

**Development and Implementation of an Airfield Pavement Management  
System for the Winnipeg International Airport**

by

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A Thesis

Submitted to the Faculty of Graduate Studies in Partial Fulfillment of the Requirements  
for the Degree of

**Master of Science**

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## **ABSTRACT**

A Pavement Management System (PMS) is a tool that aids in determining the most effective application of maintenance and reconstruction (M&R) work for a given pavement network. The purpose of this research is the development and implementation of an Airfield Pavement Management System for the Winnipeg International Airport (WIA) that expands on the capabilities and usefulness of conventional systems.

The system developed in this research utilizes geo-referenced pavement distress data collected using a GPS receiver. Time required to complete Pavement Condition Index surveys has been reduced, minimizing the impact on airport operations of conducting an airfield inspection. Using geo-referenced distress data leads to a multitude of new analysis techniques that allow for optimum management of the pavement network.

Several pavement deterioration models have been created using the collected pavement condition data. These models aim to predict pavement condition at points in the future to aid in M&R planning. Models were created using the least-squares regression technique as well as neural network modelling. The use of neural networks appears promising as they are not constrained to a single regression parameter and can account for the interaction between parameters and nonlinear relationships.

The WIA PMS represents a significant improvement to the functionality of current PMSs by expanding the analysis and modelling capabilities while reducing the effort associated with data collection.

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## LIST OF ACRONYMS

AASHO	American Association of State Highway Officials
AC	Asphalt Concrete
ACN	Aircraft Classification Number
AMS	Asset Management System
ANN	Artificial Neural Network
APMS	Airfield Pavement Management System
ASTM	American Society for Testing of Materials
CAPTG	Canadian Airfield Pavement Technical Group
FAA	Federal Aviation Administration
FOD	Foreign Object Damage
GIS	Geographic Information System
GPS	Global Positioning System
HWD	Heavy Weight Deflectometer
IRI	International Roughness Index
M&R	Maintenance and Rehabilitation
MSE	Mean Squared Error
NCHRP	National Co-operative Highway Research Program
NN	Neural Network
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
PCN	Pavement Classification Number
PMS	Pavement Management System
UTM	Universal Transverse Mercator Grid
WAA	Winnipeg Airports Authority
WIA	Winnipeg International Airport

## Chapter 1

### INTRODUCTION

A Pavement Management System (PMS) is a tool that can aid in determining the most effective application of maintenance and reconstruction (M&R) work for a given network. Airfield Pavement Systems (APMS), which deal specifically with airfield pavements are the focus of this research. Airport authorities, like highway agencies are tasked with the job of managing infrastructure networks worth millions of dollars. Budget cutbacks, shortfalls and changing priorities over several decades have led to rapidly increasing infrastructure deficits, driving agencies to find better approaches to infrastructure management. A properly designed and implemented PMS will assist an agency in making the best use of the money available for maintenance and rehabilitation by providing the ability to monitor existing performance and predict the condition of the network at points in the future.

A major driving factor behind widespread PMS implementation in the United States was legislation. Public Law 103-305, which was passed in 1994, requires state aviation agencies to have a PMS in place as a condition for receiving public funding. In Canada, airport authorities that operate the larger commercial facilities receive no ongoing federal funding for infrastructure maintenance and rehabilitation, and as such the implementation of PMSs has not proceeded as rapidly. Another factor affecting not only the implementation, but also the updating of a PMS is the time consuming nature of pavement condition inspections. Although airfields are small in comparison to provincial

highway networks, gaining access to critical areas such as busy runways or taxiways at an airfield with 24-hour operations is a major issue.

### **1.1 Research Objectives**

The focus of this research is the development and implementation of a network level Airfield Pavement Management System (APMS) for the WIA with the following objectives:

- Minimize impact of PMS implementation on airport operations
- Integrate construction history and pavement cross-section data collected by WAA and Transport Canada
- Optimize collection of pavement distress information
- Utilize GIS and GPS technologies during data collection and analysis stages
- Address problems and concerns raised regarding industry standard Pavement Condition Index inspection
- Develop deterioration models for the WIA pavement

To accomplish these objectives a partnership was formed with the Winnipeg Airports Authority (WAA) that allowed access to the WIA's facilities and resources.

## 1.2 Background

The Winnipeg International Airport dates back to the Stevenson Aerodrome, which was opened in May 1928. By 1938, there were 3 hard surfaced runways each measuring 960m in length. Continuing to grow and expand, the facility was officially named the Winnipeg International Airport in 1958 at the request of the Department of Transport ([www.waa.ca](http://www.waa.ca)). To this day, infrastructure created in the 1940s, 50s and 60s provides the base for a great deal of the airfield. After decommissioning a small portion of the airfield in 2005 to make way for the new terminal building, today's WIA is comprised of 2 runways, 12 taxiways and 7 aprons with a total area approaching 1 million square metres and it serves over 3 million passengers and over 149000 tonnes of cargo per year ([www.waa.ca](http://www.waa.ca)). The Canadian Air Force also routinely uses the facilities of the WIA as 17 Wing Winnipeg is located adjacent to the airport property. 17 Wing operates their own apron and two taxiways, but uses the runways and taxiways of the WIA to conduct their operations.

A facility the size of the WIA needs to track the performance of its airfield in such a manner that will allow it to optimize, in terms of both cost and condition improvement, the timing of maintenance and rehabilitation (M&R) work. A PMS provides a tool for this purpose and through its implementation and continual updating can be used to build a knowledgebase of effective treatments and triggers for M&R work.

### **1.3 Organization of Thesis**

The thesis has been organized as follows:

#### **Chapter 2: Literature Review**

A review of current and past work on pavement management systems with particular attention paid to airfields. A definition of a PMS is provided along with descriptions of the basic components common to all systems. Pavement condition assessment and deterioration models, two critical components are investigated thoroughly. Experiences with different types of automated collection techniques, the integration of GIS and GPS into pavement management and other advances to the state-of-the-art are also presented.

#### **Chapter 3: WIA Pavement Management System Development and Implementation**

This chapter details the components of the WIA system. A description of the work involved with developing and implementing the new system is presented. The software and equipment that were used are described as well as the pavement inspection procedures that were followed. This chapter also includes the results of an environmental scan that was conducted to assess the extent of PMS implementation at Canadian airfields.

#### **Chapter 4: Results of 2005 Pavement Condition Survey**

Chapter 4 presents the results of the initial Pavement Condition Index (PCI) inspections completed during 2005. These inspections were completed using a new method for locating, collecting and storing pavement distress information developed as part of this research. Several Condition maps, as well as the experiences encountered using the new

procedures included are included. Pavement distress information is also analyzed to assess the foreign object damage (FOD) potential of each pavement section.

### **Chapter 5: Pavement Deterioration Modelling**

Data obtained during the 2005 condition surveys forms the baseline conditions for deterioration models used to predict future pavement performance. Several pavement deterioration models were created using the constrained least squares regression modelling technique. Alternative modelling techniques were explored leading to the creation of Advanced Neural Network (ANN) models based on the 2005 PCI data. A comparison of the two modelling techniques is included. Finally, an investigation into the applicability of using deterioration models created for other airfields to model the condition of the Winnipeg airfield pavement was conducted.

### **Chapter 6: Results and Discussions**

A discussion of the major findings and results of this research are presented in Chapter 6. The unique aspects of airfield pavement management systems in general, as well as the system that was developed for the Winnipeg International Airport are presented. Experiences gained during the development and implementation of the WIA system are presented followed by a summary of the results of the analysis and modelling stages. Finally recommendations and guidance for further implementation and expansion of the WIA system are discussed.



## **Chapter 7: Conclusions and Recommendations**

Chapter 7 contains a summary of the project and the conclusions of this thesis as they relate to the original objectives. Also included are recommendations for future research on development and implementation of pavement management systems at Canadian airports.

## Chapter 2

# LITURATURE REVIEW

### 2.1 Background

The field of pavement management evolved as highway agencies emerged from the road building boom of the 1950s and 60s that saw the creation of the interstate system in the United States. As budgets became tighter, and the network was not expanding at the same rate, the focus shifted to preserving the existing network. Systems theory was first introduced into pavement engineering in the 1970s (Haas 94) and the term pavement management system (PMS) first started to appear in the late 1960s and early 70s and encompassed all the activities involved in “providing pavements” (Haas 78).

Early pavement management systems consisted of little more than a database of inventory and condition data. Condition data usually was based on subjective ratings such as the present serviceability index (PSI) developed at the AASHO Road Test (HRB 62). The systems employed simple data processing techniques to evaluate and rank rehabilitation projects on present condition (Kuklarni 03). This usually led to the ‘worst first’ approach, since future pavement condition or the application of maintenance at differing times in the life cycle was not considered. Today’s systems on the other hand, are used to predict future pavement condition and determine optimum allocation of limited financial resources. They employ objective condition indices that reduce or eliminate the subjective nature of past systems.

## 2.2 Components of a Pavement Management System

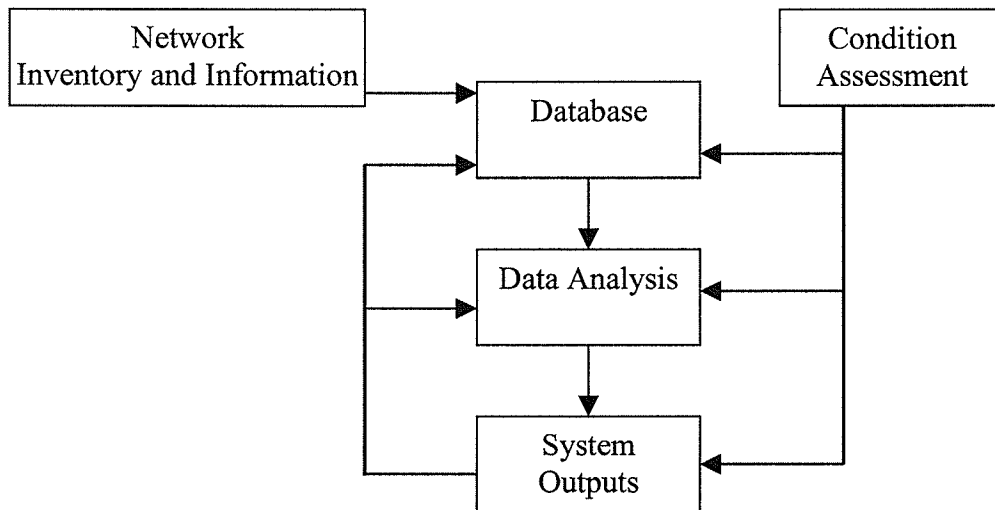
There are many possible definitions of a pavement management system, and nearly as many miss-conceptions about the potential uses for such a system. Some people feel that PMS is simply a collection of ‘buzz words’ strung together to garner attention, while others feel a PMS is the “panacea for all pavement problems” (Haas 94). Of course, both of these opinions are false. A PMS can be defined as follows:

“A pavement management system provides a consistent objective and systematic procedure for setting priorities and schedules, allocating resources, and budgeting for pavement maintenance and rehabilitation. It can also quantify information and provide specific recommendations for actions required to maintain a pavement network at an acceptable level of service while minimizing the cost of maintenance and rehabilitation.” (FAA 88)

The definition of a PMS can be further supplemented depending on its intended use as both network and project level systems exist. Network level pavement management is broad in nature, and focuses on creating the most effective use of budgetary resources for an entire network. Whereas project level management is concerned with evaluating several alternatives for specific projects identified as priorities by the network level system. The main difference between the two levels is their size and detail of information. Project level systems provide detailed information (often providing a 100% pavement inspection rate) about a single project, and network level systems provide a general condition report for the entire pavement network by sampling only a small

portion of each section. Some PMSs employ a third level in the hierarchy referred to as the “Project Selection” level (Haas 94). Most of the time however, the project selection is completed as part of a network level analysis.

To achieve the functions described in the definition above, every PMS utilizes the same basic components. Figure 2.1 shows these basic components and how they relate to each other.



**Figure 2.1: Components of a Pavement Management System**

The first component necessary for a PMS is the network inventory. All information regarding the pavement construction history, traffic, environment, maintenance, and past condition data is collected, compiled and stored in the database. This work, while very time consuming, is crucial as it forms the foundation of the PMS (Brotten 98). For

example, incorrect or unreliable information regarding pavement age, leads to erroneous outputs from pavement condition prediction models that are created using this data.

Another important element of a PMS is the pavement condition assessment. This information is used to create deterioration models for predicting future pavement condition and also provides useful data on current pavement needs. The different options available for pavement condition assessment are discussed latter in this chapter.

A database is used to house the volumes of information that are a part of a modern PMS. Historically this information might have been stored on paper-forms or keyed manually on an electronic form. This is no longer possible or practical with the volume of data present in today's systems. The database must be flexible enough to accommodate varying user queries and present the data in a format that is easy to understand. The ability to add new variables of interest, or easily change the network inventory information is also important.

The data analysis and system output stages will vary depending on if a project level or a network level analysis is desired. Data analysis at the network level produces such deliverables as the network condition at the time of last inspection, condition forecasting, and budget forecasting for the network needs (Shahin 94). At the project level, the analysis generally focuses on the evaluation of several alternatives for a project that has been identified through a network level assessment.

The final component of a PMS is the system outputs, which deliver the desired information about the pavement network to the user. Numerous outputs from a PMS are possible. Traditionally graphs, charts, and tables were produced, but modern PMSs are utilizing geographical information systems (GIS) to add a geo-referenced graphical component to the output. A further description of the uses for GIS in a PMS will follow later in this chapter. The data generated during the system output stage is inputted back into the system as historical information completing the cycle illustrated in Figure 2.1.

### **2.3 Pavement Condition Assessment**

Information regarding the present condition of the network pavement is critical to the functioning of a PMS. Without condition data, a PMS would be little more than an electronic version of a pavement inventory binder. Pavement condition assessments vary from a simple drive by of a pavement section to detailed measurement of every distress observed. The most widely implemented type of assessment involves the quantification (extent and severity) of surface distresses. This section will summarize the benefits and disadvantages of different condition assessment methods, both past and present.

In the past, agencies used a panel of experts to rate the condition of their pavements. One example of this type of system was the Pavement Quality Index (PQI), developed in Alberta in the early 1980s (Karan 83). In this system, two vehicles containing 4 raters each would travel the sections being studied, while recording values (scale of 0 to 10) for the Riding Comfort Index (RCI), Structural Adequacy Index (SAI), and Surface Distress

Index (SDI). These values were then combined together to create the PQI value (Haas 94). Analysis of variance techniques have been used to show that the only significant source of variation was due to the sections (which was to be expected) and not due to factors related to the raters (Haas 94). However, using expert opinion is still very subjective since it is not based on any measured quantities of distress. These tests also require the time of 8 experienced pavement engineers to act as the raters.

The advantages of this system are the speed at which it allows the surveys to be completed, and it is safer for the raters as they do not exit the vehicle. Both of these advantages are of great importance to highway agencies that have vast networks to inspect, usually while the roads are open to traffic.

Expert opinion can also vary depending on the qualifications of the expert. In an airport setting, the primary users of the facility are pilots, who are experts in the safe operation of their planes. One study of particular interest found that a group of pavement engineers ranked the importance of certain distresses differently than a group of pilots (Gadallah 00). This finding is important because it shows that where pavement engineers are focused more on the structural integrity (how long will the pavement last) of a pavement, the pilots (primary users) are focused more on the functional integrity (how safe is this pavement). An important distinction exists between highway pavements and airfield pavements in this regard. Airfield users expect a much higher degree of attention be paid to distresses that pose a Foreign Object Damage (FOD) potential than do highway users. FOD is defined as “a substance, debris, or article alien to a vehicle or system which

would potentially cause damage," according to the National Aerospace FOD Prevention Inc. (NAFPI) a group of aerospace professionals dedicated to the elimination of FOD. It is estimated that FOD costs about \$4 billion annually in aircraft repairs. Distresses that pose a FOD potential are easier to detect during surveys that require evaluators to walk the pavement. Engineers must take this into account when deciding which pavement condition assessment method to implement in an airport setting.

To eliminate the subjective nature of the expert opinion inspections, it is desirable to use a condition assessment that is based on measured distress quantities. The most common distress survey used by airport agencies in North America is the Pavement Condition Index (PCI). Developed by the US Army Corps of Engineers, PCI has gained widespread acceptance and is recommended by Federal Aviation Administration and the American Public Works Association (Shahin 94). Detailed procedures for completing a PCI test on both Concrete and Asphalt surfaced pavements will be contained in Chapter 3.

There are several advantages of using the PCI, the primary of which is the repeatability and non-subjective nature of the inspection. ASTM D5340 details how each distress is to be measured and recorded, leaving little room for subjective opinion. This allows agencies to compare PCI values from different facilities even if collected by different inspection crews and in different years. Another advantage is that a PCI inspection does not require the mobilization of large teams of experienced pavement engineers as with the previously described panel tests.



There are some disadvantages associated with the PCI test that have been identified over the years. A thorough description of the limitations and potential misapplications of the PCI test was completed by Broten and De Sombre in 2001 (Broten 01). A summary of some findings from that paper are presented here:

- The way longitudinal and transverse cracks are evaluated in AC pavements allows for cracks greater in 3” in width to be classified as low severity if these cracks are sealed and the sealant is in good condition. FAA regulations on the other hand require such cracks be repaired immediately.
- Difficult to prepare maintenance programs using PCI data due to the manner in which PCI is calculated and reported for both PCC and AC sections. For PCC pavements, results are reported on a section-by-section basis, where repairs are usually done on a slab-by-slab basis. For AC pavements, no distinction is made between narrow unsealed cracks and sealed cracks in good condition, which does not allow for easy computation of quantity required for joint sealing program.
- The method of computing PCI values for a pavement section can produce misleading results unless sample unit values are consistently sized. Meaning the average section PCI is calculated from the average of the sample unit PCI values (not weighted).

Similar to the previously mentioned findings (Broten 01) a study by McNerney and Harrison (McNerney 98) identified some potential areas of improvement for the PCI inspection procedure. One main drawback they identified was lack of distress location information. Since the PCI tests only reports results at the section level (Chapter 3

contains a description of the classification levels in a PCI based PMS), information regarding the exact location of individual distresses is not collected. The focus of this research will be the implementation of a PMS that utilizes the PCI while addressing the limitations and concerns identified regarding this procedure.

Other indices can also be compiled from the distress data collected during pavement inspections. As mentioned earlier, FOD is of great concern in the airport environment, giving rise to the creation of the FOD potential index. This index is a representation of the distresses most likely to cause FOD and is compiled using some of the distresses from the PCI survey (Shahin 04).

As the PCI deals only with visible surface distresses, many agencies collect additional information about their network as part of a PMS. Several non-destructive tests (NDT) are possible and can assist in giving a better picture of the overall condition of the airfield pavement. Deflection testing using machines like the Heavy Weight Deflectometer (HWD) can assess the structural condition of an in-service pavement (Shahin 94). The HWD data can also assist in determining the Pavement Classification Number (PCN) which is used by many airfields to represent the structural capacity of a given pavement (Shahin 04).

Runway friction is also a very important measure of safety that many airport agencies evaluate on a regular basis. Friction is measured using Continuous Friction Measurement (CFM) devices. Although many different types of CFM devices exist, the basic principle

is the same. They work by having a wheel of some sort constantly in contact with the pavement providing a continual friction measurement. The use of friction index measurements is much more widespread amongst the airfield community than on streets and highways. On the other end of the spectrum, many more highway agencies collect roughness data (using the International Roughness Index) than do airport agencies. Do in part to a shift in the user's priorities, but also the lack of an appropriate method for reporting roughness. The IRI is based upon the Quarter-Car simulation (Shahin 94), which does not accurately model the range of stiffness, speeds, and axle spacing of aircrafts travelling the same section.

#### **2.4 Pavement Deterioration Models**

Several methods of collecting and presenting information regarding pavement condition have been presented. Regardless of what index or property is measured however, one thing stays certain, without intervention (maintenance/repair), the condition of a pavement will deteriorate with time. Variables such as age, along with traffic, weather, construction quality, and use affect the rate of deterioration and as such there is no simple relationship for forecasting a pavements life. At the heart of any pavement management system exists models used to predict the future deterioration of the pavement. Pavement deterioration models are what allow PMSs to function. Without information about future pavement condition it is not possible to know the optimal application time for M&R work. The concept of a pavement deterioration model is presented in Figure 2.2.