Bringing Pavement Management Back to PEI

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Abstract

Prince Edward Island (PEI) was Stantec's first implementation of its pavement management software, Highway Pavement Management Application (HPMA), in the late 1970s. Unfortunately, like many other transportation agencies, the system wasn't regularly updated or maintained over time and became obsolete.

As part of the PEI Transportation and Infrastructure Renewal (TIR) Strategic Plan 2012-2015, the department vowed to focus on economic growth through infrastructure improvements. PEI TIR also committed to implement proven and innovative technologies to improve on pavement preservation methods, and determine the best means to upgrade or replace aging infrastructure.

To this end, in 2014, PEI TIR made the decision to re-invest in their pavement management system and upgrade to the latest version of HPMA. PEI TIR had a database of their National Routes and Community Connector (NRCC) roads, which included roughness and distress data. This NRCC database formed the basis for the PEI TIR pavement management database.

The project included the development and customization of the pavement management database, data loading, model development, analysis, software installation, and training. This paper presents some of the successes and challenges of implementing a pavement management system in the province of PEI.

1 INTRODUCTION

PEI was the first provincial-level transportation agency to implement Stantec's Highway Pavement Management Application (HPMA) pavement management system (PMS). However, like most agencies, they have not been able to dedicate the resources to maintain the database over the past few years.

Through its most recent strategic plan, PEI TIR has committed to promote economic growth through infrastructure improvements. PEI TIR has also committed to managing both new and existing infrastructure through proven and innovative technologies, which focus on pavement preservation. A pavement management system will assist PEI TIR with developing a program with a focus on pavement preservation. Other benefits of implementing a pavement management system include:

- Realize magnitude of pavement investment;
- Provide better chance of making the correct decisions;
- Justify maintenance and rehabilitation (M&R) programs;
- Provide objective answers to effects of lower funds on condition, implications of deferred work and/or lower standards;
- Provide comparative view of network condition (current & future); and
- Improve communications between design, construction, maintenance and planning

Recognizing the benefits of a pavement management system, PEI TIR retained Stantec Consulting Ltd (Stantec) in 2014 to upgrade their pavement management system to Stantec's latest version of HPMA. HPMA has a two-tier database structure, where detailed data is stored in the detailed highway-level database and section-level data views (SDVs) are created from the detailed highway database using rules of homogeneity. All network analyses, including maintenance and rehabilitation analysis, are performed at the section level.

All of the National Road Community Connector (NRCC) roads, covering over 1,200 km, were included as part of the initial implementation phase. Local roads may be added to the pavement management system during a subsequent phase.

2 WORK PLAN

The project work plan for the pavement management implementation project consisted of several tasks, including:

- HPMA Configuration/Customization and Database Conversion
- Review and Re-Develop Pavement Management Analysis Models

- Perform Pavement Management System Analyses
- Establish GIS Linkage
- Install Pavement Management Software
- Train Pavement Management Personnel on the Operation of the Software
- Provide Final Report
- Provide Maintenance Support

The focus on this paper will be on the pavement management data, models, and analyses.

3 PEI ROAD DATA

As part of the pavement management implementation project, the following data attributes were loaded in the pavement management system:

- Highway Definitions (NRCC network definition, including limits and length)
- Jurisdiction (region, district, city)
- Administrative (functional class)
- Environment
- Pavement Types
- Shoulders (shoulder types, shoulder widths)
- M&R Activities (treatments, unit costs)
- Distress Types (distress definition by pavement type)
- Traffic Classes (summer and winter average annual daily traffic, growth rates)
- Event Types (intersections, bridges)

PEI TIR also collects performance (roughness and distress) data for their road network, as subsequently discussed.

3.1 ROUGHNESS DATA

PEI TIR first collected IRI on the NRCC roads in 2011. Initially, it was expected that the IRI survey would be completed on a two-year cycle. As of 2013, PEI TIR moved towards an annual IRI survey on NRCC roads. PEI TIR uses a Class I COX High Speed Dual Laser Inertial Profiling System to measure the International Roughness Index (IRI). IRI data is calculated and summarized every 10 metres in both directions.

The IRI data is primarily used to award contractor penalties or bonuses based on the performance of the finished product. To a lesser extent, the roughness data is also used to justify decision making, i.e., IRI data validates that road is in rough condition. PEI TIR is expecting that a PMS will help to make better use of the IRI data from a pavement management perspective.

3.2 DISTRESS DATA

PEI TIR has conducted distress surveys on the NRCC roads every two years since 2000. The distress survey consists of a manual survey, which evaluates the severity and extent (density) of the following nine distresses:

- Raveling
- Excess Asphalt (Bleeding)
- Potholes
- Wheel Track Rutting
- Distortion
- Alligator cracking
- Longitudinal and Meandering Cracking
- Transverse Cracking
- Maintenance Patching

The severity and extent for each distress is summarized into an individual index on a scale of 0 to 10. The individual distress scores are then rolled-up to an overall Surface Distress Index (SDI) on a scale of 0 to 10. The manual survey is conducted on homogenous control sections, as defined by PEI TIR based on changes in pavement structure related to historical project limits. The control section lengths range from less than 500 metres to over 18 kilometres.

The distress data is used as a tool to assist in selecting appropriate treatments and prioritizing projects. Historically, the distress data has not been used extensively to develop a network-level work program.

3.3 DATA CHALLENGES AND SUCCESSES

The data is maintained by the GIS department, where all data is related to the PEI TIR's linear referencing system. The network definitions (i.e., highway definitions) in HPMA were setup based on PEI's linear referencing system. Fortunately, most of the attribute and performance data is tied to that linear referencing system. This is not always the case for transportation agencies, as data is often scattered throughout different departments and/or stored using different referencing systems. Loading the attribute and performance data into the PEI pavement management system was straightforward because the data was already linked to the existing linear referencing system.

Prior to implementing the PMS, the roughness and distress data was not readily available to PEI TIR staff. The data was available upon request, but there was no central location for PEI TIR staff to access the data. Moreover, the roughness and distress data is collected through different surveys, with different survey lengths; thereby, making it difficult to combine and compare roughness and distress data. One of the successes to implementing a pavement management system is that it will allow various users to access the data. HPMA has querying and reporting tools that allow users to dig down into the fine details (i.e., IRI in 10-metre increments), as well as, provide users with network-level results (i.e., overall network performance).

Roughness and distress surveys were completed in 2014, but the data was not compiled or processed at the time of the data loading. As a result, the most recently available roughness and distress data were loaded into the pavement management system. That is, roughness data from 2013 and distress data from 2012. The 2014 roughness and distress data will be loaded as part of the maintenance phase of the project. Waiting until the maintenance phase, will provide PEI TIR staff with an opportunity to load the data themselves, i.e., provide PEI TIR staff with a hands-on training opportunity.

The sample sections for the distress survey are dynamic and can change from year-to-year based on new project limits. HPMA is setup to handle dynamic segmentation as all of the data is linear referenced. As long as the data continues to be linear referenced, the survey sections can shift along the route, and all of the historical data will still be linked to the appropriate sections.

4 PERFORMANCE INDEX MODELS

Performance indicators are used to represent pavement condition. The following sections summarize the performance index model development as part of the PEI PMS implementation project.

4.1 ROUGHNESS

Roughness is a measure of the pavement surface distortion along the roadway. It is used to describe the ride quality of a road to estimate the ability of the pavement to provide a safe and comfortable ride to its users. Roughness is usually evaluated objectively through field evaluation. Roughness measurement devices typically measure the longitudinal profile of the roadway – cumulative distortion measurements per linear travel distance (e.g. m/km) - which is then used to calculate the IRI using the device’s associated software.

In some pavement management implementations, IRI is converted to a normalized performance indicator. PEI TIR currently reports IRI values on an annual basis and would like to continue reporting IRI. As such, IRI was used as the roughness index model within HPMA.

4.2 DISTRESS

PEI TIR collects nine types of surface distress. Most surface distresses are collected in five density levels (0, 1, 2, 3, 4) and four severity levels (0, 1, 2, 3), with the exception of maintenance, which is solely based on extent (no severity level). The PEI TIR distresses and severity levels are shown in Table 1.

Each distress is also assigned its own Surface Condition Rating (SCR) index on a 0-10 scale, where 10 indicates no distress present. Each pavement segment is then assigned an overall SDI, which is also on a 0-10 scale, with 10 indicating no distresses present. The SDI was used as the distress model index.

PEI TIR provided Stantec with SDI data from 2012, which was loaded into the HPMA database. The SDI data was summarized for every distress sample section surveyed in the field. The lengths of the distress sample sections range from a few metres to a few kilometres, and generally represent homogenous pavement sections.

4.3 OVERALL CONDITION

An overall condition index model is based on one or more condition index models. PEI TIR currently does not use an overall index model. They considered each performance index (roughness and distress) separately. For network-level analysis and reporting, PEI TIR have decided to move to a single overall score that incorporates both roughness and distress, which is easier to understand and communicate to the community. The Pavement Quality Index (PQI) was used as the overall index model.

Several PQI models were investigated. It was agreed that the PQI model would be equally weighted by roughness and distress. In order to join the two condition models together, the IRI data was converted to a 0-10 scale. The conversion is setup such that an IRI of 3.3 m/km corresponds to a 5 on a 10-point scale. The overall PQI model is shown in Equation 1 below.

$$\boldsymbol{PQI} = \mathbf{0.5} \times \left(\mathbf{10} \times \boldsymbol{e}^{(-\mathbf{0.2101} * \boldsymbol{IRI})}\right) + \mathbf{0.5} \times \boldsymbol{SDI} \qquad \textbf{Eq. 1}$$

Where,

PQI = Pavement Quality Index

IRI = International Roughness Index, m/km

SDI = Surface Distress Index

4.4 PERFORMANCE INDEX MODEL CHALLENGES AND SUCCESSES

PEI TIR already collects and uses IRI and SDI as performance measures. Staff are comfortable using the terms IRI and SDI and understand what they represent. Using IRI and SDI as performance indices became a natural choice to represent roughness and distress performance data.

The challenge was developing a new overall performance indicator, particularly since the two performance models use inverted scales. A low IRI value is indicative of a pavement in good condition, while a low SDI is indicative of a pavement in poor condition. As a solution, the IRI was converted to an equivalent 0 to 10 scale. Then, the PQI was developed based on equal distribution of the two performance indicators.

Over time, PEI TIR will need to develop a comfort level and understanding of the new PQI model. As they gain a better understanding of the model, PEI TIR may choose to make some modifications to the model to ensure that it is a good representation of the overall pavement condition. These reviews and potential modifications will be a part of the on-going training and communication process.

5 PAVEMENT PREDICTION MODELS

Performance prediction models are a key component of any pavement management system. These models are utilized in the pavement management system to predict future performance of a pavement section, identify the rehabilitation needs, and estimate the network condition after the implementation of different rehabilitation activities. Furthermore, these models are utilized during the maintenance and rehabilitation (M&R) analysis and subsequent budget optimization, to identify the cost-effectiveness of the different rehabilitation alternatives.

HPMA utilizes two approaches for predicting future pavement performance: a site-specific model approach and a default model approach.

The site-specific modeling approach is based on the use of the historical performance data of a section to determine the model coefficients for a section (i.e. any section created during Section Data View creation). For each individual section, the available historical performance data since the last rehabilitation or construction is analyzed to determine the model that matches the observed performance of the section and thus predict the future performance.

The default prediction model (or the family-of-models) approach is used in three cases:

- When there is inadequate historical data (i.e. less than three points);
- When the available data does not provide a reasonable site-specific trend (i.e., it yields a result outside of the last activity's minimum – maximum expected service life range); or
- When predicting the future performance of a section after the implementation of a particular maintenance or rehabilitation activity.

The default models are stored in the HPMA and are selected for individual sections based on the last applied treatment and the performance class of the section. Performance classes can be defined in terms of any variable stored in the HPMA database. Traditionally, performance classes are defined in terms of combinations of traffic, pavement thickness, and subgrade.

Figure 1 shows an outline of the approach utilized for developing the performance prediction models for the PEI TIR database. The development approach is divided into short-term and long-term phases. In the short term, default prediction models were developed using Stantec's industry experience with similar activities, coupled with PEI TIR's local experience. In the long-term, with more performance data collection, enough historical data will be available to be used in the HPMA for further refinement of the default prediction models and for the site-specific models for individual sections. Default prediction models can be enhanced using historical data accumulated through multiple performance data collection cycles. Enhanced models, based on historical data, can be generated through regression analysis available in the HPMA Feedback Module. Also, with the accumulation of future performance data, enough data will be available for more pavement sections, allowing for site-specific models to be generated.

5.1 PERFORMANCE CLASSES

The default prediction models were developed through consultation with PEI TIR's staff and building upon their local knowledge and experience with the different maintenance and rehabilitation activities. Table 2 shows the performance classes that were considered in the model development.

5.2 PREDICTION MODELS

The preliminary IRI and SDI models were developed based on Stantec's industry experience and input from PEI TIR as it relates to the initial IRI, SDI and expected service lives of the different maintenance and rehabilitation treatments as shown in Table 3.

The service life is based on how long it would take a given treatment to reach a rehabilitation trigger level. PEI TIR indicated that they generally use an IRI rehabilitation trigger level of 3.3 m/km and SDI rehabilitation trigger level of 5 to 6, depending on the functional class.

A sigmoidal (i.e., S-shaped) form is used in HPMA for modeling pavement performance due to its flexibility in describing the deterioration of a pavement section. The flexibility of the sigmoidal model allows the curves produced to be concave, convex, S-shaped, or almost linear. This has historically produced curves that adequately fit the data and describe performance.

The following sigmoidal model forms were used in the HPMA for performance prediction modeling of roughness and distress:

$$IRI = O + e^{\left(a - b \times c^{ln(age)}\right)} \quad \textbf{Eq. 2}$$

$$SDI = O - e^{\left(a - b \times c^{ln\left(1/age\right)}\right)} \quad \textbf{Eq. 3}$$

Where,

IRI = International Roughness Index, m/km

SDI = Surface Distress Index

age = age, years

O = origin or initial post-rehab performance index value

a, b, c = model parameters that shape the model

Based on the initial IRI and SDI values and expected service lives noted in Table 3, , a preliminary set of prediction models were developed. It should be noted that these models will be revised when as-built data and new performance data becomes available.

5.3 PREDICTION MODEL SUCCESS AND CHALLENGES

There is insufficient data in the system to build site-specific models (only a single data point for both roughness and distress). Therefore, the pavement management system will rely on default prediction models.

Due to insufficient data points, prediction models were developed based on engineering judgement and PEI TIR's experience. Further refinement of the default prediction models will be possible as new performance data is loaded into to the database. For example, once the 2014 roughness and distress data is added to the database, PEI TIR will be able to compare the predicted 2014 values versus the actual (or measured) 2014 values.

Another useful tool to validate the prediction models is to conduct ground truthing, whereby the results of the prediction models (predicted IRI, SDI, PQI values) are verified through field condition assessments (measured IRI, SDI, PQI values). Ground truthing is something that PEI TIR may explore as part of a future PMS implementation phase.

6 DECISION TREES

As the name implies, decision trees incorporate a set of criteria for identifying a particular M&R 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, functional class, pavement condition, environmental conditions, traffic level, etc.

Decision trees are a set of rules or criteria that are used as a practical tool in the treatment timing selection process. The decision trees are a critical component of any pavement management system that significantly affects the M&R analysis results.

The primary advantage of decision trees is that they reflect the decision processes normally used by the PEI TIR. 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.

The decision trees were developed based on discussions with PEI TIR regarding typical M&R practices, and Stantec's industry experience.

HPMA requires a separate decision tree for each pavement type and functional class combination. Currently, the PEI TIR HPMA database only contains one pavement type (asphalt) and three functional classes (arterial, collector, local). An example of the decision tree is provided in Figure 2. The treatment nodes for this sample tree are provided in Table 4.

6.1 DECISION TREE CHALLENGES AND SUCCESSES

The decision tree development is an iterative process. The challenge is trying to take the agency's M&R practices and decision making policies and model them through a series of decision nodes.

Initial decision trees were developed based on a round table discussion with PEI TIR staff regarding when each treatment might be considered, i.e., under what condition (IRI range, distresses present, drainage condition, etc.) might a full width cold plane seal treatment be applied.

To verify the results of the decision trees, Stantec ran an unconstrained budget (unlimited funding) to determine the optimal M&R treatment for each pavement section. Stantec presented the results to PEI TIR by showing the cost distribution by treatment over a ten-year analysis period. Based on these results, the decision trees were refined so that the results closely resembled the PEI TIR's current practices. It took four iterations of the decision trees before Stantec and PEI TIR were comfortable with the recommended treatments resulting from the M&R analysis. Open communication and reviewing the results were key to developing a functional set of decision trees.

Similar to the prediction models, ground truthing can be used to validate the decision trees. The results of the M&R analysis can be verified through a condition assessment to determine if the system is selecting appropriate treatments and/or if there are other factors that should be considered as part of the treatment selection process. As previously noted, ground truthing is something that PEI TIR may explore as part of a future PMS implementation phase.

7 ANALYSIS RESULTS

The main objectives of the pavement management analyses are to:

- Determine the current and future condition of the network;
- Identify the M&R needs;
- Show the implications (or the impacts) of the different level of funding on the network condition;
- Estimate the level of funding to achieve a certain network condition; and
- Develop future M&R programs.

The HPMA analysis involves three main steps: creating Section Data Views (SDVs), running the M&R analysis, and running the optimization analysis.

The main purpose of building the section data view is to create homogeneous sections from the detailed database for use in the M&R analysis and performance optimization. The creation of the section data view requires the detailed database to be loaded, and the default prediction models to be populated. The section data views are created within the system through the use of dynamic sectioning utilizing user-defined sectioning parameters, or as overrides, where users define the section limits to be included. PEI TIR has already developed their distress surveys based on homogenous sections. These sections were used in the analysis.

The performance prediction modeling takes place when building the sectional data views (i.e., the sectional database). A sample of the performance condition aged to 2014 is shown in Figure 3.

The M&R needs are identified through the M&R analysis and the optimization constraints. Figure 4 illustrates the cost distribution by treatment for a given budget constraint.

Various M&R analysis sets and optimization constraints can also be used to conduct budget trade-off analyses. That is, compare different budgets and/or optimization constraints to compare the resulting impact on the overall network. A sample of a trade-off analysis is provided in Figure 5.

7.1 PMS ANALYSIS CHALLENGES AND SUCCESSES

One of the challenges found through the M&R analysis was determining the right correlation between the treatment unit costs and the budget limits. It's important that if the budget includes engineering and overhead, then the unit costs should also include engineering and overhead. Similarly, if some of the budget is allocated to non-capital projects, i.e., traffic studies, consultant studies, etc., then the cost associated with these other programs should be excluded from the total budget available for capital road projects.

Eventually PEI TIR would like to look at adding more treatment alternatives, like hot-in-place recycling to their list of feasible treatments. PEI TIR would also like to look at performing more preservation techniques in the early stages of the pavement life cycle analysis. In order to get there, PEI TIR must become comfortable with the results being generated from the PMS to ensure that they reflect current practices and are in line with their expectations. Once that comfort level is reached, PEI TIR will be able to expand their PMS to include more out-of-box solutions, like new treatment alternative, different life cycle practices, etc.

8 CONCLUSION

In closing, there were different challenges and successes noted through PEI's PMS implementation. Overall, the PEI TIR HPMA implementation project was a success. It is expected that the PEI TIR PMS will continue to succeed because of, but not limited to, some of the following reasons:

1. PEI TIR is committed to implement proven and innovative technologies to improve on pavement preservation methods, and determine the best means to upgrade or replace aging infrastructure
2. PEI TIR has identified a PMS champion, who oversaw the implementation project and will continue to update and maintain the PMS data and run the analysis.
3. Several PEI TIR staff (and not just the PMS champion) were involved in various stages of the implementation project, including the initial kick-off project meeting, model development, and comprehensive hands-on training. This allowed PEI TIR staff to be engaged and have input into the PMS development.
4. PEI TIR has an existing linear referencing structure in place that is already being used to store/maintain various pavement related information. This will help to facilitate regular database maintenance and updates.

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TABLES

Table 1: PEI TIR Surface Distress Density and Severity Levels

Distress	Density Levels	Severity Levels
Ravelling	0, 1, 2, 3, 4	0, 1, 2, 3
Bleeding	0, 1, 2, 3, 4	0, 1, 2, 3
Potholes	0, 1, 2	0, 1, 2, 3
Rutting	0, 1, 2, 3, 4	0, 1, 2, 3
Distortion	0, 1, 2, 3, 4	0, 1, 2, 3
Alligator Cracking	0, 1, 2, 3, 4	0, 1, 2, 3
Longitudinal Cracking	0, 1, 2, 3, 4	0, 1, 2, 3
Transverse Cracking	0, 1, 2, 3, 4	0, 1, 2, 3
Maintenance	0, 1, 2, 3, 4	n/a

Density Level 0 = none (0% coverage)
Density Level 1 = rare (less than 10% coverage)
Density Level 2 = intermittent (10-30% coverage
Density Level 3 = frequent (30-60% coverage)
Density Level 4 = extensive (more than 60% coverage)

Severity Level 0 = none
Severity Level 1 = slight (varies by distress)
Severity Level 2 = moderate (varies by distress)
Severity Level 3 = severe (varies by distress)

Table 2: Pavement Performance Classes used for Prediction Modeling

Parameter	# Levels	Classes
Pavement Type	1	Asphalt
Maintenance & Rehabilitation Activities	20	Refer to Table 3.
Traffic	2	Low to Medium Traffic (ESALa < 250,000) High Traffic (ESALa ≥ 250,000)
Subgrade	2	Good Drainage Poor Drainage

ESALa = Annual Equivalent Single Axle Load

Table 3: Expected Initial Condition and Service Life Range by Treatment

Description	Initial IRI (m/km)	Initial SDI	Service Life (min-max range, years)
Long Patch (Thin Overlay ~ 40 mm)	1.5	10	4-6
Medium Overlay (60 mm)	1.1	10	5-7
White Line Cold Plane Seal	1.4	10	6-10
Full Width Cold Plane Seal	1.1	10	6-10
White Line Cold Plane Level Seal	1	10	10-12
Full Width Cold Plane Level Seal	0.8	10	10-12
Full Width Cold Plane Level Base Seal	0.8	10	11-13
HIPR (Future)	1.5	10	6-10
Arterial Reconstruction (600select/300ClassA/125Base/40 Seal)	0.8	10	12-20
Collector Reconstruction (450select/250ClassA/110Base/40Seal)	0.8	10	10-15
Arterial Reconstruction (600select/300ClassD/125Base/40 Seal)	0.8	10	12-20
Collector Reconstruction (450select/250ClassD/110Base/40Seal)	0.8	10	10-15
Arterial Reconstruction (600select/300RAP/125Base/40 Seal)	0.8	10	12-20
Collector Reconstruction (450select/250RAP/110Base/40Seal)	0.8	10	10-15
Arterial Reconstruction (600select/300ClassA/125Base/40 Seal15%RAP)	0.8	10	12-20
Collector Reconstruction (450select/250ClassA/110Base/40Seal15%RAP)	0.8	10	10-15
Arterial Reconstruction (600select/300ClassD/125Base/40 Seal15%RAP)	0.8	10	12-20
Collector Reconstruction (450select/250ClassD/110Base/40Seal15%RAP)	0.8	10	10-15
Arterial Reconstruction (600select/300RAP/125Base/40 Seal15%RAP)	0.8	10	12-20
Collector Reconstruction (450select/250RAP/110Base/40Seal15%RAP)	0.8	10	10-15

IRI = International Roughness Index

SDI = Surface Distress Index

Table 4: Explanation of Sample PEI TIR Decision Tree Nodes

Node	Description	Possible Pavement Condition	Recommended Treatment
1	SDI ≥ 9	Pavement in excellent condition	Do Nothing
2	7 ≤ SDI < 9 AND (Lon ≥ 9 AND Tran ≥ 9)	Pavement in very good condition with no visible surface cracking present	Do Nothing
3	7 ≤ SDI < 9 AND (Lon < 9 OR Tran < 9)	Pavement in very good condition with some surface cracking visible	Crack Fill
4	6 ≤ SDI < 7 AND IRI ≤ 1,8 AND (Rut ≥ 7 AND Lon ≥ 7 AND Tran ≥ 7 AND Pot ≥ 7)	Pavement in good condition with some minor surface defects	Patch
5	6 ≤ SDI < 7 AND IRI ≤ 1.8 AND (Rut < 7 OR Lon < 7 OR Tran < 7 OR Pot < 7)	Pavement in good condition with some minor to moderate surface defects present	Deep Patch
6	6 ≤ SDI <7 AND IRI < 3.3 AND Poor Soil/Drainage = No AND (Alg ≥ 7 AND Rut ≥ 7 AND Rav ≥ 7)	Pavement in fair condition with good soil/drainage characteristics and minor surface distresses present	Long Patch
7	6 ≤ SDI <7 AND IRI < 3.3 AND Poor Soil/Drainage = No AND (Alg < 7 OR Rut < 7 OR Rav < 7)	Pavement in fair condition with good soil/drainage characteristics and minor to moderate surface distresses present	Medium Overlay
8	6 ≤ SDI <7 AND IRI < 3.3 AND Poor Soil/Drainage = Yes	Pavement in fair condition with poor soil/drainage characteristics	White Line Cold Plane Seal
9	((5 ≤ SDI < 6 OR IRI > 3.3) AND (RUT ≥ 6 AND Rav ≥ 4) OR IRI ≤ 3.3) AND Poor Soil/Drainage = No	Pavement in fair to poor condition with good soil/drainage characteristics	White Line Cold Plane Seal
10	((5 ≤ SDI < 6 OR IRI > 3.3) AND (RUT ≥ 6 OR Rav ≥ 4) OR IRI ≤ 3.3) AND Poor Soil/Drainage = Yes	Pavement in fair to poor condition with good soil/drainage characteristics	Full Width Cold Plane Seal
11	(4 ≤ SDI < 5 OR Alg ≥ 3) AND IRI ≤ 4 AND (Lon ≥ 5 AND Dis ≥ 7 AND Rut ≥ 4) AND Poor Soil/Drainage = No	Pavement in poor condition with moderate roughness and moderate surface distress and good soil/drainage characteristics	White Line Cold Plane Level Seal
12	(4 ≤ SDI < 5 OR Alg ≥ 3) AND IRI ≤ 4 AND (Lon ≥ 5 AND Dis ≥ 7 AND Rut ≥ 4) AND Poor Soil/Drainage = Yes	Pavement in poor condition with moderate roughness and moderate surface distress and poor soil/drainage characteristics	Full Width Cold Plane Level Seal
13	(4 ≤ SDI < 5 OR Alg ≥ 3) AND 4 < IRI ≤ 4.5 AND (Lon < 5 OR Dis < 7 OR Rut < 4)	Pavement in poor condition with poor roughness and significant surface distress and good soil/drainage characteristics	Full Width Cold Plane Level Base Seal
14	(SDI < 4 OR Alg < 3) AND IRI > 4.5	Pavement in very poor condition with very poor roughness and significant surface distress.	Arterial Reconstruction

Alg = Alligator Cracking Index
Dis = Distortion Index
IRI = International Roughness Index, m/km
Lon = Longitudinal Cracking Index
SDI = Surface Distress Index
Pot = Pothole Index
Rav = Ravelling Index
Rut = Rutting Index
Tran = Transverse Cracking Index

FIGURES

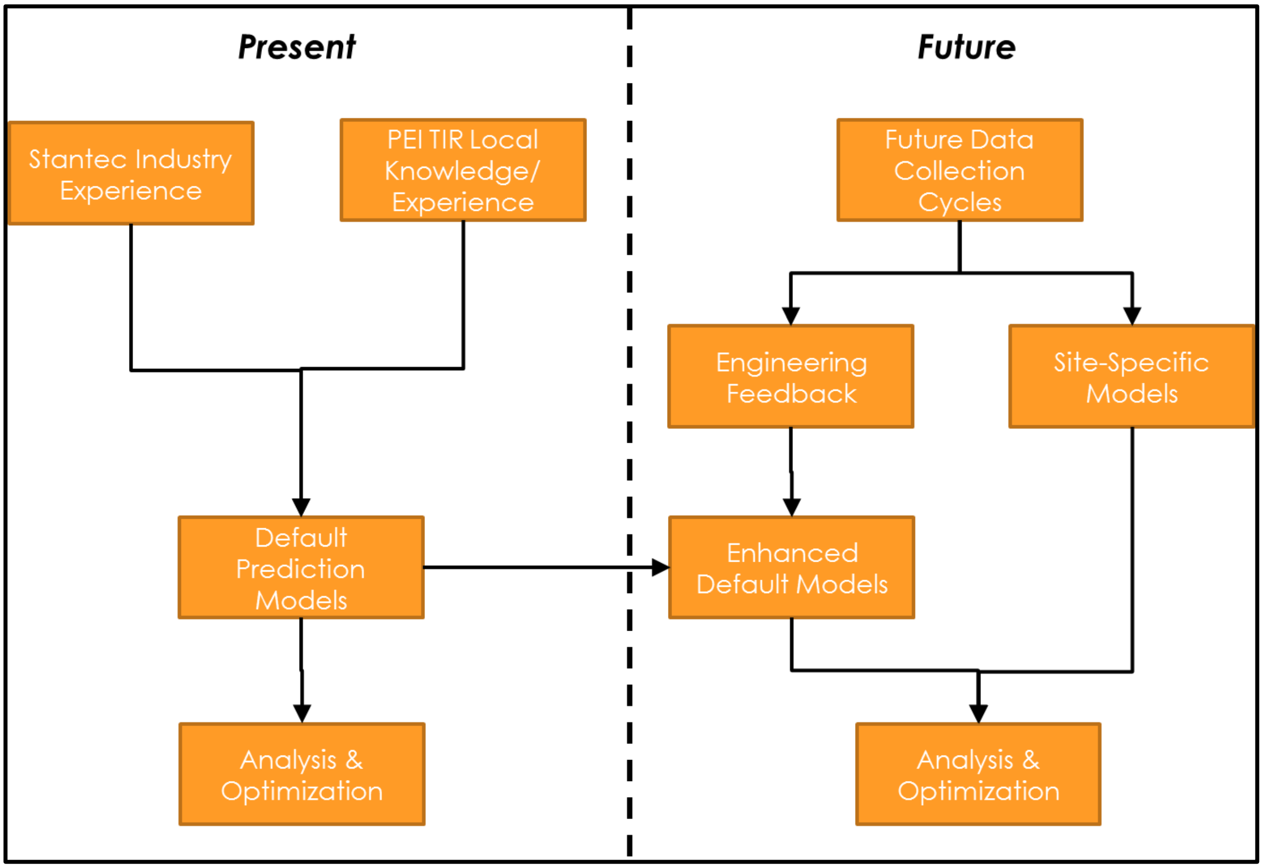

Figure 1: Pavement Prediction Model Approach

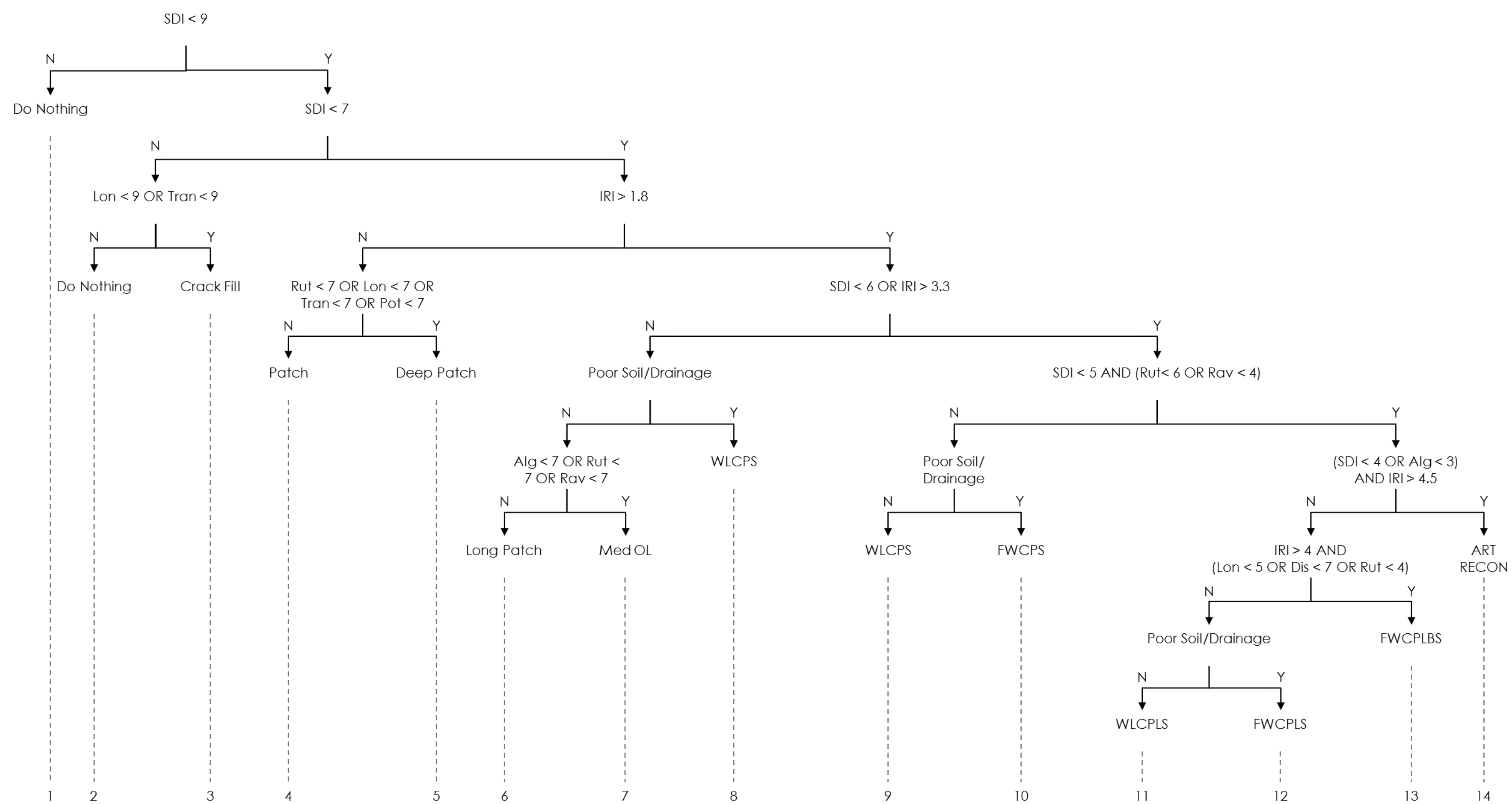

Figure 2: Sample PEI TIR Decision Tree

Alg = Alligator Cracking Index
ART RECON = Arterial Reconstruction
Dis = Distortion Index
FWCPLS = Full Width Cold Plane Level Seal
FWCPLBS = Full Width Cold Plane Level Base Seal
FWCPS = Full Width Cold Plane Seal
IRI = International Roughness Index, m/km
Lon = Longitudinal Cracking Index
Med OL = Medium Overlay
SDI = Surface Distress Index
Pot = Potholes Index
Rav = Raveling Index
Rut = Rutting Index
Tran = Transverse Cracking Index
WLCPLS = White Line Cold Plane Level Seal
WLCPS = White Line Cold Plan Seal

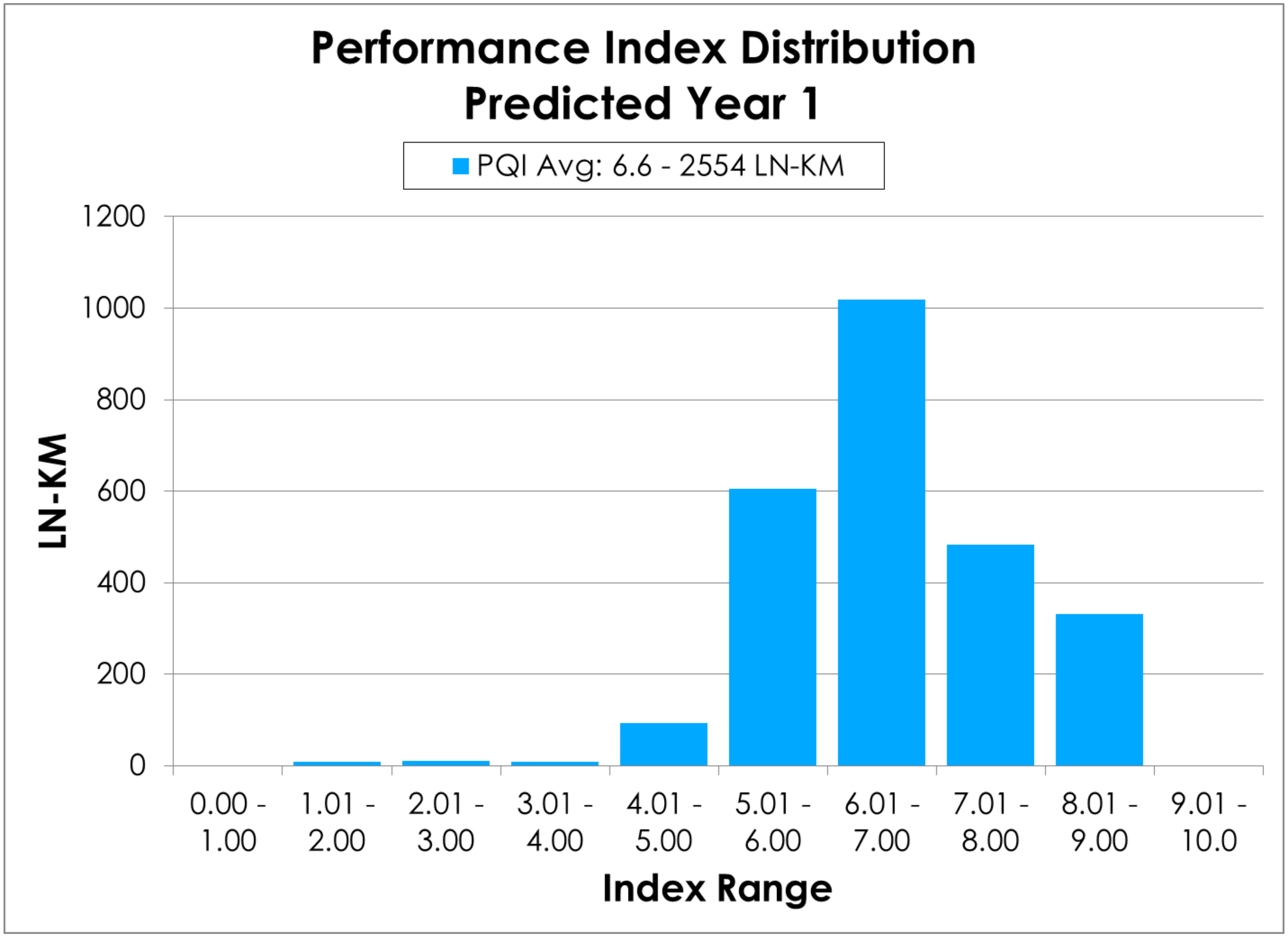

Figure 3: Sample Performance Distribution

LN-KM = Lane-kilometre

PQI = Pavement Quality Index

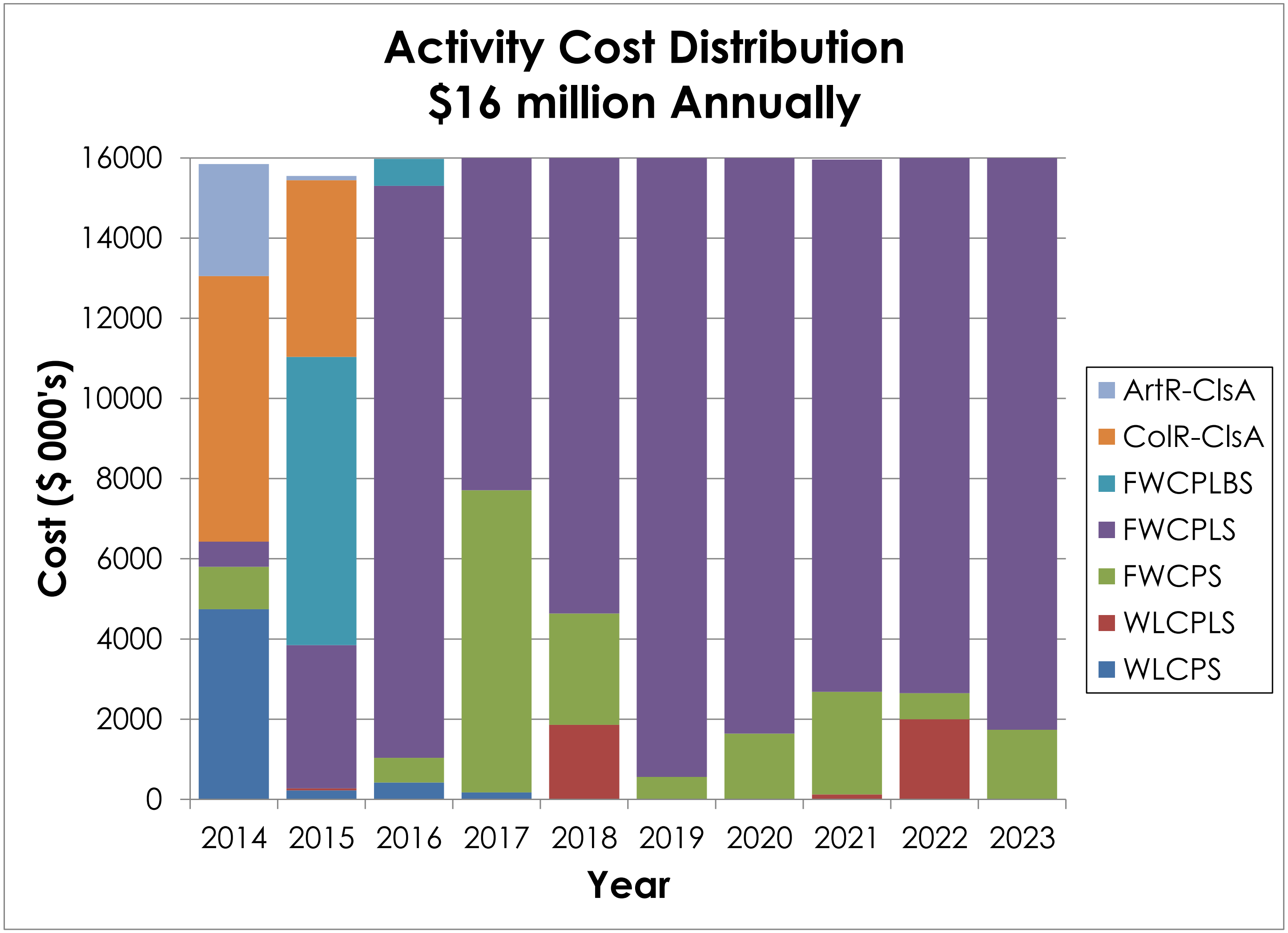

Figure 4: Sample Cost Distribution by Treatment Type

ArtR-ClsA = Arterial Reconstruction with Class A Aggregate
ColR-ClsA = Collector Reconstruction with Class A Aggregate
FWCPLBS = Full Width Cold Plane Level Base Seal
FWCPLS = Full Width Cold Place Level Seal
FWCPS = Full Width Cold Plane Seal
WLCPLS = White Line Cold Plane Level Seal
WLCPS = White Line Cold Plane Seal

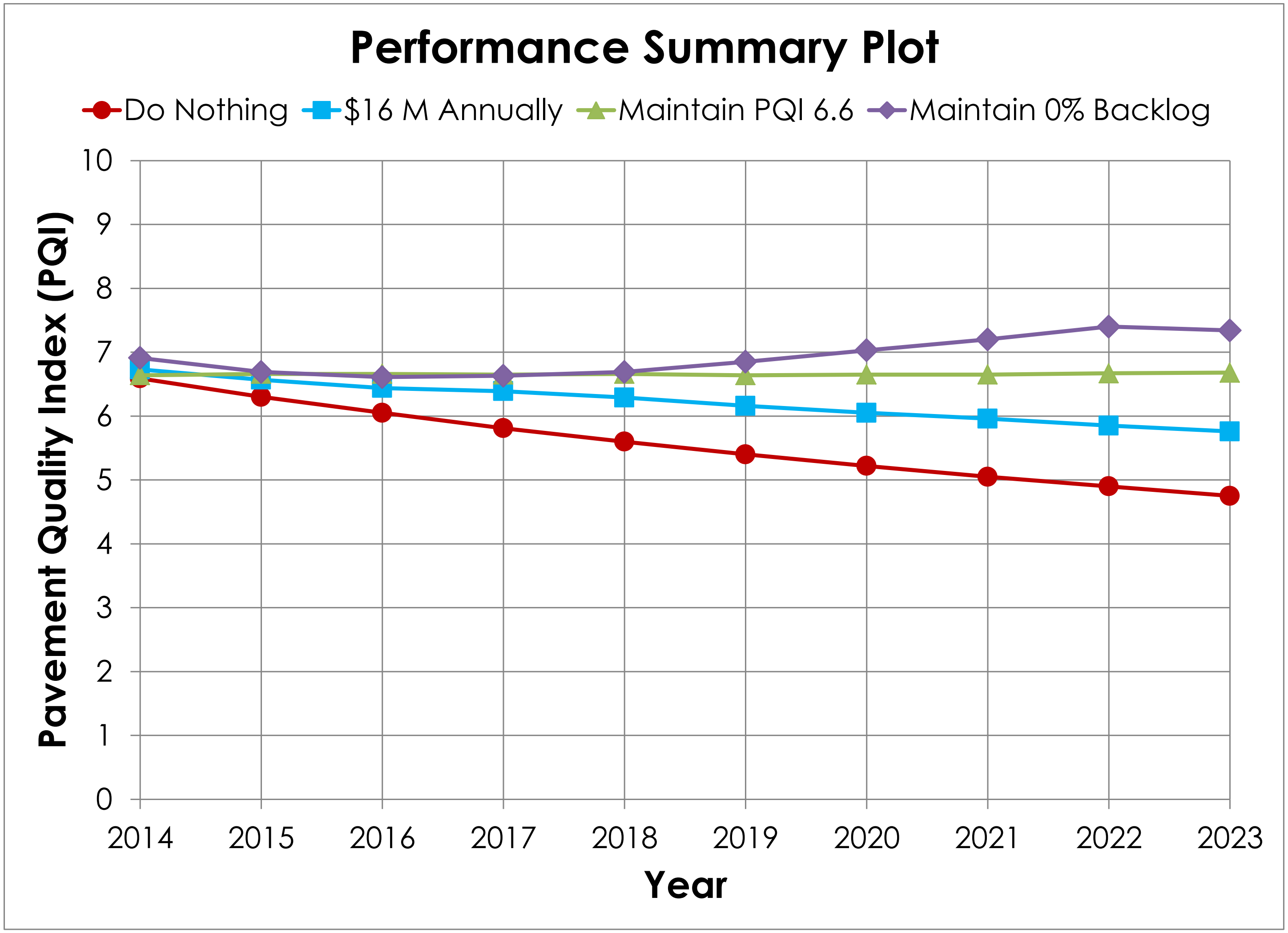

Figure 5: Sample Budget Trade-off Analysis