

**A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM DESIGNED  
FOR THE CITY OF WINNIPEG**

**BY**

**Richard A Goodman, B.Sc.C.E.**

**A report submitted to the Faculty of Graduate Studies in partial fulfillment for the Degree  
of Master of Engineering**

**Department of Civil and Geological Engineering  
University of Manitoba  
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**BY**

**RICHARD A. GOODMAN**

**A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University  
of Manitoba in partial fulfillment of the requirements of the degree  
of  
MASTER OF ENGINEERING**

**Richard A. Goodman      ©1998**

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## ABSTRACT

A large portion of the regional street network in Winnipeg is comprised of Portland Cement Concrete pavements - pavements which are susceptible to damage caused by freeze-thaw cycles. Due to the high number of freeze-thaw cycles in Winnipeg, pavement maintenance is therefore important. The goal of this project is to develop a method of selecting effective and efficient pavement maintenance strategies. There are two elements of pavement maintenance management, (1) reactive, (2) proactive. The reactive method proposed in this report involves using a maintenance activity assignment procedure that is dependent on human experience, to develop rules which are used to assign maintenance treatments to pavements based on condition. The proactive technique proposed involves assessing the probability that the pavement will deteriorate one condition category in one analysis period, and recommending a long-term maintenance strategy based on that probability and background information. Once the long-term strategy is recommended, the individual life-cycle maintenance strategies for each pavement are developed. Using a form of life-cycle cost analysis, the lowest cost alternatives are chosen. Once all of the pavements being considered have a life-cycle maintenance strategy then the pavements are ranked in order of importance. This is done so that the highest ranking pavements are funded until the budget is exhausted. Maintenance on lower-ranking projects is deferred until sufficient funding can be obtained. The system depends on a level of funding that has not been available to maintenance engineers and planners in recent years.

## ACKNOWLEDGMENTS

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# **CHAPTER 1: INTRODUCTION**

## **CHAPTER 1: INTRODUCTION**

This chapter describes the objective, background, methodology and scope for the project

### **1.1 OBJECTIVE**

To develop a pavement condition sensitive method for developing, evaluating and selecting effective and efficient pavement maintenance strategies using data gathered by the City of Winnipeg's pavement monitoring program.

### **1.2 BACKGROUND**

The City of Winnipeg gathers Pavement Condition Index (PCI) data on the regional street system and uses PAVER ( pavement management database software ) to store and display the information. Within PAVER there is a maintenance management program that includes budget allocation, alternative evaluation, network level project selection and ranking. To implement this program completely would require excessive resources. For example, this type of technology is generally not easily transferable from one geographical area to another due to climatic differences and their effect on pavements. To incorporate the effects of Winnipeg's unique environment would require substantial customization.

The environment in Winnipeg is unique because of the large number of freeze - thaw cycles that occur each year, and because there is a large percentage of streets with Portland Cement Concrete pavement. This type of pavement is very susceptible to environmental degradation. Maintenance management in this area is a complex problem but is necessary to help maintain the network in the face of shrinking budgets.

Maintenance management includes the inspection of candidate projects, recommendation of immediate treatments, future treatments, and the economic analysis of alternatives. The treatments that are recommended are preventative or corrective. Maintenance management does not include major rehabilitation or reconstruction as these are pavement management issues.

### **1.3 METHODOLOGY**

In this particular system, there are circumstances which trigger rehabilitation or reconstruction analysis but none of these activities are recommended by the system. Some of the types of activities that are recommended by the maintenance management system are: crack sealing, joint sealing, joint repair, grinding, drainage repair and patching.

Triggers are developed by associating distress / severity combinations in each PCI range with standard treatments. Using stage five inspection [ 2 ] for the ongoing City of Winnipeg pavement monitoring program each of the nine distresses has a standard treatment that is recommended each time the distress occurs in each PCI range. After inspection, where the data is analyzed, if one particular treatment is recommended the correct number of times then this would be the recommended course of action. The number of times that a treatment needs to be recommended before it becomes the desired course of action can be determined from expert opinion. There are other keys attached to the distresses including drainage analysis, resurfacing analysis, and detailed inspection. These triggers are used so that if, for example, a situation arises which generally indicates the drainage of that pavement is insufficient, the drainage analysis key will tell the operator of the system that drainage analysis is necessary and repairs may be required. This is the same for resurfacing analysis. In the event that the condition of the pavement requires that the resurfacing option be analyzed, the users would be alerted to this.

The detailed inspection key is used differently. When the initial course of action is preventative, no detailed inspection is required. If the initial course of action is corrective, a detailed inspection should be performed to ensure that no other problems exist and to ascertain the effectiveness of the maintenance. Then a strategy can be developed for this pavement. The reason for this is that the effectiveness of future preventative repairs is hampered by underlying pavement problems. Managers must be certain that corrective actions have had the intended effect prior to designing and implementing a long - term strategy.

Maintenance strategies are developed by recommending a treatment that satisfies the immediate needs of the pavement, and by recommending future treatment types. The former are recommended based on distress/severity combinations and PCI range. After

this, background information is required so that educated decisions can be made about the future requirements of the pavement. The types of information that are required are construction histories, maintenance histories, traffic, percentage trucks, growth rates, transition probabilities, PCI and PCI composition. PCI composition is the sum of the deduct values from surface distress, structural distress and joint related distress. The types of background information suggested in this report may be excessive. Experience and analysis will dictate what background information is most useful.

Once a set of maintenance strategies has been developed, the most efficient one must be picked. If all the strategies provide the same benefit, the most economical strategy can be chosen. There are two methods used to evaluate strategies. For strategies with unequal lives, the equivalent uniform annual cost for each is calculated and the lowest one is the best strategy ( the cost divided by the life of the strategy could be used). If the former is used, a reinvestment assumption is required. For strategies with equal life spans, the present worth of the costs is calculated and the lowest is the best strategy.

Candidate maintenance projects are developed and evaluated using the above system. When analyzing inspection data all inspected sections are candidates for maintenance. Many of them will not have enough instances of distress to warrant a maintenance treatment. The recommended course of action for these sections will be to do nothing. Since the regional network is completely inspected every five years ( at the current staffing level, this could be reduced using stage rating [2] ), it is unlikely that if a pavement is good enough for a "do nothing" recommendation one year, any serious distresses will develop before the next rating. Even though a pavement may have a strategy already in place, it is still necessary to inspect that pavement to track the progress of the strategy over time. Inspection frequency is an important aspect of the system.

#### **1.4 SCOPE**

This project will use information gathered on the Portland Cement Concrete components of the regional street system of the City of Winnipeg.

# CHAPTER 2: DATA

## **CHAPTER 2: DATA**

This chapter describes the sources and uses of data in this project

### **2.1 DATA TYPES**

There are six types of data that are used in this project. They are: maintenance histories, pavement condition histories, maintenance costs, maintenance activities/treatments, pavement section definitions and traffic data.

A maintenance history is a record that shows branch and section numbers, construction date, street type, surface type, geometric information and the date and type of maintenance treatments that have been performed on each section.

Pavement condition histories show how the PCI varies over time. This plot also shows when a pavement section was inspected and what values on the plot are created by prediction.

A pavement section definition is a listing of branch and section numbers and the corresponding street names, e.g., Branch A0062 section 3 &4, Portage Avenue from Century to Main.

Traffic data is traffic histories and projections. The rest of the data types require no explanation.

### **2.2 DATA USES**

Each of the data types mentioned above have different uses in the project. Pavement condition prediction uses pavement condition histories to establish behavior patterns. These behavior patterns are extrapolated to predict pavement conditions. There are two prediction techniques that use this approach: they are the straight line

extrapolation method and the family curve method. This project uses the family curve method [1].

Ranking maintenance projects uses the traffic data. A method of ranking maintenance projects based on Average Annual Daily Traffic (AADT) multiplied by PCI is proposed. With this combination, the regional streets with the highest AADT and highest PCI will receive funding before the lower volume, lower PCI regional streets. Streets that are in better condition with more traffic will get more maintenance dollars. Currently there is no actual AADT calculated for the City of Winnipeg, any traffic flow measurement that delineates differences in flow would be adequate.

Pavement family [1] definition can utilize construction and maintenance information and traffic data. A pavement family is a group of pavement sections that have similar deterioration characteristics. These families often consist of pavements that were constructed at approximately the same time, and that are subjected to similar loads. All of the regional streets constructed of Portland Cement Concrete are considered to be in the same family for the this project. Smaller families would improve the performance of the prediction model and thus the entire system.

### **2.3 DATA SOURCES**

- a) Paver ( PCI's, section definitions.... )
- b) Field observations
- c) Interviews
- d) Literature search
- e) Questionnaires
- f) Transportation Research Board publications

## **2.4 PREDICTION MODEL USED**

This project uses the family curve method [1] for predicting pavement condition.

Once the pavements are grouped into families, the pavement condition histories for each family are analyzed. During this operation, data outlier analysis is performed and the data is filtered. These two processes are designed to remove suspicious data points that would corrupt the models. After this has been done, a fourth degree polynomial - constrained least square error model is fit to the data.

The PCI vs AGE curve developed for the family represents the average condition of all the pavement sections in the database. To predict the condition for an individual section, the appropriate PCI, AGE point on the curve must be determined. It is assumed that the deterioration of the individual pavement section will run parallel to the family curve.

## **2.5 OTHER PREDICTION METHODS**

There are other prediction models which are frequently used in pavement condition prediction. These all have different areas for which they are more suitable. The City of Winnipeg uses the PAVER software, and since the family curve method [1] is the prediction method used within PAVER, it is also used in this project.

Straight line extrapolation is the simplest prediction technique. To predict, the straight line connecting the last two known condition points is extrapolated, producing an adequate result. This method is accurate for short term predictions where maintenance levels and traffic loading remain constant.

Regression analysis can also be used for model development. This method establishes a relationship between two or more variables. The resulting models are

powerful since explanatory variables can be used. For example, a model could be developed based on pavement condition, drainage and underlying soil type to predict future pavement condition. The variable that is widely accepted as the most important is pavement age. Age alone accounts for the largest portion of pavement deterioration [34].

Finally, a mechanistic empirical model can be used. These types of models generally determine a pavement's response to loading i.e., stress and strain. Although these measures can not be used directly for predicting future condition, it is possible to develop a regression model using this information.

# **CHAPTER 3: MAINTENANCE ACTIVITIES**

## **CHAPTER 3: MAINTENANCE ACTIVITIES**

This chapter describes maintenance priorities, goals and activities. A discussion of the calculation of maintenance effectiveness is presented. A discussion of the major distress types and their causes is also included.

### **3.1 MAINTENANCE PRIORITIES**

Maintenance priorities are designed to provide a safe and efficient road network. These priorities are structured so that pavements in good condition receive maintenance funding before pavements in poor condition, and all pavements are safe to travel on. This is done because maintenance funds spent on pavements in good condition achieve a better return than funds spent on pavements in poor condition. The following is an example of a set of pavement maintenance priorities.

#### *3.1.1 Priority #1 - Safety*

Safety maintenance takes precedence over other maintenance and is applied in all ranges of PCI. On roads with a low PCI it is often desirable, from an economic perspective, to discontinue maintenance until funding can be secured to rebuild. This often results in severe distresses which cause safety problems. This type of maintenance is applied to any pavement that develops a safety problem regardless of PCI range. Currently the City of Winnipeg uses 0 - 45 as the range in which safety maintenance is the only maintenance applied. Pavements above this range are still subject to other maintenance. Safety maintenance typically consists of patching large holes and cracks.

#### *3.1.2 Priority #2 - Preventative*

This type of maintenance is designed to reduce the deterioration rate. For example crack routing and sealing ( random sawing ) is designed to stop water and other incompressible debris from entering cracks. Both of these occurrences lead to a number

of failure - producing distresses. This type of activity is performed on pavements in the higher PCI ranges. Currently the City of Winnipeg uses a PCI of 45 as the bottom of the range to which this type of maintenance is applied. Applying this type of maintenance to pavements with a PCI less than 45 is not cost - effective because the rate of deterioration is too fast and the repairs would not last for long. Once repairs are in place, their effectiveness will decrease at a rate similar to that of the pavement section. This is why maintenance on low PCI roads is not effective. The ranges mentioned may vary as experience and necessity dictates. Even though a PCI of 50 may be eligible for this type of maintenance, the effectiveness at this level would be marginal. Preventative maintenance produces more benefit on higher PCI pavements. Pavements which require more than preventative maintenance, and are still in good condition, receive corrective maintenance. This type of maintenance is generally performed on pavements with a PCI between 45 and 100. Corrective maintenance is not a separate priority since it is a type of maintenance used to restore a pavement to a condition that is appropriate for resuming the original preventative priority.

### *3.1.3 Priority #3 - Major Maintenance*

Major maintenance is applied to an entire pavement section with the goal of improving the structural capacity and functional characteristics of the section. After major maintenance, the PCI of the section generally returns to 100. Some examples of this type of maintenance include reconstruction and heavy overlays. This type of activity is expensive, and because of this major maintenance is deferred with proper maintenance management.

These priorities are subject to criteria other than pavement condition. For example, branch use and pavement type also play a role. With only the priorities listed, a pavement with a safety concern on Portage Avenue would rank equally with one on a local street. This is why road class is the next defining criterion, in the following order:

- 1 - Regional
- 2 - Bus Route
- 3 - Collector
- 4 - Local

It is desirable to further define priorities with pavement type. Maintenance on Portland Cement Concrete ( PCC ) streets is generally more important than that on asphalt concrete ( AC ) streets. since the cost of deferring maintenance on PCC streets in Winnipeg is higher than that on AC streets. The cost for deferral is higher for PCC pavements because of the occurrence of freeze-thaw cracking, which can in turn lead to severe failure-producing distresses.

Priorities do not apply to safety maintenance. This type of maintenance is performed regardless of street type or PCI on an as-needed basis.

### **3.2 MAINTENANCE GOALS**

In keeping with maintenance priorities, there are goals for all maintenance regardless of PCI, branch use or pavement type. They are fundamental to preserving a pavement investment. Maintenance goals and priorities are discussed here because they are important in determining maintenance policy. The goals are, in order of importance:

#### *3.2.1 Ensure drainage*

Drainage is a fundamental aspect of pavement performance. A large number of distresses are caused because moisture infiltrates the pavement system and erodes the sub

grade, causing a loss of support. For example, corner breaks, pumping, faulting and longitudinal cracking are all caused by loss of support. Moisture can also infiltrate existing cracks and increase their severity. To ensure drainage, the moisture must run off the surface into whatever drainage system may be provided e.g., running into ditches off the shoulders or curb and gutter flowing into catch basins. This requires that the pavement be graded at a cross fall of at least 2 % from the center line down on both sides. The moisture must not be allowed to accumulate on the surface as this could lead to infiltration and surface breakdown. The 2 percent grade must be continuous not disjointed.

Along with transverse drainage, longitudinal drainage is also important. It is this type of drainage drains water into catch basins along the gutter of a roadway. If one type of drainage is not functional then ponding will occur. This will lead to pavement failure. Ponding allows more water to penetrate the surface of the pavement which makes the surface susceptible to freeze - thaw damage.

### *3.2.2 Ensure cracks and joints are sealed*

Once the drainage is continuous with the moisture running off the pavement into the drainage system, there must be no surface distress that permits the ingress of moisture into the sub grade or into the pavement itself.

Moisture is not the only concern with cracks and joints. Joints are put into PCC pavement to allow for contraction and expansion, and to relieve warping and other deforming stresses [13]. If incompressible material e.g., broken concrete, winter abrasives or other debris enters into a joint, then the joint will not perform properly. If an expansion joint is not cleaned properly.(wire brushed, cleaned with solvent then blown out) before it

is sealed, there will be no room for it to move when the pavement expands. This will cause joint-spalling and blow-ups.

### *3.2.3 Ensure ride is smooth*

On regional streets where traffic is heavier and faster, the ride needs to be smooth. Uneven ride leads to pounding on the pavement. As the unevenness between successive pavement sections increases the distance through which the loads travel increases, the momentum imparted to the pavement increases. This is particularly evident in faulting situations where, as the distance between the top of the leading pavement section and where the tire hits on the arriving pavement section increases, the rate at which the fault grows increases. Generally, a pavement that is designed properly will have a smooth ride and a distress free surface when it is new. This priority applies to streets that are beginning to deteriorate. Smooth ride is included as a priority to ensure that maintenance strategies address distresses that otherwise may not be looked after.

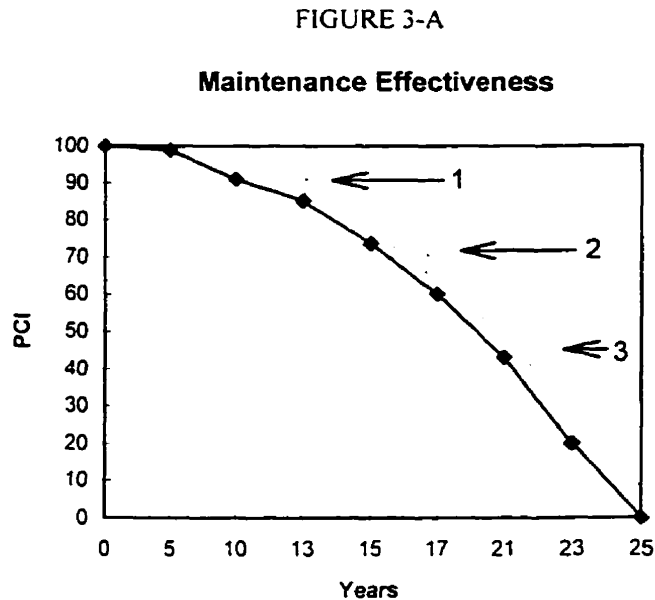
Many surface defects also contribute to rough rides, and act in a similar manner. For example, once popouts, scaling, D-cracking and polishing are allowed to reach a certain point, the severity of these distresses increases faster and faster.

## **3.3 MAINTENANCE EFFECTIVENESS**

The effectiveness of pavement maintenance is an important part of the decision criteria for selecting activities for a life-cycle strategy. A life-cycle strategy is a group of maintenance activities that is planned, performed and scheduled so that the life of the pavement is extended beyond that of zero maintenance. The objective of this report is to develop a method for selecting the strategy which has the lowest life cycle cost.

### 3.3.1 Assessing maintenance requirements

This project uses the family curve method [1] of predicting pavement condition. This method assumes that the deterioration rate is a function of age and PCI for pavements in the same family. Consider the pavement condition prediction plot below.



The life-cycle strategy that has been recommended consists of treatment one in year 13, treatment two in year 17 and treatment three in year 22. The effectiveness of each treatment is the spike in the PCI vs age curve at each of those years [8,7]. The overall effect of the strategy is to increase the life of the pavement. It is unlikely that a curve of this shape will be developed because it requires that inspections be made immediately after maintenance treatments have been completed. What is more likely to happen is that the inspections will occur several years after the treatments. The result will be a curve that is smooth and slightly higher than the zero maintenance curve, but which doesn't accurately depict what has happened over the life of the pavement. The system that this

paper describes recommends that after corrective maintenance, detailed inspections be performed so that more information on the effectiveness of maintenance is available to maintenance planners.

### *3.3.2 Calculating maintenance effectiveness*

The maintenance effectiveness calculation uses a similar principle to the calculation of PCI in the PAVER manual [1].

Consider a pavement that has been observed to contain several distresses. Each of these distresses has a deduct value. If a maintenance treatment is applied to the pavement such that all of the distresses are fixed, the change in PCI would be equal to a percentage of the deduct values ( the deduct values are not zero after maintenance as a crack that has been repaired is rated as a low severity crack ). Therefore the effectiveness of the maintenance treatment is the total of the deduct values prior to maintenance minus the total of the deduct values after the maintenance is performed. For example, if a pavement section contains high severity linear cracking with 20 percent distress density, the total of the deduct values is 30. When this crack is routed, cleaned and sealed it becomes a low severity crack, with 20 percent distress density having a deduct value of 10. Therefore the actual effectiveness of this maintenance is to raise the PCI by 20.

Consider the following example. A pavement section has severe linear cracking and a severe blow-up. The total deduct value before maintenance is 55 ( according to the appropriate charts in the PAVER manual ). After maintenance is performed, the new total deduct value is 20. Thus the PCI of the section was raised by 35 points due to this maintenance. The condition of the pavement will deteriorate on a parallel path as before

[14,15]. This information is useful in planning maintenance treatments and timings as part of maintenance strategies.

### **3.4 MAINTENANCE METHODS**

This section describes the basic preventative maintenance activities that the City of Winnipeg currently employs, and the types of distresses they fix. The information in this section is derived from field work and interviews with the City of Winnipeg street maintenance personnel.

#### *3.4.1 - Routing and Sealing Cracks: ( Random Sawing )*

As cracks increase in severity, the likelihood of a severe pavement failure increases. Cracks are best fixed by sealing them with a flexible sealant that bonds to both edges. When expansions and contractions occur, the crack will remain sealed. In order to provide clearly defined clean edges to adhere to, the cracks are first routed with an industrial router tool. The router cuts the concrete 30 mm to 40 mm deep and 10 mm to 15 mm wide. The resulting groove is then cleaned and filled with a bituminous sealant. Even though many of the cracks may extend through the entire thickness of the pavement, it is not necessary to rout to this depth, for the primary objective is to seal not repair the crack. Cracks that are too wide for this procedure are generally patched.

#### *3.4.2 - Partial Depth Patching*

Often it is necessary to patch a roadway at a joint or mid slab to prevent further damage, where the distresses can not be randomly sawed and sealed. The distress types associated with partial depth patches are spalling, scaling, polishing or blow-ups. Any of these distresses, if allowed to progress, represent a major problem. The City of Winnipeg patches with a mixture of small course aggregate and bitumen. This is known as AMZ

patching. AMZ patching seals the distresses and retards their progression. An AMZ crew consists of a drum of heated bitumen with an auger that stirs the mixture of coarse aggregate and bitumen. The mixture is then forced under pressure into the distress. This is either a three-man / two-vehicle operation or a single vehicle custom unit operation that does this as well. This type of repair can also be performed by Asphalt or hot mix patching. Basically this is using asphalt material to patch concrete.

Partial depth patching can also refer to the operation where the concrete at the joint is partially replaced. The top portion of the pavement is removed with pneumatic hammers, the area is cleaned, a bonding agent is applied and the concrete is replaced with new concrete. This method repairs distresses that are confined to the top few inches of the slab, and is not done often in Winnipeg.

#### *3.4.3 - Mud-Jacking*

Mud-jacking can be used for two purposes. First, when a crack or failed joint leads to moisture infiltration, which in turn leads to a large void under the pavement, a hole is drilled through the slab near the affected area and the void is filled with grout ( a mixture of cement, sand and water ), this stops a cave - in from occurring and may help to ensure a proper grade exists for drainage. This application is also referred to as undersealing the pavement. Mud-jacking has also been used for raising the level of a slab to ensure that moisture runs off into the drainage system. Using mud-jacking for this purpose is not the most efficient use of this resource since the hole that is drilled often causes cracking. Often, a substantial volume of grout produces a minimal effect on the grade of the slab. In this instance, the best use of the resource is to fill any voids under the pavement to stop further sagging and to employ a surface treatment such as an overlay to

restore the drainage. Mud-jacking can also cause multiple cracks in the pavement due to uneven pressure exerted on the underside of the pavement.

#### *3.4.4 - Sealing Joints*

In the preceding section, the most prevalent cause of major distresses was the infiltration of moisture and incompressible material through failed joints and unsealed cracks. If the seals on existing joints are damaged, the random saw ( defined in 3.5.1 ) is used to remove the affected seals, and the groove is cleaned. The seals are then replaced with a flexible bituminous sealant.

#### *3.5.5 - Joint Replacement and Load Transfer Restoration*

With PCC pavement, most maintenance work takes place at the joints. This is because if the joints fail, the rest of the slab will fail quickly. As a vehicle travels from one slab to the next, the load is transferred between the slabs. This transfer is facilitated by steel dowels connecting the two slabs. If the load transfer has failed, as evidenced by serious faulting or by a blow-up, it is essential that it be replaced. This is generally done by cutting out the affected concrete and replacing the concrete, the dowels and the base layer. This operation is also referred to as full-depth patching. On a low-volume street, it is recommended that the patch be at least 1.3 meters square, and for higher traffic volumes a minimum dimension of 2.0 meters square is recommended.

This type of patching can be used at mid-slab as well. If there is sufficient distress to warrant a full-depth patch, the concrete is removed and replaced. In the middle of the slab, the area is squared off, rebar is drilled and grouted into the neighboring concrete, tie bars are placed in the middle of the patch ( if bar mats have been used throughout the pavement ), and the concrete is replaced. This is done to prevent faulting of the patch, but

is not done very often since generally if there is substantial distress at mid-slab, the entire slab requires replacement. In this instance, patching at mid slab would not be cost-effective. An instance that would be suited to mid-slab full-depth patching would be a punch-out.

## **CHAPTER 4: ACTIVITY ASSIGNMENT**

## **CHAPTER 4: MAINTENANCE ACTIVITY ASSIGNMENT**

This chapter describes the procedure for assigning maintenance activities as part of a life-cycle strategy for a pavement.

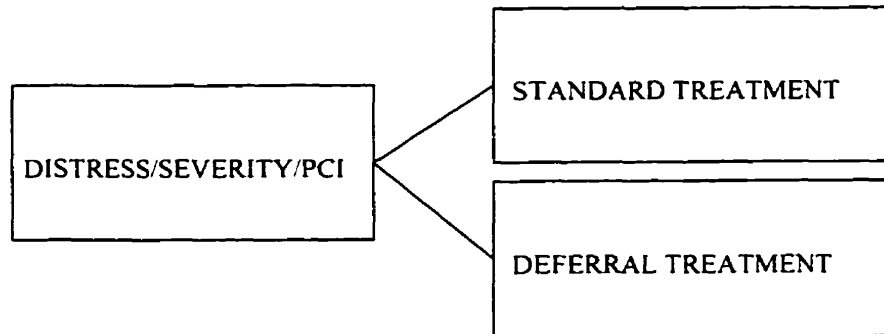
### **4.1 TRIGGER SYSTEM**

Maintenance management is a complex area due to the large number of variables involved. For this reason, rules are developed using human experience where possible. The rules are based on PCI, which is divided into three ranges. The first range is the high range where preventative maintenance is the primary goal. The second range is one in which corrective maintenance is generally required, followed by preventative maintenance. Corrective maintenance is defined in the next chapter. The third range, is one in which maintenance is generally not cost-effective. The only maintenance that is permitted in this range is safety maintenance. It is assumed that as capital budgets permit, these roads will be reconstructed.

Using the ranges described above, pavement distresses are associated with maintenance treatments in each range. There are two types of maintenance treatments for each distress/severity combination: standard and deferral [33] [Refer to the diagram below]. The standard treatment is dependent on PCI range. The deferral treatment is generally “do- nothing” in this system. The requirement is that PCI does not change much during the time that the deferral strategy is in place and, that it allows for the saving of enough resources to apply the standard treatment. The time frame for a deferral strategy is usually 1 - 2 years.

Below is a schematic of the assignment procedure that shows how the standard and deferral treatments are associated with the distress/PCI combination.

FIGURE 4-A



A maintenance activity is assigned by frequency of occurrence of distresses. If, after the pavement monitoring has been done and the data has been analyzed it is found that a particular standard treatment has been triggered enough, this treatment becomes the next course of action for that pavement. The frequency at which the distress / severity combination needs to occur in order for a treatment to become the desired course of action is determined by human experience. The deferral treatment is selected only when it is found that there is insufficient funds to use the standard treatment. The standard treatment should be used on the highest-ranking maintenance projects [33]. Ranking is discussed later in the report. The deferral treatments are selected from the lowest ranking project up the list until there is enough funding to execute the remaining standard treatments ( see figure below ). These recommendations are designed to satisfy the immediate needs of the pavement. This type of reactive maintenance is an essential part of any maintenance management system. In order to ensure that maintenance treatments are economically sound, a long-range planning tool that considers how long repairs will

last and how effective they will be is required as well. This is discussed in the next chapter.

TABLE 4-A

RANK	TREATMENT TYPE
1	STANDARD
2	STANDARD
3	STANDARD
4	STANDARD
5	<i>DEFERRAL</i>
6	<i>DEFERRAL</i>
7	<i>DEFERRAL</i>
8	<i>DEFERRAL</i>

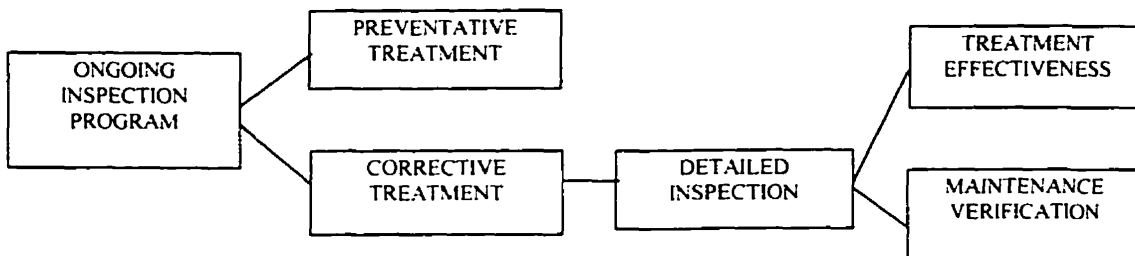
There are other triggers in this system, including detailed inspection, drainage analysis and resurfacing analysis.

Part of this system includes a recommendation for the ongoing pavement monitoring program that stage five pavement evaluation [2] be adopted. This would permit more of the regional network to be evaluated each year because there would only be nine distresses looked for and recorded rather than nineteen. For detailed inspections, it would be prudent to catalogue all distresses present.

Maintenance management systems are information-dependent. For this reason, it is suggested that after any corrective maintenance a detailed inspection be executed so that the effect of the maintenance can be determined. The maintenance effectiveness information will benefit the management system in the future by better enabling experts to develop optimal strategies. Knowing how effective a maintenance treatment is on certain distresses will help allocate that resource. After an initial corrective maintenance action, the detailed inspection key will be activated. If the initial action is preventative

there will be no detailed inspection. Unlike the previous keys, this is not frequency-activated. It is activated each time corrective maintenance is recommended as the desired course of action. This key is included because inspection resources are equally as important as other resources. The diagram below shows the maintenance activity assignment system with the detailed inspection key. Once the detailed inspection is complete, this information is put into the appropriate PCI database to be used by maintenance planners.

FIGURE 4-B



The drainage and resurfacing keys function differently. Proper pavement drainage is an essential element of pavement design that will contribute to long life and a good return on investment. For this reason a drainage key was included. There are some distresses that will occur frequently when ponding is occurring. e.g., scaling and D-cracking. If these occur frequently on a pavement, the managers of that pavement should be notified that a drainage analysis is required. If it is found that the drainage is deficient, it must be restored. This system indicates when the drainage should be analyzed but does not recommend how to repair it.

The resurfacing key is similar. If there is a distress or group of distresses present in enough quantity on a pavement that would indicate that resurfacing was the best next

course of action, resurfacing analysis is recommended. These keys are developed based on human experience. There is no algorithmic or numerical method used to determine them.

**4.2 MAINTENANCE ACTIVITY ACTION TABLES**

The standard and deferral treatments discussed earlier were developed using a maintenance policy. This maintenance policy was developed with assistance from City of Winnipeg staff.

The maintenance activity, PCI range, and distress type/severity combinations in these maintenance action tables were developed based on the desire to postpone major rehabilitation whenever possible and to get the most out of maintenance funds. This is accomplished through focusing most maintenance funds on the pavements that are still in good condition, e.g., PCI from 76 - 100. In the relevant action table below notice that when the PCI is in the 0 - 45 range, there is no maintenance performed except for safety maintenance. In this low range, the maintenance treatments will not last long since the road is deteriorating rapidly. According to the family curve method [1] for pavement condition prediction, maintenance treatments will push the curve up, and the section curve will run parallel to the family curve. Therefore, at the low PCI range, maintenance treatments are not cost-effective since the slope of the curve is high ( pavements are deteriorating rapidly ). In the higher ranges, maintenance treatments will last longer and provide more benefit. This maintenance policy is designed to be preventative. Therefore, even in the low-severity action table in the higher PCI ranges, the distresses are repaired. In the highest PCI range there is an activity assigned regardless of the severity. It would be desirable to repair all distresses at the low-severity level in the middle PCI range as

well, however it is doubtful that any civic budget in today's fiscal environment will permit such an aggressive maintenance policy . Notice that in the middle PCI range for the high and medium severity action tables there is a "do-nothing" option, which is the deferral strategy. Focusing funds on the roads in the higher PCI ranges will provide considerable life cycle cost savings.

These action tables are guidelines, to be interpreted along with detailed inspection reports, explanatory variables and background information such as., network rank, maintenance priority and traffic data. Pavements with a multitude of distresses may require more than one treatment, and maintenance treatments must be selected carefully so that there is no duplication of effort in the strategy. For example, if the distresses are severe enough to warrant a slab replacement in one or two years then sealing cracks now would not be beneficial. There may be activities suggested in the tables that do not concur with current maintenance practices. In this case, the activities suggested in the tables may be changed to reflect the maintenance requirements.

The ranges used in these action tables should be adjusted as experience dictates. For example, if it is found that once PCI decreases from 55 to 35 most linear cracking is severe, then the bottom range can be adjusted to 0 - 35 so that the three ranges are as physically distinct as possible. This will help further maintenance policy development. The three tables below are the maintenance policy that is used for assigning maintenance activities. There is a table for each distress severity - high, medium and low.

TABLE 4- B

**HIGH SEVERITY ACTION TABLE**

PCI RANGE	LINEAR CRACK	JOINT SEAL	BLOW- UPS	CORNER SPALL	JOINT SPALL	CORNER BREAK	PUNCH OUTS
0 - 45	NOTHING	NOTHING	PATCH	NOTHING	NOTHING	NOTHING	PATCH
46 - 75	AMZ NOTHING	NEW SEAL NOTHING	AMZ REPL JOINT	AMZ NOTHING	AMZ NOTHING	PATCH NOTHING	PATCH NOTHING
76 - 100	REPLACE SLAB	REPLACE SEAL	REPLACE JOINT	REPLACE JOINT	REPLACE JOINT	PCC PATCH	PCC PATCH
DISTRESS TYPE	SCALING	DIVIDED SLAB	FAULT	D-CRACK	LANE DROPOFF	POLISH AGG.	PUMPING
0 - 45	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING
46 - 75	AMZ NOTHING	REPL. SLAB NOTHING	GRIND NOTHING	AC PATCH NOTHING	GRIND NOTHING	NOTHING	*DRAINAGE NOTHING
76 - 100	GRND/PCH	REPLACE SLAB	GRIND SMOOTH	AC GRD/PCH	GRADE SMOOTH	GRIND OVERLAY	REPLACE JOINT

- DRAINAGE - this could be repaired by mud jacking to fix the base and joint sealant to ensure proper joint seal.

TABLE 4 - C

**MEDIUM SEVERITY ACTION TABLE**

PCI RANGE	LINEAR CRACK	JOINT SEAL	BLOW- UPS	CORNER SPALL	JOINT SPALL	CORNER BREAK	PUNCH OUTS
0 - 45	NOTHING	NOTHING	AMZ	NOTHING	NOTHING	NOTHING	AMZ
46 - 75	SAW & SEAL NOTHING	RE SEAL NOTHING	AMZ	AMZ NOTHING	AMZ NOTHING	AMZ NOTHING	PATCH NOTHING
76 - 100	SAW AND SEAL	RE SEAL	REPLACE JOINT	PCC PATCH	REPLACE JOINT	PCC PATCH	PCC PATCH

DISTRESS TYPE	SCALING	DIVIDED SLAB	FAULT	D-CRACK	LANE DROPOFF	POLISH AGG.	PUMPING
0 - 45	NOTHING	NOTHING	NOTHING	NOTHING	GRADE	NOTHING	NOTHING
46 - 75	NOTHING	REPL SLAB	GRIND	PATCH	GRADE	NOTHING	*DRAINAGE
		NOTHING	NOTHING	NOTHING	NOTHING		NOTHING
76 - 100	PATCH	REPLACE SLAB	GRIND	PATCH	GRADE	GRIND	REPLACE
			SMOOTH		SMOOTH	PATCH	JOINT

\*DRAINAGE - fix the base by mud jacking then seal joint to ensure no more water infiltrates.

TABLE 4 - D

LOW SEVERITY ACTION TABLE

PCI RANGE	LINEAR CRACK	JOINT SEAL	BLOW-UPS	CORNER SPALL	JOINT SPALL	CORNER BREAK	PUNCH OUTS
0 - 45	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING
46 - 75	SEAL	SEAL	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING
	NOTHING	NOTHING					
76 - 100	SAW AND SEAL	RE SEAL	REPLACE JOINT	NOTHING	NOTHING	SEAL	PATCH
						CRACK	
DISTRESS TYPE	SCALING	DIVIDED SLAB	FAULT	D-CRACK	LANE DROPOFF	POLISH AGG.	PUMPING
0 - 45	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING
46 - 75	NOTHING	SEAL	NOTHING	NOTHING	NOTHING	NOTHING	NOTHING
		NOTHING					
76 - 100	NOTHING	SAW AND SEAL	GRIND	NOTHING	NOTHING	NOTHING	NOTHING
			NOTHING				

# **CHAPTER 5: RULE DEVELOPMENT**

## **CHAPTER 5: RULE DEVELOPMENT**

This chapter includes a discussion of the rules developed for the pavement maintenance management system and a description of the questionnaire used to solicit the information.

### **5.1 QUESTIONNAIRE**

The questionnaire that was sent to the City of Winnipeg Street Maintenance Department is listed in Appendix B. This questionnaire was given to engineers and technical assistants involved in street maintenance and pavement management at the City of Winnipeg.

The first question is designed to determine the three most important ranges in PCI. Many of the experts believe that 0 - 40, 40 - 60 and 60 - 100 are the most suitable ranges. The average of the ranges was 0 - 45, 46 - 75 and 76 - 100. 60 - 100 is the range where most preventative maintenance dollars should be spent, 40 - 60 is the range where, if needed, corrective maintenance should be performed, and 0 - 40 is the range where no money should be spent except for safety maintenance. For this project, the average ranges were used.

In the questionnaire, the difference between corrective and preventative maintenance activities is determined. Preventative maintenance includes activities such as sealing joints and cracks, repairing spalls, and patching and fixing seals. Corrective maintenance includes joint replacements, overlays and micro-surfacing.

Another goal of the questionnaire was to isolate the recurring distresses that are a result of poor drainage. These distresses are pumping, joint and corner spalls, and joint

sealant damage. If the occurrence of these distresses is frequent enough, it is time to fix or study the drainage of the pavement in question.

With all maintenance activities, it is important to know when to act. This is why in the questionnaire questions were asked to determine how often a distress must occur before performing a maintenance treatment. This question did not produce the expected result, which was an estimate as to the frequency of occurrence at which it would be reasonable to act for some of the distresses. It was not expected that a frequency for all of the distresses would result from the questionnaire. The result from the questionnaire was intended to be a starting point from which a frequency policy could be developed. Having a frequency threshold for one distress is of little practical use, since they rarely occur in isolation from other distresses. It is possible to include the frequency for individual distresses and combinations of distresses in the rule structure so that actual pavement distress regimes could be accounted for. In the system described in this report, a treatment is recommended each time a distress is recorded. The problem is: how often should this recommendation be made before the treatment is put into action?. It is recommended that threshold distress occurrence frequencies be developed for this purpose. For example, if a pavement has a PCI of 55, and one instance of joint and corner spall is reported, it is not efficient to mobilize all the necessary equipment and resources to repair the pavement. However, if there are 50 occurrences, then it would be efficient ( 50 is obviously a high number for this ).

The last major objective of the survey was to ascertain what background information is important when making maintenance decisions. The results of this question were not as expected. The most important background information involves type

and degree of distress and pavement age. but this result does not mean that models or decisions will not improve by including more explanatory variables.

## 5.2 THE RULES

A complete listing of the rules is listed in Appendix A. As mentioned earlier, controlling moisture is an important element in maintenance management. This is the reason for the questions regarding drainage. The answers to these questions were translated into rules. The distresses which indicate possible drainage problems are pumping, joint and corner spalls, and joint sealant damage.

In pavement maintenance management, the emphasis in the highest PCI range is on preventative maintenance. With a drainage problem this is not always the case. Notice that if there is severe joint or corner spalls in the highest PCI range, the joint is replaced and drainage is restored. This is done so that the distresses do not spread and destroy the remainder of the slab. It is unlikely that these severe distresses will appear on a high PCI pavement, but these occurrences must be planned for.

There is always a "do-nothing" threshold. In the system described in this report, there is no corrective or preventative maintenance performed on a pavement with a PCI between 0 and 45. The rule is:

```
IF PCI = 0 - 45 AND
  D = ANYTHING THEN
  SA = DO NOTHING
  DA = DO NOTHING
( SAFETY MAINTENANCE IS NOT PART OF THIS SYSTEM. SAFETY MAINTENANCE IS REQUIRED REGARDLESS OF
PCI THIS INCLUDES BLOW UPS AND PUNCHOUTS )
D = distress
SA = standard activity
DA = deferral activity
```

A pavement in this stage may be a candidate for resurfacing or reconstruction. These two options include a number of complex variables, including capital budget, politics, traffic

disruption and user costs. This system does have rules which recommend that resurfacing or reconstruction be considered, but that is the extent.

# **CHAPTER 6: LONG-RANGE STRATEGIES**

## CHAPTER 6: LONG-RANGE STRATEGY SELECTION

This chapter describes the steps taken in development of a method for the selection of appropriate long term strategies for pavement maintenance.

### 6.1 TRANSITION PROBABILITIES

A transition probability is the probability that a pavement condition index for a pavement section will decrease from one stage to the next lowest stage in one period. One period is three years for this project. For the purpose of the calculation of transition probability, the PCI index has been divided into six stages:

TABLE 6-A

STAGE	FROM	TO
1	91	100
2	81	90
3	71	80
4	61	70
5	46	60
6	0	45

These stages were chosen so that the progression of a pavement section can be tracked. Previously in the report, three ranges of PCI were used for maintenance activity assignment, but these ranges are not suitable for transition probability because they are too large. If the ranges of PCI are larger, it is more difficult to observe the pavement as it deteriorates. There are no divisions between zero and forty-five because once a pavement reaches a PCI of forty-five, there is no maintenance that is recommended ( as was explained earlier ). Using narrow ranges allows for more control and for better decision-making.

The transition probabilities were calculated using historical and predicted pavement condition data. There was interpolation required to determine conditions at

three-year intervals in some cases. The transition probability is determined by counting the number of sections in the sample that move from stage one to stage two, stage two to stage three and stage three to stage four in one period. The sample contained pavements of various ages and conditions. The ratio of sections that did move from one stage to the next, to those sections that did not, is the transition probability. It is recommended that transition probabilities be calculated for all pavement families separately since different families have substantially different behavior patterns.

The transition analysis was done so that there are separate transition tables for different pavement ages: 0 - 3 years; 3 - 6; 6 - 9; 9 - 12; and 12 - 15. The analysis stopped after 15 years since the reliability of some of the pavement predictions was suspect. The results are as follows:

[These numbers are the probability that a pavement in the database will deteriorate one stage within one analysis period. An end-of-year convention is adopted for consistency.]

**TABLE 6-B**

		TO STAGE				
FROM STAGE	1	2	3	4	5	
1	0.217	0.792	0	0	0	
2	0	0.0625	0.938	0	0	
3	0	0	0.400	0.600	0	
4	0	0	0	0	1.0	
5	0	0	0	0	0	

The transition probability for years 0 - 3

**TABLE 6-C**

FROM STAGE		TO STAGE				
		1	2	3	4	5
1	0	1.0	0	0	0	0
2	0	0.578	0.421	0	0	0
3	0	0	0.600	0.400	0	0
4	0	0	0	0.714	0.286	0
5	0	0	0	0	0	0

The transition probability for years 3 - 6

**TABLE 6-D**

FROM STAGE		TO STAGE				
		1	2	3	4	5
1	0	0	0	0	0	0
2	0	0	1.0	0	0	0
3	0	0	0.350	0.650	0	0
4	0	0	0	0.643	0.357	0
5	0	0	0	0	0	0

The transition probability for years 6 - 9

**TABLE 6-E**

FROM STAGE		TO STAGE				
		1	2	3	4	5
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0.478	0.522	0	0
4	0	0	0	0.727	0.273	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

The transition probability for years 9 - 12

**TABLE 6-F**

FROM STAGE		TO STAGE					
		1	2	3	4	5	6
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0.590	0.410	0	0
5	0	0	0	0	0.857	0.143	0

The transition probability for years 12 - 15

The transition probabilities for young pavements in good condition are higher than those for older pavements. This reflects the rapid decrease in PCI in the first few years. As the pavements get older and more deteriorated, the PCI is less sensitive to moderate increments in pavement distress. Thus the transition probabilities tend to decrease with

the age of the pavement. The variations in the 0 - 3 year histogram could be explained by the increased sensitivity of PCI to moderate increases in pavement distress at higher levels of PCI and by the relatively small size of this pavement database.

The probabilities should be updated as more data becomes available. Some predicted data was used for this analysis. It would be desirable to perform the analysis using only observed PCI data.

The results of the transition analysis were as expected. Considering the 0 - 3 year table, the probability of a pavement in stage 1 decreasing to stage 2 is 0.792. This is a high probability, which is as expected since the steepest part of the pavement condition curve is the first 5 - 6 years. Notice that in the 3 - 6 year table any pavements that were in stage 1 after 3 years always decreased to stage 2. This also corresponds to expectations. The probabilities generally decrease in each category as the condition gets worse.

## **6.2 - LONG-TERM STRATEGIES**

There are three types of long-term pavement maintenance strategies. These are preventative, corrective and deferral. Each type of strategy is selected based on the current condition of the pavement, the transition probability of the pavement family and background information. The types of background information considered include AADT, utility cuts, percent trucks and maintenance histories.

Background information is used to aid in decision making. For example, consider a pavement in good condition with a high transition probability. This pavement would normally be a candidate for preventative maintenance. If it is found that the pavement has high traffic with a large percentage of trucks and that past preventative maintenance treatments have had little effect, it may be prudent to take a more substantial course of

action e.g., some moderate repairs and an overlay. Each candidate project requires a similar analysis.

Preventative maintenance is generally limited to pavements that are in good condition ( stages 1, 2 or 3 ) with moderate to high transition probabilities. If the transition probability is high, the repairs will not be cost-effective. In this case, therefore a more substantial course of action would be suitable.

Corrective maintenance should be limited to pavements that are in fair to good condition ( stages 2,3,4 or 5 ), with moderate to high transition probabilities. Corrective maintenance on pavements in worse condition is not cost-effective. The types of activities that are preventative are joint replacement, thin overlays, slab replacement and concrete patching.

The “do-nothing” strategy is employed when pavements are in poor condition ( stage 6 ). The only maintenance that is performed in this range is safety maintenance, which includes patching large holes and cracks to ensure a safe ride. A “do-nothing” approach could also be used when transition probabilities are very low. This would permit the use of resources elsewhere.

Transition probabilities can be used for long-term strategy selection. These guidelines need to be interpreted with background information. Consider the table below:

TABLE 6-G

CONDITION STAGE	TRANSITION PROBABILITY		
	LOW	MEDIUM	HIGH
1	DEFERRAL	PREVENTATIVE	PREVENTATIVE
2	DEFERRAL	PREVENTATIVE	PREVENTATIVE
3	PREVENTATIVE	PREVENTATIVE	CORRECTIVE
4	CORRECTIVE	CORRECTIVE	CORRECTIVE
5	CORRECTIVE	CORRECTIVE	CORRECTIVE
6	DEFERRAL	DEFERRAL	DEFERRAL

In previous chapters the system that is described is reactive. The part of the system in this chapter is the proactive component. A complete solution to a pavement maintenance problem has both components. In a situation where a pavement requires immediate treatments, these will be recommended by the rules that were developed in the previous chapter. The long-range strategy is recommended by assessing the transition probability of the pavement and analyzing the background information available in the manner described above.

The recommendation from this analysis will be corrective maintenance, preventative maintenance or deferral. This, plus the reactive maintenance, is the maintenance strategy. Before implementing a strategy one must first determine the timings, treatments and quantities required. Once these have been established, they are translated into costs. This information is then used for a life-cycle cost analysis which will help select the most efficient strategy. This process is described in more detail in the life-cycle cost analysis chapter.

# **CHAPTER 7: LIFE-CYCLE COST ANALYSIS**

## **CHAPTER 7: LIFE CYCLE COST ANALYSIS**

This chapter describes the techniques that are used to evaluate and select a maintenance strategy based on life-cycle cost analysis.

### **7.1 METHODS OF LIFE CYCLE COST ANALYSIS**

Life-cycle cost analysis involves selecting pavement maintenance strategies based on a life cycle-cost comparison. There are two basic types of life-cycle cost analysis.. (1) equivalent uniform annual cost. and (2) cost/life.

Equivalent uniform annual cost involves aggregating the present worth of costs of all treatments in a strategy, and then using the annuity factor to determine what the uniform annual cost is. When selecting from a group of alternatives, the one with the lowest annual cost would be selected. Projects with high initial costs are generally not selected with this method since high initial costs have a high present worth and hence a high annual cost. For strategies with unequal lives a reinvestment assumption would be required.

The second method is the cost of the strategy divided by the expected length of time that the strategy will be in place. The length of time that the strategy is in place is the length of time that the pavement will perform up to a predetermined standard. This method would be suitable for strategies with equal or unequal lives. The cost of the strategy is the total of all funds required for the completion of the strategy.

Although it may seem that by using one of the above methods to select the lowest cost project each time this will minimize the life-cycle cost of the network, this is not so.

In order to minimize the life cycle cost of a pavement network, the following maintenance guidelines must be observed.

a) *Consider network benefit when selecting projects*

b) *Use life-cycle cost of projects to select appropriate course of action*

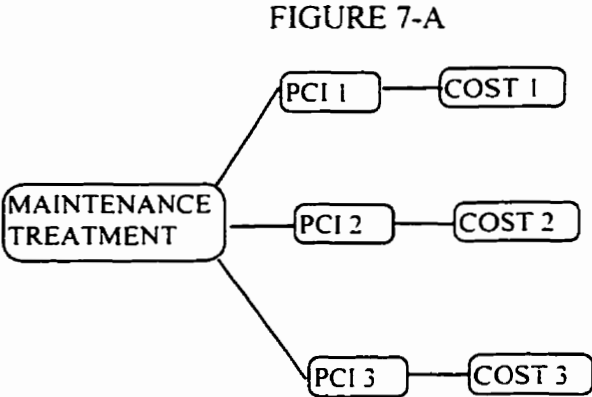
These guidelines form the basics of network life-cycle cost analysis. This project focuses on project life-cycle cost analysis within the City of Winnipeg's pavement maintenance management system. The difference between project and network life-cycle cost is that project life-cycle cost selects the best solution from a group of alternative maintenance treatments, while network life-cycle cost analysis involves selecting projects that maximize network benefits. Once the projects have been selected, project life cycle cost is used [28].

#### *7.1.1 Information requirement for project life-cycle cost analysis*

The information that is required for project life-cycle cost analysis involves some estimating and use of historical data. First, the timings of the different treatments must be known. These can be ascertained from the experts developing the plan, and from historical maintenance data detailing the effectiveness of maintenance treatments. This is important because many of the maintenance treatments are not applied until the pavements reach a certain PCI level. This can only be determined by ascertaining how effective previous treatments were, and then using the family curve of the pavement in question to project when the desired PCI level will be reached so that the next treatment can be applied.

After the treatment timings have been determined, the cost of each separate treatment must be known. This presents more of a problem when the information is

entirely derived from historical data. In order for this to work, as maintenance projects are completed the cost of a maintenance treatment must be correlated with the PCI prior to the treatment of the pavement in question. Once a large enough database is built, the funds required can be easily estimated. Ideally, the database will contain all maintenance treatments, all PCI levels where each maintenance treatment is applicable, and the associated cost for each treatment in each category. Each database record will be as follows:



While this database is under construction another method for estimating costs must be used.

**7.2 STAGE BY STAGE CONDITION DESCRIPTIONS**

This section discusses the different maintenance requirements and distress regimes in the eight PCI stages.

*STAGE 1 PCI = 91 - 100*

The data for this stage was limited. All pavements in this condition had two main distresses, joint seal damage and polished aggregate, in equal proportions. There was no structural damage. Pavements in this condition require that joint seals be fixed.

### *STAGE 2 PCI = 81 - 90*

Pavements in this stage begin to show more signs of deterioration. There are 12 observed distresses in the data for this stage, all low and medium severities. The distresses are mostly on the surface of the pavement, including joint and corner spalling and polished aggregate. Faulting, joint seal damage, and linear cracking are also present in limited quantities. There are no signs of structural damage to the pavement. An appropriate strategy for these types of pavements would be to ensure that joint seals and cracks are repaired, and that joint/corner spalls of medium severity or higher are repaired.

### *STAGE 3 PCI = 71 - 80*

Stage 3 pavements have the same basic types of distresses as pavements in stage 2. The frequency of the distresses in stage 3 is higher than in stage 2. The occurrences of joint and corner spalls, polished aggregate, linear cracking and joint seal damage double from stage 2 to stage 3, but all remain as low or medium severity. The basic preventative repairs are more costly than they were in the previous stage due to the increase in the amount of labor and materials required for the work.

### *STAGE 4 PCI = 61 - 70*

These pavements are beginning to show severe joint deterioration with increasing occurrences of corner and joint spalls of all severities. There are also substantial structural problems in these pavements, such as divided slab, severe linear cracking, and corner breaks. Surface and joint seal distresses are present as well. In this circumstance, it is important to restore load transfer between slabs. This is done by replacing bad joints and

repairing the ones that still function but are about to fail. In the instances where there is considerable severe linear cracking or divided slab, the entire slab must be replaced. As in the other stages it is also important to ensure that cracks and joints are sealed to prevent further distresses due to moisture infiltration.

#### *STAGE 5 PCI = 46 - 60*

Pavements in this stage are beginning to deteriorate rapidly. All of the distresses present in the previous stage are present here in larger numbers. The major change from stage 4 to stage 5 is the dramatic increase in faulting, linear cracking, divided slabs, and corner and joint spalling. The frequency of the surface distresses have increased as well. These pavements require similar structural rehabilitation to pavements in the previous stage. This includes replacing the bad joints and the slabs that have structural failure, and sealing all cracks and joints. It is obvious that the number of cases requiring structural rehabilitation in this instance would increase. Thus the cost for such repairs would increase as well. In this stage, the pavements are past the "knee" on the pavement condition vs time plot, which means that the rate of deterioration is increasing. These types of repairs will not last as long as they would if the pavement was in better condition. This stage would be a good stage for a thick structural asphalt overlay. An overlay such as this would return the pavement to a higher PCI. The distresses in the concrete must be repaired before the overlay, or else the distresses will appear in the asphalt as they were in the concrete.

### *STAGE 6 PCI = 0 - 45*

Stage 6 pavements have reached the point where maintenance is no longer cost-effective. The differences from stage 5 pavements are increases in medium and severe linear cracking, medium scaling, and severe large patching. The rest of the data for this stage does not reflect the change in PCI. This could be because of inherent problems associated with data-gathering such as the having so many distresses, making it difficult to rate pavements in great detail, or due to the lack of specimens in this category. Regardless of the inadequacy of the data, the only maintenance that would be permissible in this stage would be safety maintenance. This would entail patching large holes, grinding large faults, and generally ensuring that the road was safe. The costs for preventative or corrective maintenance in this stage are prohibitive.

Condition information is important in selecting life-cycle strategies, but there is other information, including maintenance histories, construction type, traffic data, and transition probabilities, that must be considered when developing alternatives for pavement maintenance. For example, when considering a major corridor for a maintenance strategy that has high truck volumes, high transition probability or a poor response to previous preventative maintenance, an aggressive maintenance policy may be appropriate so that the structural performance is improved. These alternatives are further subjected to life-cycle cost analysis to determine the best one.

# CHAPTER 8: RANKING MAINTENANCE PROJECTS

## CHAPTER 8: RANKING MAINTENANCE PROJECTS

This chapter describes the proposed ranking methodology and the reasoning behind it.

### 8.1 RANKING METHODS

Ranking is an essential part of any pavement maintenance management system. Properly ranking maintenance projects will help to ensure that network benefit is maximized.

Ranking is made possible by developing priority indexes. These indexes are put into descending order. The highest-ranking project has the highest number. Below are some of the different types of indexes that are possible.

#### *8.1.1 AADT x PCI*

This priority index ensures that the high volume/high PCI roads receive most of the maintenance budget. The index is tabulated for all pavement sections in the database, and then put into descending order. The candidate projects are costed using maintenance unit costs and pavement condition survey data. The maintenance budget is distributed as far down the list as possible. The roads that do not receive full maintenance funding still receive safety maintenance and deferral maintenance.

#### *8.1.2 AADT*

Using AADT alone for ranking could result in roads that are in poor condition receiving maintenance dollars, thus wasting funds. As stated earlier, once a pavement reaches a PCI of 45, only safety maintenance should be performed. Any other maintenance is not cost-effective.

### 8.1.3 PCI

Ranking based on current PCI is not a satisfactory method. The importance of the street to the network must be considered, and this is accomplished by using AADT in the ranking system.

In a maintenance management system, much energy and money is expended in the data-gathering phase, i.e., pavement condition monitoring. Failure to use an appropriate ranking system would result in large deficiencies over the entire network and would not make proper use of all the information gathered. The ranking stage of maintenance management is one in which optimization can be employed. The algorithms necessary to determine exactly what projects to do, and when, are often cumbersome. Ranking based on AADT x PCI is sufficient. There are more complex ranking systems that may produce better results, and these should be explored as well.

Using AADT x PCI to rank maintenance priorities will ensure that pavement sections which are in good and fair condition ( high PCI ) will be a maintenance priority while sections which are so bad that maintenance is no longer cost-effective will be left until they are rebuilt ( safety maintenance is a constant on all street segments ). Network priorities will also be addressed. Streets that have the highest AADT will rank over lower volume links. Higher AADT streets are more important to a network than lower volume ones. Combining AADT and PCI in the ranking will ensure that major arterials are not allowed to deteriorate to the point where major maintenance is required prematurely. This will minimize traffic disruption and associated user costs. This ranking method is to be applied separately to all different street classes, including regional, collector and locals. These can be further subdivided into bus routes and truck routes, so that all pavement

sections are not ranked in one large list. The budget can be divided into portions for each road type. This will ensure that the correct projects will be funded so that a minimum percentage of the network will be in poor condition.

This is not an immediate process. Over time, as the sections that are currently in poor condition and not qualifying for maintenance are rebuilt, they are entered into the maintenance management system. After they have all been rebuilt, the effects of improved ranking will show. The results will be less sections in poor condition than before and a lower annual budget deficit.

To improve on the proposed ranking system, one could also include road class and pavement type. The ranking variables would be AADT, PCI, road class, and pavement type.

To further refine this ranking process, one could set aside a portion of the budget for each category. Within this portion of the budget, a portion could be set aside for certain maintenance activities [3.26]. For example, on regional truck routes and bus routes it would be desirable to have funds set aside for crack sealing, drainage, and joint repair. On collector bus routes, crack sealing and joint repair are important. The balance of the budget for each ranking category would be distributed from the top down for the remaining candidate projects on each list.

# CHAPTER 9: IMPLEMENTATION

## CHAPTER 9: IMPLEMENTATION

This chapter describes the basic steps required for implementation. A commentary on how the proposed system could be used for overlaid pavements is also included.

In order to implement the system recommended in this report, the following steps should be followed:

- 1) Rank all current maintenance projects using the method proposed in this report and compare the result to the maintenance plan that is currently in effect. This will allow for a comparison between current ranking procedures and the proposed method, illustrating the effect that the proposed method will have on the order in which projects are completed.

- 2) Once maintenance projects are ranked, the most recent inspection data is used for developing reactive maintenance solutions based on the current condition of the pavement. For subsequent pavement condition monitoring, stage 5 evaluation could be used if deemed appropriate by the pavement experts.

- 3) The transition probabilities are calculated separately for each pavement family. This data is then used to develop long term general strategies.

- 4) The general strategies are then developed into detailed applications and timings and evaluated based on life cycle cost.

The scope of this project is limited to portland cement concrete regional street pavements. It is possible to include pavements that have been overlaid with asphalt. Most of the distresses in these pavements come from the PCC pavement, not from the asphalt overlay. For this reason, during the inspection process, the distresses present in the PCC

pavement must be separated from the asphalt distresses. All aspects of calculating the transition probabilities and ranking projects could be directly transferred. The maintenance activity assignment tables will have to be altered to reflect the different activities and maintenance requirements associated with these pavements. Once the pavements have been overlaid, they are in a separate family, thus the transition probabilities must be calculated separately.

# **CHAPTER 10: RECOMMENDATIONS**

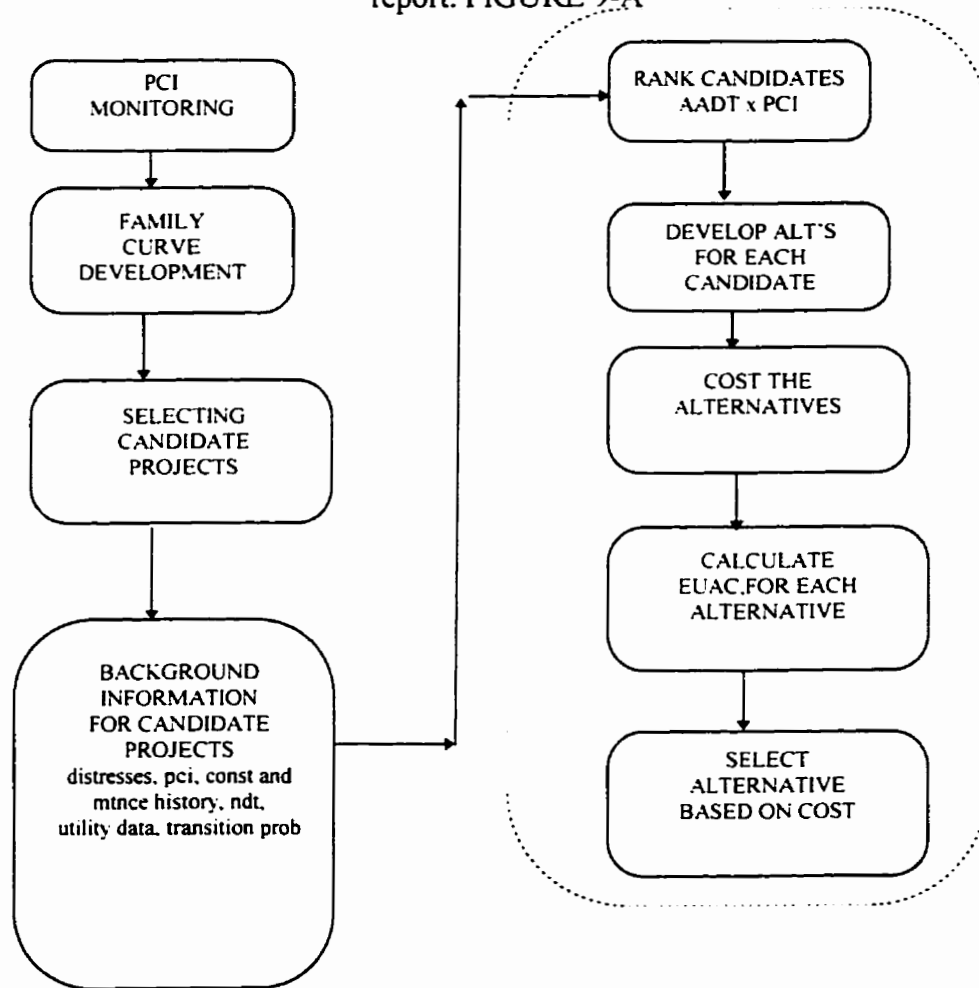
## CHAPTER 10: RECOMMENDATIONS

This chapter summarizes the recommendations that are made throughout the report.

### 10.1 RECOMMENDATIONS

10.1.1 The first recommendation is in the form of a flow chart. This chart provides an overview of the reactive maintenance management system described in this

report. FIGURE 9-A



This flow chart summarizes the recommendations made throughout the report

The above flow chart summarizes the recommendations in this report, but, there are some details that the flow chart does not encompass. When monitoring PCI for example, it is required that more of the network be monitored each year than is currently done. This could be accomplished by utilizing the stage monitoring techniques that are discussed in this report and in the undergraduate thesis by Colleen Lodge [2].

Also, in developing family curves, there are explanatory variables introduced. For example a drainage coefficient and AADT are two of many possibilities.

As noted in the body of the report, inspection data must be correlated with maintenance data. In particular, after corrective maintenance has been performed the site needs to be inspected so that the effectiveness of the maintenance can be verified. This information can then be used to enhance the maintenance planning process.

In the above flow chart, the area within the dotted line is where an expert system could be used to automate some of the procedures. For example, ranking is done by multiplying  $AADT \times PCI$ , and this type of calculation is ideal for automation. Once the alternatives have been developed for each candidate, the equivalent uniform annual cost must be calculated. This procedure is also suited to some form of automation.

#### *10.1.2 Maintenance priority system*

As described in Chapter Two of the report, maintenance priorities are important to ensure a safe and efficient road network. The basic maintenance priorities are in this order:

- 1) safety maintenance
- 2) preventative/ corrective

### 3) major maintenance

These categories do not include branch use or pavement type. Branch use must be included as follows:

- 1) regional
- 2) bus route
- 3) collector
- 4) local

Surface type plays a role in the priorities as well. Surface type is included as follows:

- 1) PCC pavement
- 2) Asphalt pavement

The first section comprises the primary priorities, the second section the secondary variables, and the third section contains the tertiary priority-setting variables.

#### *10.1.3 Maintenance goals*

There are three basic maintenance goals that need to be adopted. First, ensure drainage, both longitudinal and transverse. Second, seal cracks and joints. Third, maintain a smooth ride wherever possible.

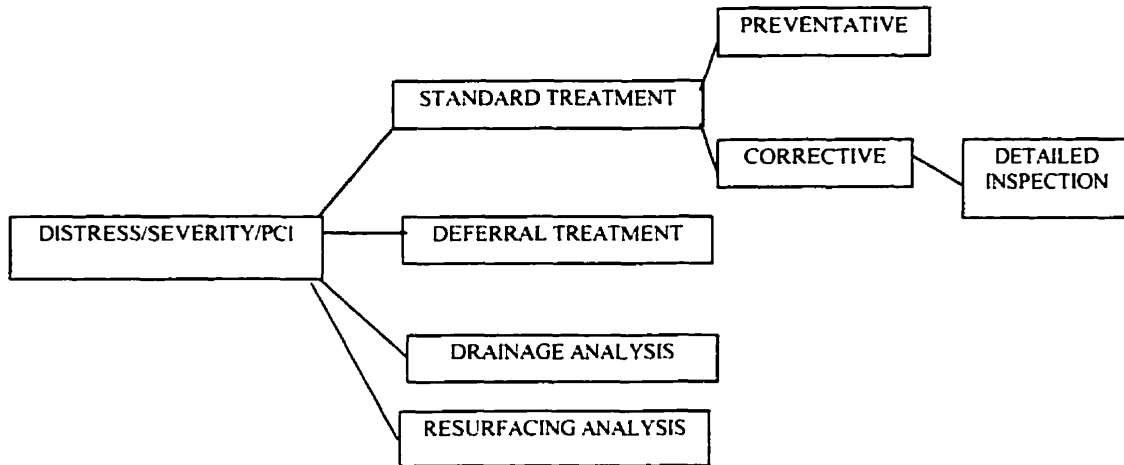
#### *10.1.4 Detailed inspections*

Detailed inspections should be carried out after all corrective maintenance. Knowing the effectiveness of the maintenance will help maintenance planners.

#### *10.1.5 Trigger system*

A trigger or key system should be used for assigning maintenance activities and inspections.

FIGURE 9-B



This flow chart describes the trigger system. There is a feedback loop that returns information to the appropriate managers.

#### *10.1.6 Transition probabilities*

Use transition probabilities to help in long-range maintenance planning.

#### *10.1.7 Paver*

Paver should be used to the fullest extent possible to help determine maintenance effectiveness in the planning stage. unless there is better information available from another source. There are numerous modules in Paver that could be of value to a maintenance planning unit. These should be explored.

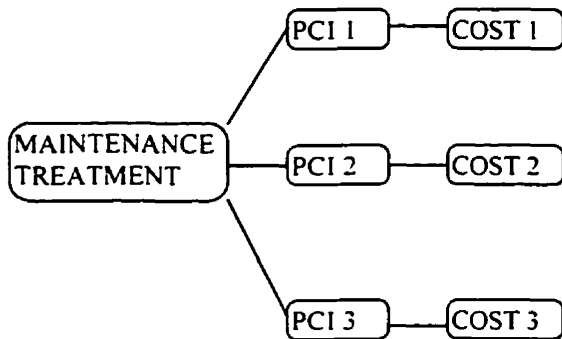
#### *10.1.8 Life-cycle cost comparisons*

Life cycle cost comparisons should be used in the selection of appropriate maintenance strategies. For this, much information is required. This information requirement is detailed throughout the report.

### 10.1.9 Database construction

A database that correlates every maintenance treatment and different PCI levels should be developed to aid in maintenance planning. The database records will look as follows:

FIGURE 10-C



### 10.1.10 Network benefit

Overall network benefit needs to be considered in the ranking of maintenance projects. This is made possible by using  $AADT \times PCI$ , but this is not the end-solution to the problem. As more information is gathered, the ranking system will evolve to reflect new information on network and user benefit.

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## APPENDIX A - RULE LIST

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These are the rules for the reactive pavement maintenance expert system.

- 1) IF PCI = 0 - 45 AND  
D = ANYTHING THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
( SAFETY MAINTENANCE IS NOT PART OF THIS SYSTEM. SAFETY MAINTENANCE IS REQUIRED REGARDLESS OF PCI THIS INCLUDES BLOW UPS AND PUNCHOUTS )
- 2) IF PCI = 76 - 100 AND  
D = PUMPING THEN:  
SA = UNDERSEAL, ENSURING DRAINAGE  
DA = DO NOTHING  
IA = DRAINAGE ANALYSIS
- 3) IF PCI = 76 - 100 AND  
D = HIGH JOINT SEAL DAMAGE OR  
D = MEDIUM JOINT SEAL DAMAGE OR  
D = LOW JOINT SEAL DAMAGE THEN:  
SA = REPAIR SEAL, ENSURING DRAINAGE  
DA = DO NOTHING IF LOW OR MEDIUM, HIGH SEVERITY MUST BE REPAIRED  
IA = DRAINAGE ANALYSIS
- 4) IF PCI = 76 - 100 AND  
D = HIGH SEVERITY JOINT SPALL AND/OR  
D = MEDIUM SEVERITY JOINT SPALL THEN:  
SA = REPLACE JOINT, ENSURING DRAINAGE  
DA = AMZ PATCH  
IA = DRAINAGE ANALYSIS
- 5) IF PCI = 76 - 100 AND  
D = HIGH SEVERITY CORNER SPALL AND/OR  
D = MEDIUM SEVERITY CORNER SPALL THEN:  
SA = REPLACE JOINT, ENSURING DRAINAGE  
DA = AMZ PATCH  
IA = DRAINAGE ANALYSIS
- 6) IF PCI = 76 - 100 AND  
D = LOW SEVERITY JOINT SPALL AND/OR  
D = LOW SEVERITY CORNER SPALL THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DRAINAGE ANALYSIS
- 7) IF PCI = 46 - 75 AND  
D = PUMPING THEN:  
SA = UNDER SEAL, ENSURING DRAINAGE  
DA = DO NOTHING  
IA = DRAINAGE ANALYSIS/DETAILED INSPECTION

- 8) IF PCI = 46 - 75 AND  
D = HIGH JOINT SEAL DAMAGE OR  
D = MEDIUM JOINT SEAL DAMAGE OR  
D = LOW JOINT SEAL DAMAGE THEN:  
SA = RE SEAL, ENSURING DRAINAGE  
DA = DO NOTHING IF LOW OR MEDIUM, HIGH SEVERITY MUST BE FIXED  
IA = DRAINAGE ANALYSIS/DETAILED INSPECTION
- 9) IF PCI = 46 - 75 AND  
D = HIGH SEVERITY JOINT SPALL AND/OR  
D = MEDIUM SEVERITY JOINT SPALL THEN:  
SA = AMZ PATCH  
DA = DO NOTHING  
IA = DRAINAGE ANALYSIS/DETAILED INSPECTION
- 10) IF PCI = 46 - 75 AND  
D = HIGH SEVERITY CORNER SPALL AND/OR  
D = MEDIUM SEVERITY CORNER SPALL THEN:  
SA = AMZ PATCH  
DA = DO NOTHING  
IA = DRAINAGE ANALYSIS/DETAILED INSPECTION
- 11) IF PCI = 46 - 75 AND  
D = LOW SEVERITY JOINT SPALL AND/OR  
D = LOW SEVERITY CORNER SPALL THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DRAINAGE ANALYSIS/DETAILED INSPECTION
- 12) IF PCI = 76 - 100 AND  
D = POPOUTS AND/OR  
D = SCALING AND/OR  
D = SEVERE LINEAR CRACKING AND/OR  
D = MEDIUM LINEAR CRACKING THEN:  
SA = RESURFACE  
DA = THIN OVERLAY  
IA = RESURFACING ANALYSIS/DETAILED INSPECTION
- 13) IF PCI = 46 - 75 AND  
D = POPOUTS AND/OR  
D = SCALING AND/OR  
D = SEVERE LINEAR CRACKING AND/OR  
D = MEDIUM LINEAR CRACKING THEN:  
SA = RESURFACE  
DA = THIN OVERLAY  
IA = RESURFACING ANALYSIS/DETAILED INSPECTION
- 14) IF PCI = 76 - 100 OR 46 - 75 AND  
D = SEVERE LINEAR CRACKING THEN:  
SA = REPLACE SLAB  
DA = RANDOM SAW AND SEAL  
IA = DETAILED INSPECTION/RECONSTRUCTION ANALYSIS

- 15) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = MEDIUM LINEAR CRACKING THEN:  
SA = RANDOM SAW AND SEAL CRACKS  
DA = AMZ PATCH ( IF POSSIBLE )  
IA = DETAILED INSPECTION/RECONSTRUCTION ANALYSIS
- 16) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW CRACKING THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DO NOTHING
- 17 ) IF PCI = 76 - 100 AND  
D = SEVERE D - CRACKING OR  
D = MEDIUM D - CRACKING THEN:  
SA = AC PATCH  
DA = DO NOTHING IF MEDIUM, HIGH SEVERITY MUST BE REPAIRED  
IA = DETAILED INSPECTION
- 18) IF PCI = 46 - 75 AND  
D = SEVERE D - CRACKING OR  
D = MEDIUM D - CRACKING THEN:  
SA = AC PATCH  
DA = DO NOTHING IF MEDIUM, HIGH SEVERITY MUST BE REPAIRED  
IA = DETAILED INSPECTION/RECONSTRUCTION ANALYSIS
- 19) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW D - CRACKING THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DO NOTHING
- 20) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = SEVERE DIVIDED SLAB OR  
D = MEDIUM DIVIDED SLAB THEN:  
SA = REPLACE SLAB  
DA = SAW AND SEAL CRACKS  
IA = DETAILED INSPECTION/RECONSTRUCTION ANALYSIS
- 21) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW DIVIDED SLAB THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DO NOTHING
- 22) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = SEVERE CORNER BREAK OR  
D = MEDIUM CORNER BREAK THEN:  
SA = CONCRETE PATCH  
DA = DO NOTHING IF MEDIUM, HIGH SEVERITY MUST BE FIXED  
IA = DETAILED INSPECTION

- 23) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW CORNER BREAK THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DO NOTHING
- 24) IF PCI = 76 - 100 AND  
D = POPOUTS THEN:  
SA = CONCRETE PATCH  
DA = THIN OVERLAY  
IA = NORMAL INSPECTION PROGRAM/RESURFACING ANALYSIS
- 25) IF PCI = 46 - 75 AND  
D = POPOUTS THEN:  
SA = OVERLAY  
DA = DO NOTHING  
IA = RESURFACING ANALYSIS
- 26) IF PCI = 76 - 100 AND  
D = SCALING THEN:  
SA = AMZ PATCH  
DA = DO NOTHING  
IA = NORMAL INSPECTION PROGRAM/RESURFACING ANALYSIS
- 27) IF PCI = 46 - 75 AND  
D = SCALING THEN:  
SA = AMZ PATCH  
DA = DO NOTHING  
IA = DO NOTHING
- 28) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = SEVERE FAULTING OR  
D = MEDIUM FAULTING THEN:  
SA = GRIND AND OVERLAY  
DA = DO NOTHING IF MEDIUM, HIGH SEVERITY MUST BE REPAIRED  
IA = DETAILED INSPECTION
- 29) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW FAULTING THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DO NOTHING
- 30) IF PCI = 76 - 100 AND  
D = SEVERE BLOW UP OR  
D = MEDIUM BLOW UP THEN:  
SA = REPLACE JOINT  
DA = AMZ PATCH  
IA = DETAILED INSPECTION

- 31) IF PCI = 46 - 75 AND  
D = SEVERE BLOW UP OR  
D = MEDIUM BLOW UP THEN:  
SA = AMZ PATCH  
DA = AMZ PATCH  
IA = DETAILED INSPECTION
- 32) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW BLOW UP THEN:  
SA = AMZ PATCH  
DA = DO NOTHING  
IA = DO NOTHING
- 33) IF PCI = 76 - 100 AND  
D = POLISHED AGGREGATE THEN:  
SA = GRIND & PATCH  
DA = DO NOTHING  
IA = DETAILED INSPECTION/RESURFACING ANALYSIS
- 34) IF PCI = 46 - 75 AND  
D = POLISHED AGGREGATE THEN:  
SA = GRIND & PATCH  
DA = DO NOTHING  
IA = DO NOTHING
- 35) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = HIGH PUNCHOUTS OR  
D = MEDIUM PUNCHOUTS THEN:  
SA = AMZ PATCH  
DA = AMZ PATCH  
IA = DETAILED INSPECTION
- 36) IF PCI = 76 - 100 OR 46 - 75 ( 45 - 100 ) AND  
D = LOW PUNCHOUT THEN:  
SA = DO NOTHING  
DA = DO NOTHING  
IA = DO NOTHING

In these rules:

D refers to distress

SA refers to standard activity

DA refers to deferral activity

IA refers to inspection activity

## APPENDIX B - QUESTIONNAIRE

## APPENDIX B - QUESTIONNAIRE

1 - If you had to divide PCI into three distinct ranges, and each range would include pavements in visibly different conditions, what would these ranges be ?

<i>RANGE #</i>	<i>RESPONSE 1</i>	<i>RESPONSE 2</i>	<i>RESPONSE 3</i>	<i>RESPONSE 4</i>	<i>RESPONSE 5</i>
<i>1</i>	<i>0 - 30</i>	<i>0 - 39</i>	<i>0 - 40</i>	<i>0 - 60</i>	<i>0 - 40</i>
<i>2</i>	<i>31 - 70</i>	<i>40 - 70</i>	<i>40 - 60</i>	<i>61 - 80</i>	<i>41 - 70</i>
<i>3</i>	<i>71 - 100</i>	<i>71 - 100</i>	<i>60 - 100</i>	<i>81 - 100</i>	<i>71 - 100</i>

2 - In what range of PCI would you suggest that preventative maintenance be the main goal?

*All responses had preventative maintenance as the primary goal in the highest PCI range.*

3 - In what range in PCI would you suggest that corrective maintenance be used ?

*All responses had corrective maintenance as the primary goal in the middle PCI range.*

4 - What maintenance activities would you characterize as preventative? as corrective?

### PREVENTATIVE REPAIRS

Joint/crack sealing  
 asphalt overlay  
 amz patching  
 undersealing  
 spall repairs- grinding  
 partial depth repairs

### CORRECTIVE REPAIRS

joint/slab repairs  
 thin asphalt overlay  
 asphalt patching  
 full depth repairs  
 microsurfacing  
 slab replacement

5 - Consider a pavement, where the PCI of which is in the highest range of the three ranges from question #1. What recurring distress /severity combinations would lead you to believe that the pavement had a drainage problem.? What would you recommend as a course of action , a maintenance treatment or an inspection?

<b>DISTRESS</b>	<b>REPAIRS</b>
lane / shoulder drop off	build up shoulders
pumping	underseal
joint/corner spalling	joint repairs
D - cracking	ensure drainage
scaling	ensure drainage
joint seal damage	joint/crack seal

6 - How often should these distress/ severity combinations occur in a pavement sample before either an inspection or a treatment is recommended?

*All responses explained that since the pavement is in the highest PCI category any instance of this should be repaired immediately.*

7 - Consider another pavement, in the middle PCI range. What recurring distress/severity combination would lead you to believe that this pavement had a drainage problem? What would you recommend as a course of action?, treatment or inspection?

*Responses were the same as number 5.*

8 - How often should this distress/severity combination occur in a pavement sample before either an inspection or a treatment is recommended?

*Responses were the same as number 6.*

9 - Consider a pavement in the highest PCI range. What recurring distress/severity combinations would lead you to believe that resurfacing was the proper next course of action?

*Responses were high joint-seal damage, high cracking, popouts, multiple patches and scaling.*

10 - How often should these distress/severity combinations occur in a pavement sample before resurfacing is recommended?

*Response was medium frequency. Only one of the participants answered this question.*

11 - Consider a pavement in the middle PCI range. What recurring distress/severity combinations would lead you to believe that resurfacing was the proper next course of action?

*Responses included joint spalling, faulting, cracking, patching and polished aggregate.*

12 - How often should these distress/ severity combinations occur in a pavement sample before resurfacing is recommended?

*Again only one participant answered this question. The response was medium frequency.*

13 - What background information is important to you when recommending a maintenance strategy for a pavement? Why?

*The types and degree of distresses, age of pavement, previous maintenance and adjacent maintenance projects.*

14 - Do you believe that knowing the composition of a PCI value would enable you to recommend better maintenance strategies?

*Responses were Yes, Yes , Yes and Maybe.*

15 - Of the 19 distresses that are observed to determine PCI, which of these would you characterize as being structural, surface, joint-related and general?

**STRUCTURAL**

corner break  
divided slab  
d - cracking  
linear cracking  
small patching  
large patching  
pumping  
punchout

**SURFACE**

polished aggregate  
popouts  
scaling/map cracking  
corner spalling

**JOINT RELATED**

blow up/buckling  
faulting  
joint seal damage  
joint spalling

**GENERAL**

lane/shldr dropoff  
railroad crossing  
shrinkage cracks

## APPENDIX C - MAJOR DISTRESSES AND THEIR CAUSES

## APPENDIX C -MAJOR DISTRESSES AND THEIR CAUSES

This section describes what are the major pavement distresses and their causes. The information contained in this section is derived from field work, interviews and the City of Winnipeg pavement inspection manual [13].

1 - Blow-Up: A blow-up or buckle, occurs due to expansion of a concrete pavement section. The blow-up will occur at a transverse crack or joint that has insufficient space for heat expansion. Expansion joints are put into pavement to prevent this. When joint seals fail and allow incompressible material to enter, this creates a situation prone to blow-up. A failed joint does not provide enough space for expansion pressure relief. This pressure then pushes against adjacent slabs. If the concrete is weak it will break and create a large hole at the joint. If the concrete is strong then both slabs can heave and cause a large rise in the pavement section at the joint. Blow-Ups can occur in varying severities, from what appears to be severe spalling to large holes that cause safety problems.

2 - Corner Break: Corner breaks consist of a crack that intersects the transverse and longitudinal joints at a distance of up to 50 percent of the slab width and length. This crack extends through the entire slab thickness. The cause of this distress is a loss of support under the slab. This happens due to moisture infiltration of the sub grade and subsequent reduction of the base/sub grade layer. Once the layer(s) under the corner of the pavement has been washed away the corner of the pavement can no longer resist loads due to traffic and dead weight.

3 - Divided Slab: This distress occurs when a slab is divided by cracks into four or more pieces. These cracks can be caused by overloading, freeze-thaw action, or moisture infiltration into existing cracks and joints. Once moisture infiltrates any crack or joint, it can wash away support material and cause cracking. Once the support layers have been reduced, the concrete is very susceptible to cracking. If the water in the cracks freezes, this forces the cracks open wider and the deterioration accelerates.

4 - Durability Cracking ( D Cracking ): This type of cracking appears close to joints and major cracks. It takes the form of small curved cracks running parallel to the major crack or joint. This happens because the concrete becomes saturated near the joint due to over-finishing or infiltration ( if joints have failed and no longer shed moisture ). The large aggregate in the concrete break down when they are exposed to moisture and freeze-thaw cycles. Once this progresses, it can lead to disintegration of large portions of the slab.

5 - Faulting: This is defined as a pronounced difference in elevation across a joint between adjacent slabs of concrete. A fault can occur for two reasons. First, settlement of the foundation. This occurs when sub-grades are improperly prepared ie., inadequate compaction, or when moisture infiltrates and softens or reduces the foundation. Once the moisture infiltrates, the load action on the slab can produce pumping. This is when the slab "rocks" back and forth, pumping out the liquefied material that was created when new moisture was added to the sub grade. After enough of the material is pumped out, the natural resting place of the slab is lower than the adjacent slab. Secondly, temperature and moisture differential changes can produce curling stresses in a slab of concrete. These

stresses cause the edges of a slab to curl downward. Unless the adjacent slab behaves similarly, a fault forms.

6 - Joint Seal Damage: Joint seal damage is damage that permits the infiltration of moisture, rocks or soil into the designed expansion joints. Joint seal damage includes stripping or extrusion of the joint sealant, growth of substantial vegetation into the joint, hardening of the sealant material, and loss of the bond to the slab edges. Any of these occurrences are detrimental to pavement performance. Once moisture can infiltrate the sub grade or incompressible material can infiltrate a joint, many different distresses may occur, including, distresses 1 through 5 in this list.

7 - Linear Cracking: This includes longitudinal, transverse and diagonal cracking. These cracks are caused by the same things that contribute to all the distresses listed above ( moisture infiltration, traffic loading and curling stresses ).

8 - Polished Aggregate: Polished aggregate is caused by traffic wear on the pavement surface. Stopping, starting and turning movements cause the most damage. After many traffic applications, the top portion of concrete is worn off and the exposed aggregate is worn smooth. This is caused simply by traffic and by over-finishing of the concrete. If the concrete is over-finished, there is more fine material and less coarse aggregate at the surface. Without the coarse aggregate, the fine material can not withstand repeated traffic loadings.

9 - Pop-outs: Pop-outs are caused by the same agents as D-cracking. Freeze thaw cycles and aggregate expansion combine to produce pop-outs. They appear as small cups or dips in the surface of the concrete. Insufficient air content in concrete can also cause pop-outs.

10 - Scaling ( Map Cracking ): These cracks appear as a network of shallow, fine cracks extending through the surface of the concrete. The cracks generally intersect at an angle of 120 degrees. If allowed to progress, this will lead to scaling of the entire surface of the pavement. Scaling can be caused by extensive use of de-icing salts, over- finishing of the concrete, freeze-thaw cycles and aggregate expansion.

11 - Shrinkage Cracks: Shrinkage cracks are hairline cracks which are 3 to 4 feet long but do not extend across the entire slab. These cracks are formed during the setting and curing stage of concrete, and are caused by differential thermal stresses.

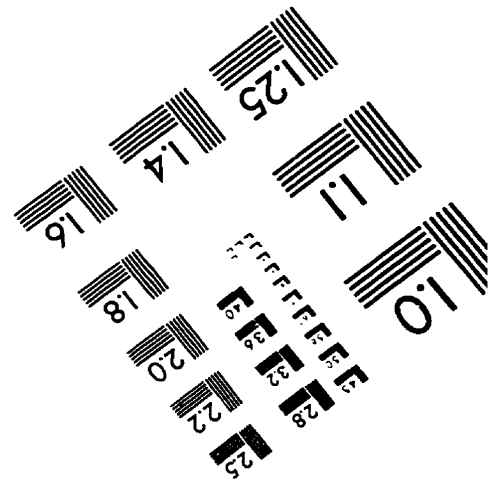
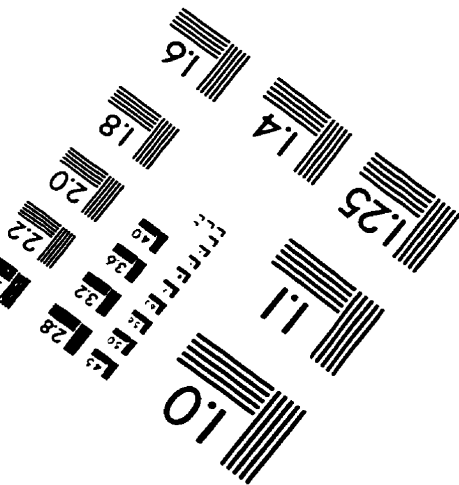
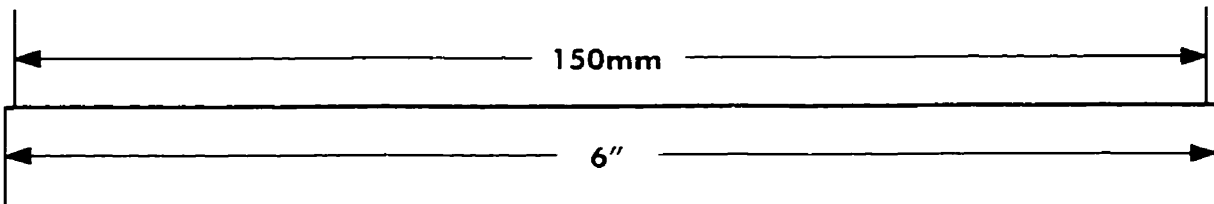
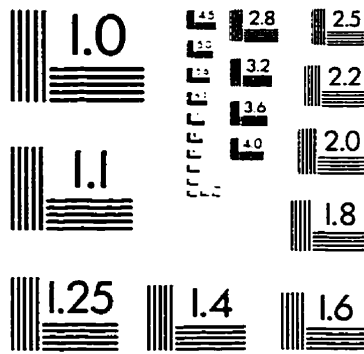
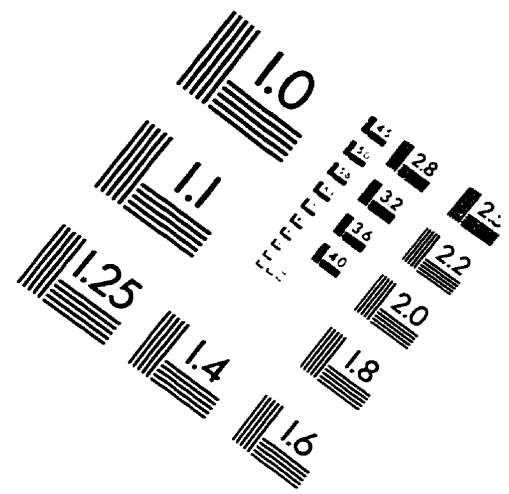
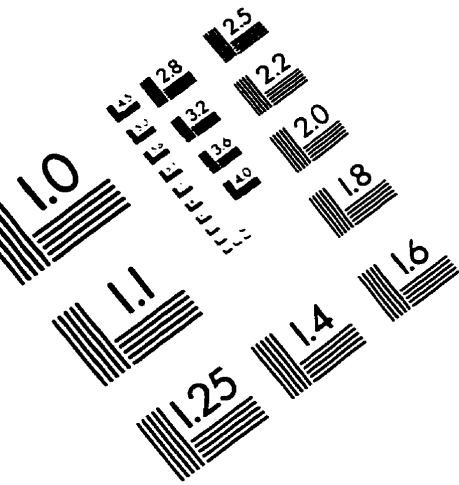
12 - Corner Spalling: This is defined as the breakdown of the slab near the corner. A corner spall has the same basic shape as a corner break. The difference is that the spall does not extend vertically through the slab but rather angles downward to intersect the joint. This slab breakdown is caused by exposure to moisture, freeze-thaw, and over-finishing of the concrete. Spalling can also occur at joints. The patterns are similar except that the spall travels along the joint and angles downward to it.

13 - Punch-outs: A localized area of the slab that is broken into pieces. Punch-outs are defined by a crack and a joint or two cracks, and are caused by heavy repeated loading, inadequate pavement structure, loss of foundation and material flaws in the concrete.

14 - Patching: Patches are the result of the repair of other distresses or utility cuts. If poorly constructed can lead to a severe pavement distress and loss of performance of the pavement.

15 - Railroad crossing: These are considered a distress as well. If poorly maintained can cause poor riding characteristics.

# IMAGE EVALUATION TEST TARGET (QA-3)



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