be attributed to sections from MPMA that were merged or split to match the City's GIS. The slightly reduced length in HPMA as compared to MPMA can be attributed to multiple MPMA sections being represented by one GIS centerline, particularly for return runs used in MPMA. The 29% reduction in length for RCI data on the Industrial roads can be attributed to the fact that there are very few roads designated as Industrial and there is one section in particular.

As a result of linking the street definitions to the City's GIS through dynamic segmentation, the results from any SDV can be graphically shown in ArcGIS. A map showing the 2011 network present status based on the HPMA results is provided in Figure 2.

3.2 BUDGET/OPTIMIZATION RESULTS

Two sets of analyses were performed: performance-driven analysis and the budget optimization analysis. The performance-driven analysis is carried out by applying performance constraints. The objective of this type of analysis it to answer the question: "How much should be spent to achieve a certain network condition?". The objective of the budget optimization analysis is to address the question of what the network condition will be under different budget scenarios. The following scenarios were considered in the analysis:

- Do Nothing
- Annual Budgets of $15M, $20M, and $25M, respectively
- Maintain PQI @ 6.8
- Need Driven (Unlimited Funds)

The results of the MPMA and HPMA optimization results are noted in Table 2. The results from the HPMA are slightly better than those from the MPMA. That can be attributed to the difference in the present status results. The present status results in HPMA are very slightly higher than in MPMA. However, that slight increase has an impact on the overall budget results. That being said, the results from the two systems are quite compatible.

3.3 DECISION TREES

The decision trees depend upon certain rules and criteria set forth by an agency based upon past experience, and represent a practical aid in the treatment timing selection process. The decision trees are a critical component of any pavement management system that significantly affects the analysis results.

The primary advantage of these decision trees is that they reflect the decision processes normally used by an agency. Other advantages include:

- Flexibility to modify both the decision criteria and the associated treatments,
- Capability to generate consistent recommendations, and
- Relative ease with which the selection process can be explained or programmed.

As the name applies, decision trees incorporate a set of criteria for identifying a particular maintenance or rehabilitation activity through the use of “nodes”. Each node represents a specific set of conditions that ultimately leads to the identification of a particular treatment. The general types of data that could be considered in the development of the decision trees include:

- Pavement type,
- Construction,
- History,

- Functional classification,
- Traffic level,
- Pavement condition,
- Section geometrics, and
- Environmental condition, etc.

As part of the MPMA to HPMA migration, the existing MPMA decision trees were added to the database. In addition, a new decision tree set was developed during a Decision Tree Workshop with the City conducted in the summer of 2011. The focus at the Decision Tree Workshop was to develop decision trees for the bituminous granular base pavement types given that the majority (97 percent based on centerline-kilometres) of the pavement sections in the Calgary network are bituminous granular base pavements.

Similar to the MPMA, the HPMA requires a separate decision tree for each pavement type and functional class combination. A separate decision tree was developed for the following pavement type and functional class combinations:

- Bituminous granular base – Major Arterial,
- Bituminous granular base – Collector,
- Bituminous granular base – Industrial, and
- Bituminous granular base – Local.

A sample decision trees is shown in Figure 3.

3.4 UPDATED BUDGET/OPTIMIZATION RESULTS

The previous results have shown the comparison between the MPMA and the HPMA results. As previously noted, a new set of decision trees were created based on discussions with City staff. In addition, a new SDV based on dynamic segmentation was created with the following criteria:

- Minimum length of a section is 0.2 km or the actual total length of the road for short roads, which have a total length less than 0.2 km.
- Maximum length of a section is 3.0 km.
- Roads are sectioned at changes pavement types or changing functional classes.

- Homogeneous performance, such that a significant change in the pavement condition will cause a section break. This homogeneity is defined as a change in more than 2 points in the overall pavement quality index (PQI).

The predicted year 1 (i.e., 2011) PQI results are shown graphically in Figure 4. As can be seen, the network average PQI is 6.9 and includes data for 4,167 centreline-kilometres.

The M&R analysis was performed on all non-Deerfoot sections in the SDV using the updated decision trees from HPMA. These analysis parameters include the following:

- The analysis extends over an 11-year period, starting in 2011. However, it should be noted that there are no budgets allocated in 2011. Therefore, the work program is a ten-year period, starting in 2012.

- The analysis is performed using 2% inflation and 4% discount rate as used in the MPMA.

- The analysis is performed using ‘Always Analyze’, which means that all sections will be analyzed using the decision trees in each year of the analysis period.

- The ‘Multiple Implementation’ option was selected, which means that if a section reaches the trigger level again within the rehabilitation period, another M&R activity is selected for that section.

- The activities unit costs in the analysis have been updated to reflect the City’s current estimates.

- Incidental costs have been added to the reconstruction (20%) and overlay (15%) activities and a 20% engineering cost has been added to the M&R unit costs.

The results of the HPMA optimization results are noted in Table 3. The performance results, in terms of both network average PQI and %backlog are shown graphically in Figure 5 and Figure 6, respectively.

These results differ from the MPMA and previous HPMA results because the sections are different, different decision trees were employed during the analysis, and cost factors have been included in the second analysis set. It is understood that these results better reflect the City’s future rehabilitation needs.

4.0 CLOSING REMARKS

This paper has presented some of the key challenges that were overcome during the City of Calgary’s migration from MPMA to HPMA, including the development of a new street definition, linking the City’s pavement management data to their GIS, understanding a few new database structure, and staff training. As a result of the linkage between the City's GIS and HPMA and the dynamic sectioning, the City is now able to create maps to report their network condition results.

In addition, the paper presents a comparison of the results between the MPMA and HPMA. The comparison shows that the even with some minor variations in lengths between the two data sets, the results are comparable.

New decision trees were created as part of the implementation process. The result is slightly different optimization results compared to the previous MPMA results. However, the new results seem to better reflect the City's future rehabilitation needs.

Despite some of the challenges faced during this migration/implementation project, the HPMA has successfully been installed and implemented for the City of Calgary. The City's fully functional pavement management system is being used and maintained by City staff.

TABLES

Table 1:2011 City of Calgary Network Present Status Comparison between HPMA and MPMA

Functional Class	Present Status				Backlog	
	PQI (km)	RCI (km)	VCI (km)	SAI (km)	CL-km	% F/C
Arterial	5% (-12%)	4% (-10%)	3% (-11%)	4% (-52%)	-6%	-6%
Collector	0% (-11%)	0% (-7%)	-1% (-11%)	n/a	-3%	-3%
Local	1% (-9%)	2% (-1%)	1% (-9%)	n/a	0%	0%
Industrial	0% (-6%)	-2% (-29%)	0% (-6%)	n/a	0%	0%
Road Network*	**3% (-10%)**	**2% (-9%)**	**1% (-10%)**	**4% (-52%)**	**-2%**	**-2%**

Note *The Road Network does not include any Deerfoot Trail highway or ramps.

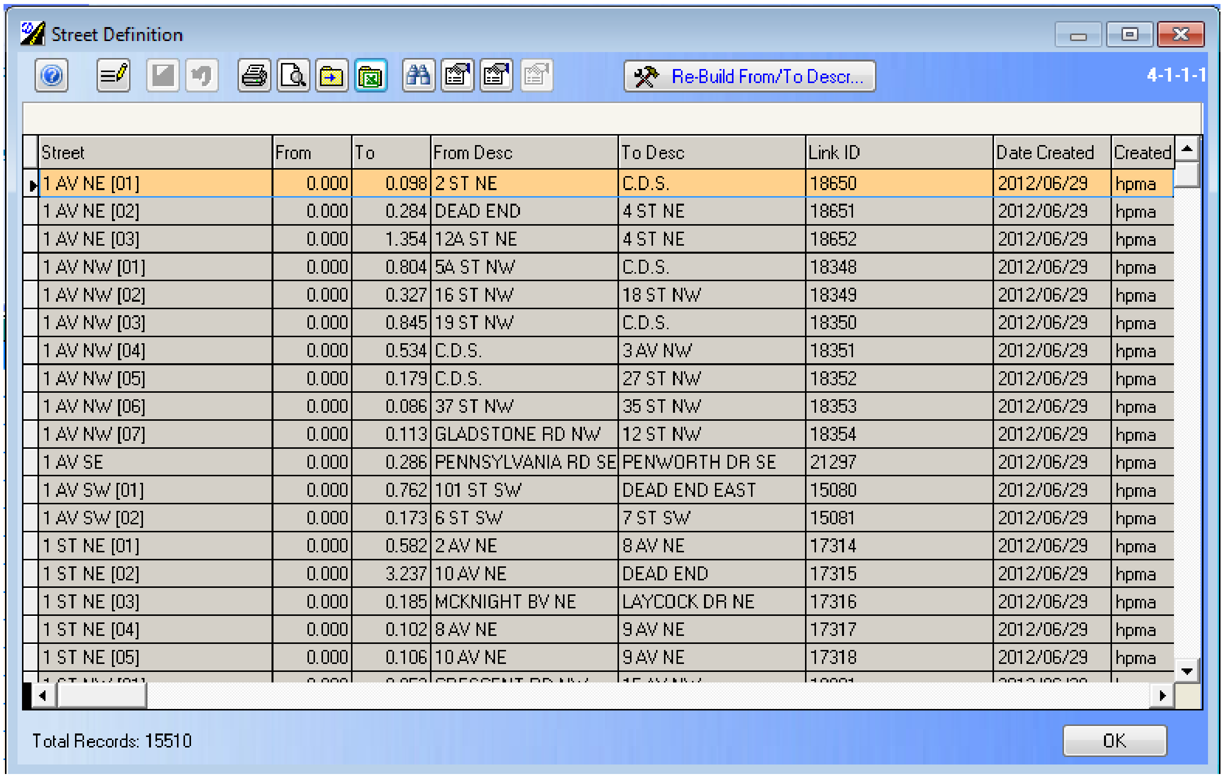
Table 2: MPMA vs. HPMA Optimization Performance Results

Budget Scenario	MPMA Results					HPMA Results				
	Total Budget	Network Performance				Total Budget	Network Performance			
		PQI_{AVG}		% Network Backlog			PQI_{AVG}		% Network Backlog	
		2012	2021	2012	2021		2012	2021	2012	2021
Do Nothing	$ 0 M	6.6	5.2	21%	44%	$0	6.8	5.5	18.4	41.2
$15 Million/year	$ 150 M	6.7	5.9	19%	22%	$150 M	6.9	6.3	15.7	17.3
$20 Million/year	$ 200 M	6.7	6.2	18%	16%	$200 M	6.9	6.5	14.8	10.3
$25 Million/year	$ 250 M	6.8	6.4	17%	10%	$249 M	7.0	6.7	13.9	4.5
Maintain Current PQI (6.8)	$ 297 M	6.8	6.6	16%	4%	$178 M	7.3	6.4	3.5	16.5
Need Driven	$ 283 M	7.3	6.6	4%	5%	$211 M	7.4	6.5	1.9	10.8

Table 3: HPMA Optimization Performance Results with New Decision Trees

Budget Scenario	Total Budget	Network Performance			
		PQI_{AVG}		% Network Backlog	
		2012	2021	2012	2021
Do Nothing	$ 0M	6.8	5.4	20.7	43.7
$15 Million/year	$150 M	6.9	6.1	18.4	24.7
$20 Million/year	$200 M	6.9	6.3	17.8	19.1
$25 Million/year	$250 M	6.9	6.7	17.2	14.8
Maintain Current PQI (7.0)	$317 M	6.9	6.9	17.8	7.9
Need Driven	$339 M	7.2	6.7	10.0	4.0

FIGURES



Street	From	To	From Desc	To Desc	Link ID	Date Created	Created
1 AV NE [01]	0.000	0.098	2 ST NE	C.D.S.	18650	2012/06/29	hpma
1 AV NE [02]	0.000	0.284	DEAD END	4 ST NE	18651	2012/06/29	hpma
1 AV NE [03]	0.000	1.354	12A ST NE	4 ST NE	18652	2012/06/29	hpma
1 AV NW [01]	0.000	0.804	5A ST NW	C.D.S.	18348	2012/06/29	hpma
1 AV NW [02]	0.000	0.327	16 ST NW	18 ST NW	18349	2012/06/29	hpma
1 AV NW [03]	0.000	0.845	19 ST NW	C.D.S.	18350	2012/06/29	hpma
1 AV NW [04]	0.000	0.534	C.D.S.	3 AV NW	18351	2012/06/29	hpma
1 AV NW [05]	0.000	0.179	C.D.S.	27 ST NW	18352	2012/06/29	hpma
1 AV NW [06]	0.000	0.086	37 ST NW	35 ST NW	18353	2012/06/29	hpma
1 AV NW [07]	0.000	0.113	GLADSTONE RD NW	12 ST NW	18354	2012/06/29	hpma
1 AV SE	0.000	0.286	PENNSYLVANIA RD SE	PENWORTH DR SE	21297	2012/06/29	hpma
1 AV SW [01]	0.000	0.762	101 ST SW	DEAD END EAST	15080	2012/06/29	hpma
1 AV SW [02]	0.000	0.173	6 ST SW	7 ST SW	15081	2012/06/29	hpma
1 ST NE [01]	0.000	0.582	2 AV NE	8 AV NE	17314	2012/06/29	hpma
1 ST NE [02]	0.000	3.237	10 AV NE	DEAD END	17315	2012/06/29	hpma
1 ST NE [03]	0.000	0.185	MCKNIGHT BV NE	LAYCOCK DR NE	17316	2012/06/29	hpma
1 ST NE [04]	0.000	0.102	8 AV NE	9 AV NE	17317	2012/06/29	hpma
1 ST NE [05]	0.000	0.106	10 AV NE	9 AV NE	17318	2012/06/29	hpma

Figure 1: Sample Street Definitions

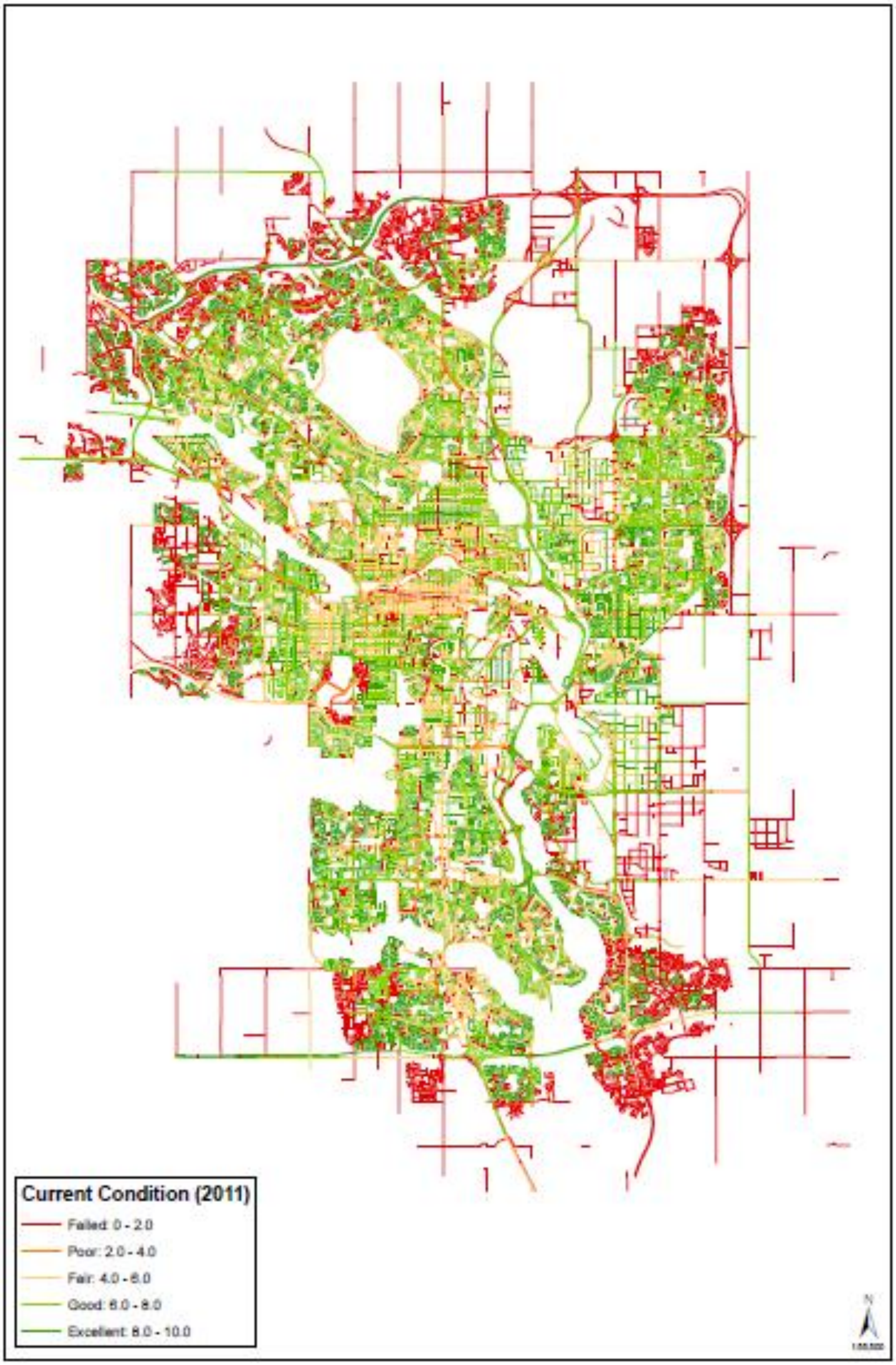


Figure 2: 2011 City of Calgary HPMA Network Present Status Map

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PQI<1.00 & 30% Allg & High Allg/Edge/Rutt
  Y: Eq_Thk<200.00 OR Surf_Thk<180.0
    Y: RECON LOC
    N: FDRC-LCBGB
  N: PQI<1.50 AND AADT>100
    Y: BMIX80-1A
    N: PQI<2.50 AND AADT>100
      Y: BMIX60-1A
      N: PQI<3.00 AND AADT>100
        Y: BMIX50-1A
        N: PQI<4.00
          Y: AADT>100
            Y: BMIX40-1A
            N: JMIX30-5A
          N: PQI<6.00 AND Allg=0.0 AND Edge=0.0 AND Rutt=0.0
            Y: SLRY M
            N: Low Rutt/Allg & Mod-High Long/Tran
              Y: SPOT PAT
              N: VCI>3.00 AND VCI<5.00 AND LgTr_High=0.0 AND Edge_High=0.0 AND Edge_Mod=0.0
                Y: CK SEAL
                N: VCI>4.00 AND VCI<9.00 AND LgTr_High=0.0 AND Age<4
                  Y: CK SEAL
                  N: NONE
```

Figure 3: Sample Decision Tree

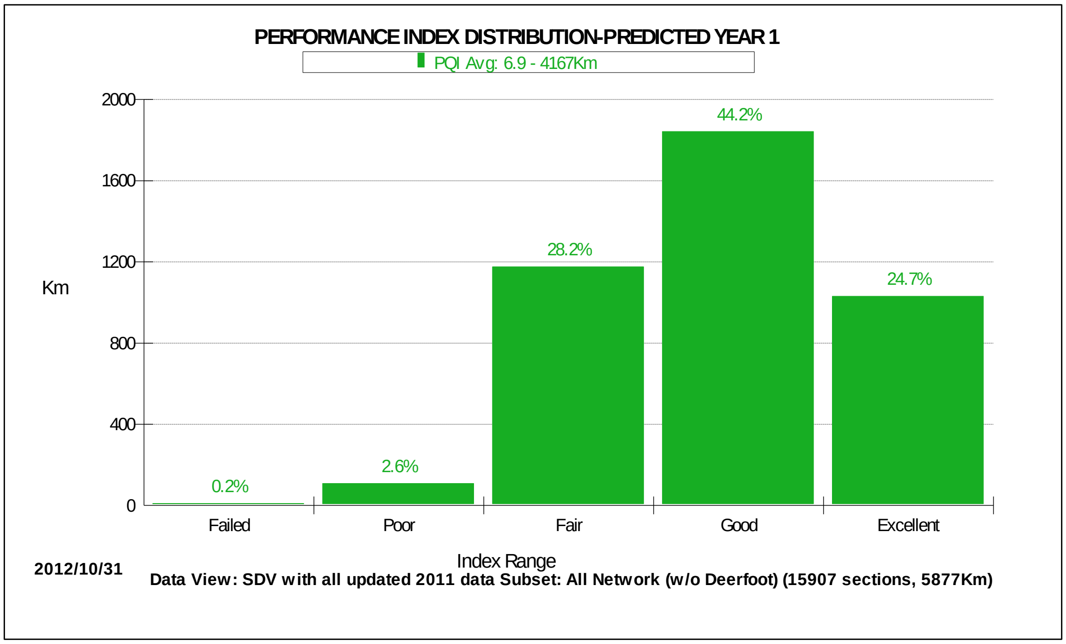

Figure 4: Predicted Year 1 PQI for SDV2011 (w/o Deerfoot)

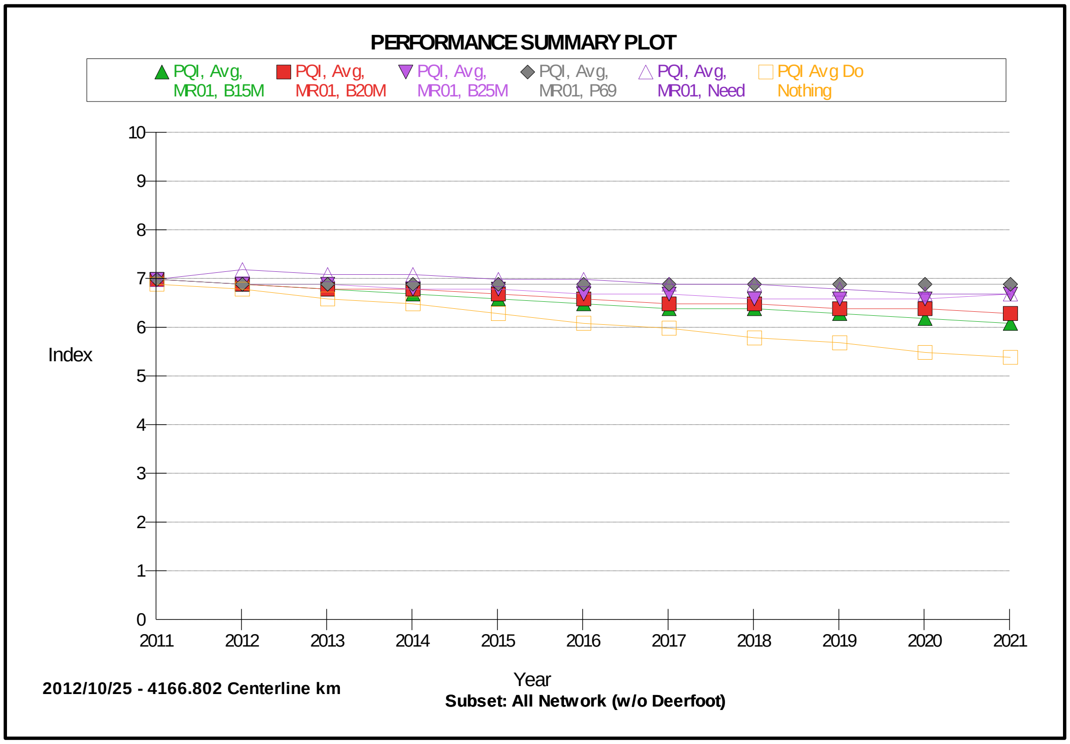

Figure 5: Budget Impact on Network Average PQI

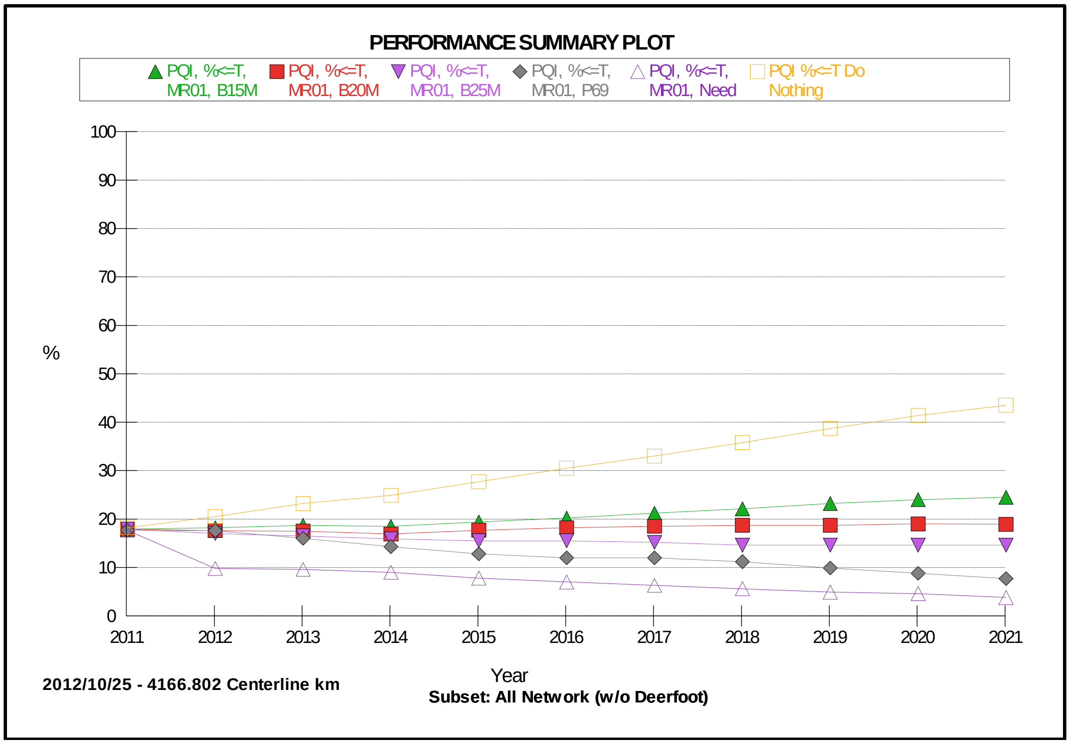

Figure 6: Budget Impact on Network Backlog