

**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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Winnipeg, Manitoba

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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). 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). 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.

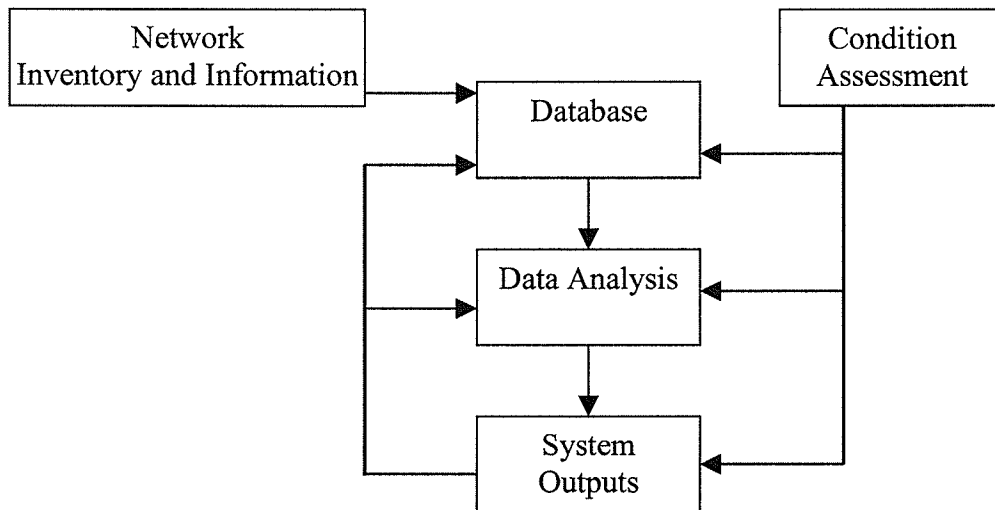


Figure 2.1: Components of a Pavement Management System

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).

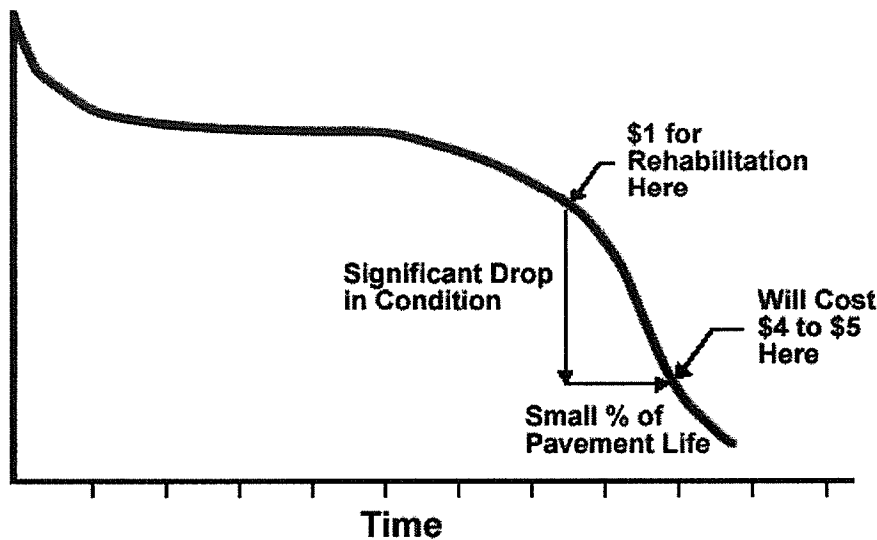
As the PCI deals only with visible surface distresses, many agencies collect additional information about their network as part of a PMS. Several non-destructive tests (NDT) are possible and can assist in giving a better picture of the overall condition of the airfield pavement. Deflection testing using 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.



Source: <http://www.cecer.army.mil/paver/>

FIGURE 2.2: Sample Pavement Deterioration Model

An example of how pavement deterioration models are used is contained in Figure 2.2. In this case if the rehabilitation is undertaken while the pavement is still in the “Fair” condition state it will only cost \$1, but if the pavement is allowed to deteriorate to the “Serious” condition state the cost of rehabilitation will now be 4 to 5 times as much. The determination of where the accelerated deterioration will begin is the main objective of pavement deterioration models.

There are numerous types of pavement condition models available. These include straight-line extrapolation, regression (empirical), mechanistic empirical, polynomial least square, probability distribution, Markovian, and neural network models. Obviously the most simplistic model would be straight-line extrapolation, used when only limited

information regarding the rate of deterioration is available. This technique is not very accurate and should be used for predicting only short periods into the future (Shahin 94).

2.4.1 Regression Models

Regression models can be used to create empirical relationships between observed variables. The most basic model would be linear regression between two variables (Shahin 94). Purely mechanistic models are not used, as primary response variables (stress, strain) are not used as a measure of pavement condition (Haas 94). However, mechanistic variables such as strain can be used as input variables for regression models creating mechanistic-empirical models (Shahin 94).

A polynomial constrained least squares regression model is a very useful model for predicting pavement condition due to the effect of one variable (Shahin 94). These models fit polynomials to predict the values of Y (PCI or other condition assessment) as a function of x (age, traffic, etc) by using the least squares technique. To make the models more effective at modelling real world behaviour, constraints are often placed on them. For example, when using the PCI as the measure of distress, a value greater than 100 is not possible, yet an unconstrained model might very well predict a value greater than 100. In order to minimize the least squares error; the model might also predict an increase in condition with age, something that will not typically be seen in the field (without maintenance work). Figure 2.3 shows the difference between constrained and unconstrained models created from the same data set.

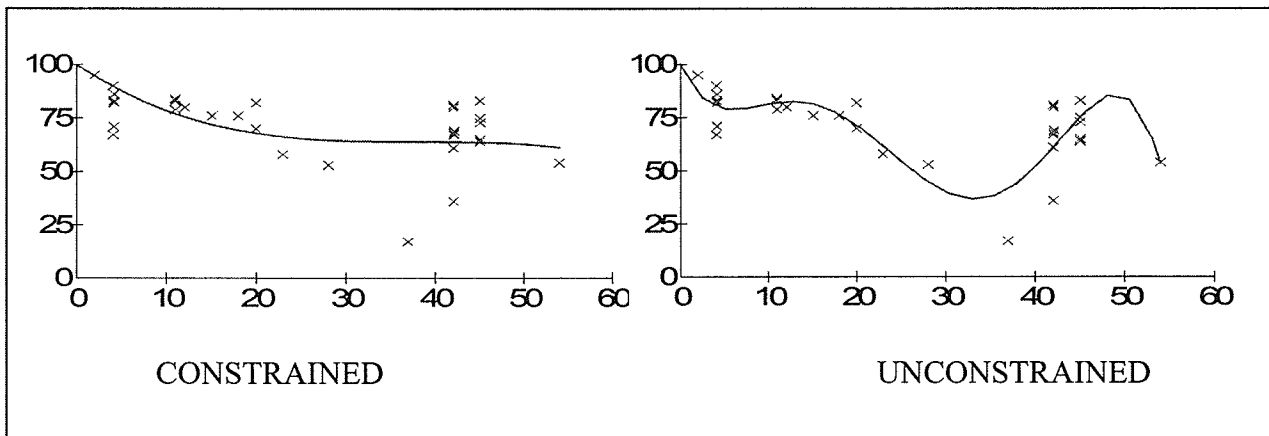


Figure 2.3: Constrained vs. Unconstrained Deterioration Models

Pavement performance is clearly affected by more than one variable, which might lead some to suggest the constrained polynomial method is therefore not practical for modelling pavement deterioration. To overcome this obstacle, the Family Method has been proposed (Shahin 94). This method works by clustering similar pavement sections together, eliminating the need to use their common variables in a prediction model. Families can be created for numerous variables including use, surface type, location, last construction date, rank and PCI (Shahin 94). This model allows for subsets of data for which condition vs. age models can be generated. Using the family technique, it is possible to create deterioration models with as little as one year of inspection data (at the network level). If all the sections grouped together to form a family are the same age (time since last construction date) this technique will not work. The reason for this is that all the points would be the same x value on a plot, not allowing a model to be calculated from the data.

2.4.2 Probability Distribution

Probability distribution can also be used to model a pavement condition measure such as PCI or IRI. The purpose of a probability distribution model is to find the probabilities associated with each of the values of a random variable. Since this technique requires knowledge of the statistical distribution for the variable or condition in question it is recommended that it only be used for individual distress prediction (i.e. Joint Spalling, not PCI) (Shahin 94).

2.4.3 Markovian Modelling

Markovian models divide a variable (PCI, IRI) into discrete condition states, and function by determining the probabilities that a pavement in a given condition state will move to another condition state (Shahin 94). One particular advantage of Markovian models is that an improvement in condition can be forecast (increase in PCI) thereby modelling the effect of maintenance works (Abaza 04). Using matrices of present condition states and probability matrices that predict the chances a pavement in each state will improve, decrease or remain in the same condition state, pavement performance can be quite accurately modelled. Obviously a great deal of work is involved with calculating the probability matrix, and large models with numerous condition states (especially ones that allow the possibility of increasing condition) can become quite complex (Abaza 04). An example of a Markovian model is presented in Figure 2.4. The example network contains only 3 condition states (Good, Fair, Poor) but does contain probabilities of pavement sections improving in condition.

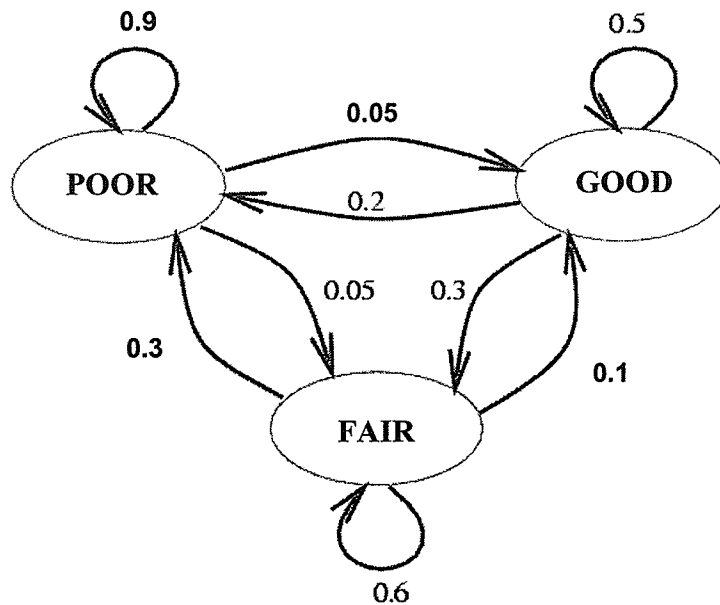


Figure 2.4: Example Markovian Model

2.4.4 Neural Networks

Modelling pavement deterioration is not a simple task, as no straight forward relationship exists between inputs (age, traffic, and environment) and pavement performance. This has led to the study of Artificial Neural Networks (ANNs) as a tool for modelling pavement performance. Neural networks are modelled on the current understanding of the brain, although on a much lesser complexity (Shekharan 00). An ANN is ‘trained’ to ‘learn’ the relationship between a set of given inputs and outputs. The benefit of ANNs is that the relationship between the inputs and outputs, which is often complex, does not have to be known before the modelling stage is begun (Shekharan 00). The typical structure of an ANN contains input, hidden and output layers, and is presented in Figure 2.5.

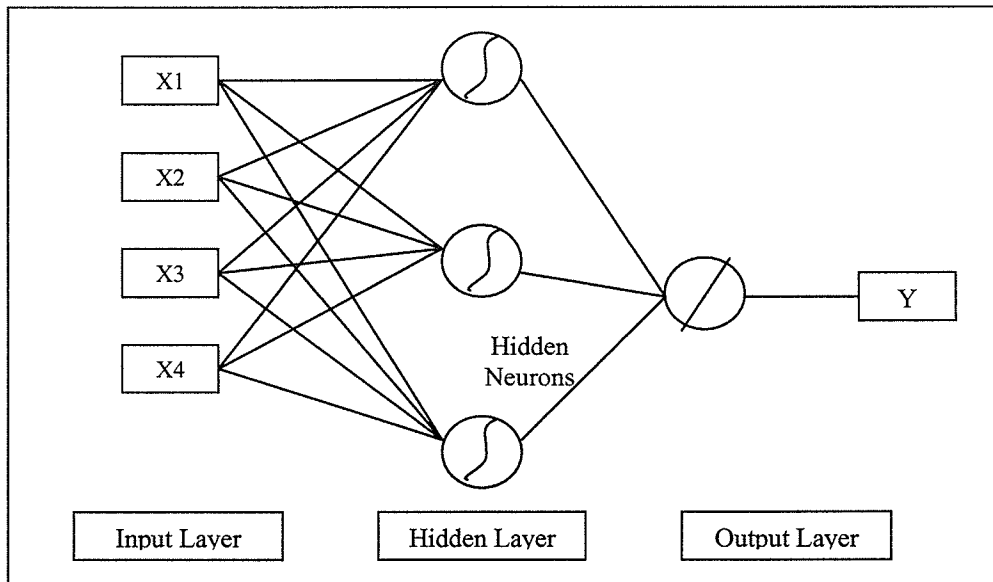


Figure 2.5: Typical Neural Network Architecture

Each layer consists of nodes, or neurons that function like biological neurons in the brain, they receive stimuli (input), process the signal, and deliver a response (output). Different weights and biases are assigned to the links between the neurons. These weights affect how the data is processed between the layers. The detailed workings of ANNs are much more complex than what is described here and beyond the scope of this research, but a general idea has been given. Research has been completed into the applicability of using ANNs in place of other more traditional pavement deterioration modelling techniques. This work has shown that ANNs are better at predicting pavement deterioration than regression techniques (Shekharan 00). Another study explored using different types of ANNs for predicting IRI based on several input variables, and showed that certain forms of ANNs produced better results than others (Roberts 98).

Use of neural networks looks promising, especially for agencies with large amounts of historical condition data available for modelling. If there is not enough data available to create both a training sub-set and validation sub-set, the possibility exists that the ANN will simply memorize the data set and be ineffective at predicting responses not present in the original data.

2.5 Advances and Future Trends

Pavement management systems have evolved considerably over the years and with further investment in research and development will continue to do so. New methods of collecting, storing and analyzing pavement condition data are being developed. Other advances are making the output of PMSs easier to understand by staff outside the engineering realm. This is an extremely important enhancement as the decision to fund the implementation and continual upkeep of a PMS often rests with senior non-engineering staff.

The use of automated data collection technology is of great interest to many agencies. Provincial highway departments are especially interested in utilizing these technologies as their networks cover vast regions with thousands of lane kilometres worth of data to collect. While the ability of automated systems to collect roughness and rutting data while travelling at highway speeds has been demonstrated, many airport agencies have not yet adopted this technology (Wang 02). One reason is that the cost of these surveys on such small network (in comparison to a highway network) makes them less attractive

than manual surveys. The main reason for the lack of implementation is the inability of these vehicles to collect information that would allow the calculation of PCI values (Wang 02). As explained earlier, PCI is the preferred method for reporting airport pavement condition in North America and agencies are not likely to abandon this practice. Research into using automated survey data to calculate a PCI value was completed but researchers were unable to capture all distress types listed in ASTM D5340 using automated equipment (Wang 02). If in the future this technology can be demonstrated to reliably calculate a PCI value its use amongst the airport community would certainly grow.

Incorporating GIS into pavement management systems has been occurring rapidly for the last 10 years and is greatly expanding their capability (McNerney 98, Lee 04, and Hede 01). The ability to store location-referenced information about the pavement in graphical form is making PMSs more user-friendly. Retrieving information regarding construction history of a particular section of pavement is now as easy as clicking on that section in a map. GIS based systems also allow for a myriad of graphical outputs to be created from the PMS data. As previously mentioned, this helps to sell the concept of a PMS to senior executives. Whereas engineers might be used to reading and interpreting tables, lists and graphs, non-engineering staff usually find a map or picture easier to understand. A study of US airport executives in 1999 showed that over 60% were using (or had planned implementation within 3 years) GIS for such things as infrastructure management, environmental analysis and airport operations (McNerney 00).

Use of GIS amongst state DOTs is also widespread. A 2004 study indicated that 60% used GIS to support their pavement management activities (NCHRP 04). Several of the remaining agencies have implemented GIS, but reported only using it for map generation. One interesting finding of this study was that despite widespread use, only a small percentage were using the full spatial analysis tools available in a GIS based platform. One reason for this is that some have questioned if the expense (monetary and time) involved with fully implementing/utilizing the spatial analysis tools is worth the effort. Reports from two of the states that have developed such systems (Florida and Illinois) indicate that within 5-7 years the “estimated efficiency and effectiveness benefits clearly outweighed the costs” (NCHRP 04).

Building on the successful incorporation of GIS into PMSs, the use of global positioning system (GPS) technology is now being researched as part of a “state-of-the-art” system (McNerney 00). Using a GPS receiver, distress location information can be stored along with the standard extent and severity values. The distress information collected in the field is then transferred to the GIS system allowing for individual distress maps to be created. The time required to complete field inspections is also expected to be much less using this type of system, as the need for traditional paper forms is eliminated (McNerney 00, Huang 04).

Pavement management systems provide valuable information to many levels of an organization. GIS based systems, supplemented with more data than just the PCI values can provide some added capabilities that increase their usefulness. Examples include

maintenance crews sealing cracks identified during a GPS survey to management viewing the latest condition maps giving them a complete visual of the airports condition. In the past this might have required each person to have the appropriate software on their computer, and the knowledge how to use that software. One recent development that addresses this problem is the creation of web-based PMSs. Highway agencies wishing to share information with regional offices and regional aviation authorities can all benefit from the connectivity of a web-based system. A case study in Oklahoma showed that through the implementation of a web-based PMS for the 88 general aviation airports, they were able to drastically increase efficiency (Mooney 05). Efficiency in this case is measured as the ratio of management costs to airport funding, which was cut by over 50%. Even within a single facility, the potential for such a system is immense. For example, maintenance crews could log onto the system from their vehicles (equipped with wireless internet access and a GPS receiver) and locate distresses that require immediate attention, or update the system as they complete repairs. Currently, this type of small repair would likely go untracked as no record of its location is kept.

The term integrated, or enhanced is being applied to pavement management systems that employ many of the enhancements mentioned in this section (Hede 01). These systems supplement standard surface distress information (PCI) with a range of additional objective measurements (structural, friction, and roughness). This allows for a more complete reporting of the pavement condition, as three condition indices (structural index, frictional index, and surface distress index) are used (Hede 01). To store, analyze and

display this information, these integrated systems make extensive use of GIS software and GPS technology.

2.6 Summary

Pavement management systems have evolved considerably from the initial systems developed in the early 1970s to the systems being implemented by agencies today. The major components of a standard PMS were described in this chapter, along with descriptions of several types of pavement condition inspections and pavement deterioration models. The latest advances being made in the field of pavement management were also described.

The focus of this research is on creating and implementing an APMS that expands on the works presented in this chapter. Limitations identified regarding the most widely used pavement condition procedure, the PCI, are addressed in the newly developed system. In addition much work went into the extensive integration of GPS and GIS technologies into the APMS. Finally deterioration models were created using two of the methods described in this chapter, the Family modelling technique and Neural Network modelling.

Chapter 3

WIA PAVEMENT MANAGEMENT SYSTEM DEVELOPMENT AND IMPLEMENTATION

Prior to this project the Winnipeg International Airport did not have a PMS. Pavement inspections were not based on measurable distresses and most often decisions on which sections to repair or replace were based on the opinion of the senior airfield engineer. This situation is far from ideal, as without the extensive knowledge of the airfield engineer the airport would have no basis for decision-making.

Before a proper PMS can be implemented, an organization needs to determine what deliverables and features the system should be capable of. Pavement management systems vary from one agency to the next and have many different features as discussed in Chapter 2. This chapter will deal with the work that went into taking the WIA airfield pavement management system from the conception stage to completion of the initial pavement condition inspections.

3.1 Site Description

The Winnipeg International Airport has evolved greatly since its inception in 1928. Today the airport has 2 runways, 18-36 at 3350 m and 13-31 at 2650 m in length. Airfield operations are carried out on 7 aprons connected to the runways through a system of 14 taxiways. Connected to the passenger terminal, Apron 1 is the main apron

on the airfield, with the remainder of the aprons being used for cargo, general aviation, de-icing, and maintenance operations. Figure 3.1 contains a labelled site plan.

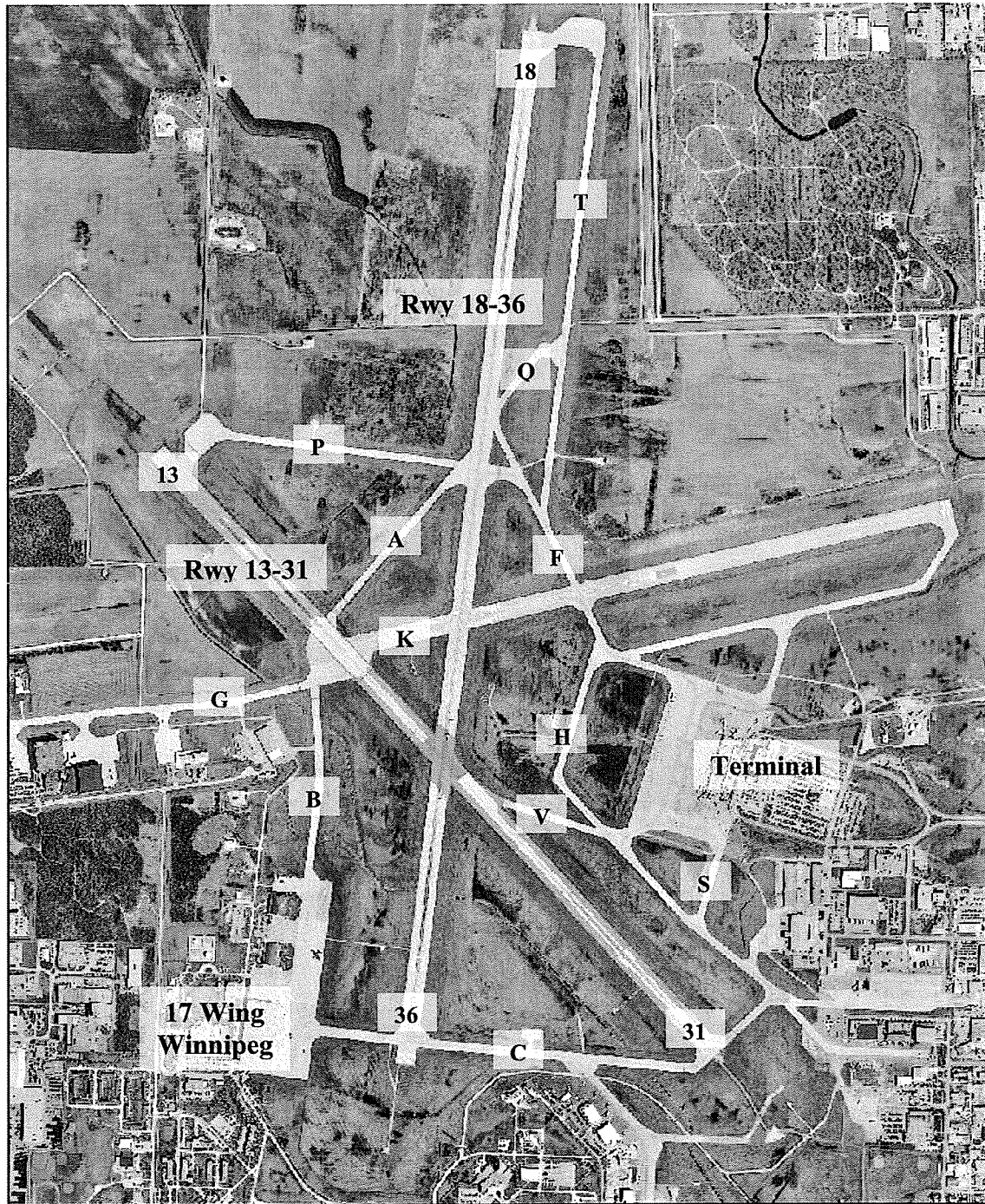


Figure 3.1: WIA Site Plan

3.2 Explanation of Airport Facility Designation

Runways are named using a 2-digit code such as 13-31 or 18-36 at the WIA. A letter such as R or L indicating left or right is also added to the numbers in the case of parallel runways. The process for naming a runway involves taking the compass heading of one end, and rounding it to the nearest 10 degrees to obtain the first number. The second number is simply the reciprocal of the other, meaning the two numbers differ by 180 degrees on the compass. For example, the compass reading on one of the Winnipeg runways might have read 129 degrees; this is rounded to 130, the reciprocal of which is 310. For simplicity sake the zero is dropped and the runway is named 13-31. To avoid any possible confusion regarding which end of a runway to land on, pilots are given instruction to land on either runway 13 or runway 31.

Taxiways are named using a single letter designation, with a unique letter being used for each new taxiway. If multiple parallel taxiways exist, then numbers may be added to the letter (A1, A2, and A3 for example). When taxiways are discussed over the radio, they are referred to using the standard military alphabet. This means each letter is assigned a word, for example, Taxiways A, B, and C would be referred to as Taxiways Alpha, Bravo and Charlie.

3.3 Network Classification

Once the needs of an organization have been identified, the task of implementing a PMS begins with classification. The purpose of classification is to break a network down into a manageable scale. Within a PMS there exists four levels of classification: Network,

Branch, Section and Sample Unit. Network level classification treats an entire facility, in this instance the Winnipeg International Airport, as one entity. This is particularly useful for agencies that manage several facilities such as the military or Transport Canada with the smaller regional airports. This means that in a single database, agencies could store several networks.

Another advantage of an airfield network is that in relative terms, it covers only a single geographic location when compared to a provincial highway network. This eliminates the need to study impacts of different climatic zones as possible sources of accelerated deterioration in one section of the airfield over another, as it can be assumed that the entire airfield is subjected to the same climatic conditions.

The broadest classification level within a given network is the branch, comprised of an entire segment of infrastructure such as a runway or taxiway. For the purposes of this PMS, the airside network was subdivided into 3 types of branches based on functional classification: runways, taxiways and aprons. This research only focused on airside pavements. Groundside pavement can be incorporated into the PMS in the future as additional branch types (service-road, parking lot, etc.) if an airport authority manages such pavements. Figure 3.2 displays the branch network created for the WIA and Table 3.1 contains the approximate total area of each branch type. Calculating total area per branch type is important as different branch types are often inspected at different percentages. Therefore an approximate total area that must be surveyed during the pavement inspection process can be computed.

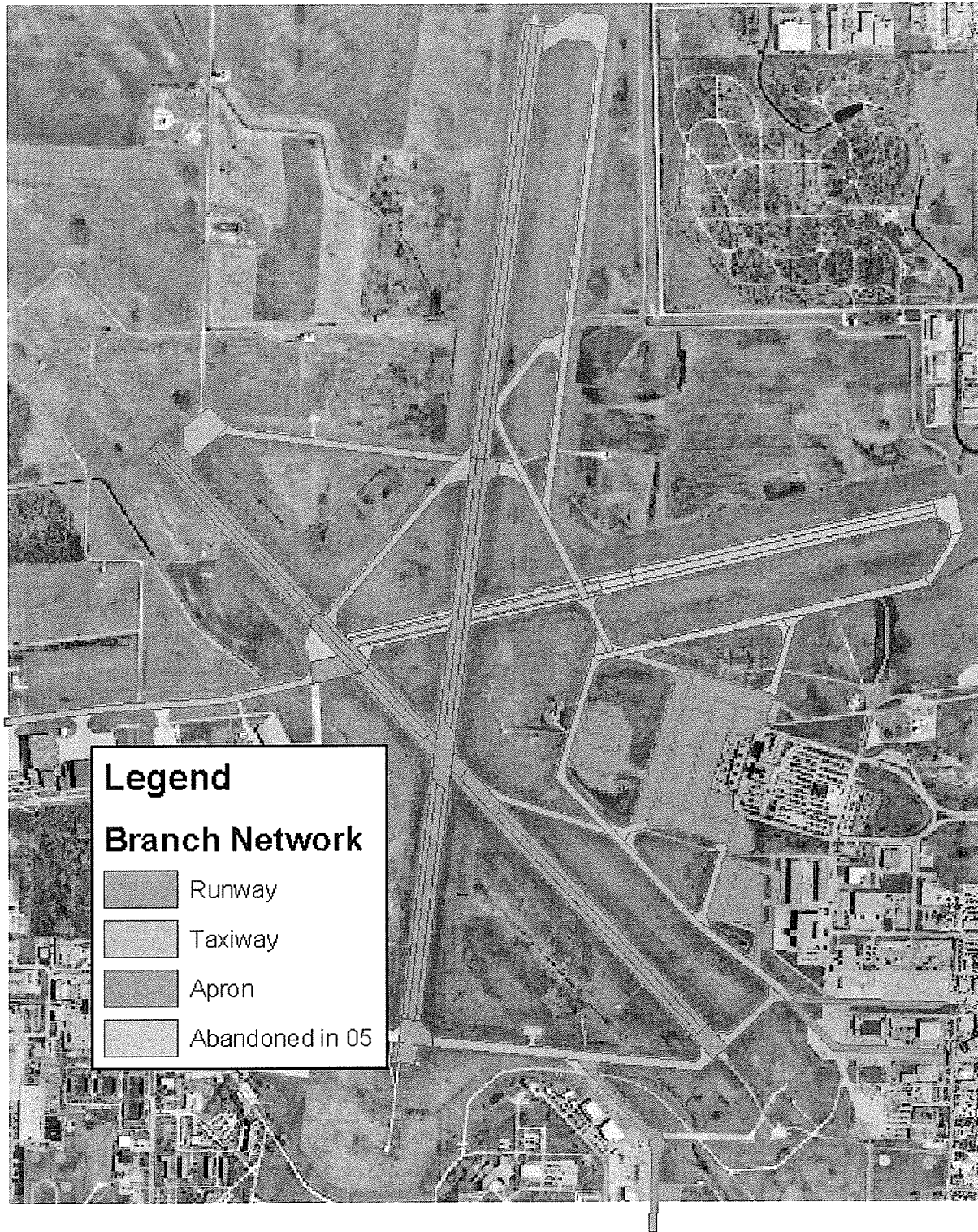


Figure 3.2: Branch Network for WIA Airfield Pavement Management System

Table 3.1: Approximate Quantities of Each Branch Type in Winnipeg APMS

Branch Type	Quantity (m²)
Runway	380,222
Taxiway	269,526
Apron	270,061
Abandoned in 2005	142,658
Total	1,062,466 m²

The next stages of classification were critical to the proper functioning of the PMS. Using the existing Pavement Inventory Binder, contract drawings, and as-built drawings, each branch was broken into homogenous functional use or pavement type sections. Sectioning is extremely important as variables that might account for differing rates of deterioration, such as traffic or pavement surface type must be isolated properly. For example, since taxiways generally see the same traffic across their width (usually 23m) changes in pavement cross-section were most often used to create sections. Runways, being 60m wide see different traffic loadings across their width. The outer edges see less traffic than the centre of the runway. Creating sections containing the entire width of the runway would therefore be inappropriate, even if the pavement cross-section remained uniform across the runway.

Appropriately defined sections allow for the results of pavement inspections from similar sections to be grouped together to form families as described in Chapter 2. These families are then used to create deterioration models for the different pavement types or branches present on the airfield as will be described in a later chapter. Figure 3.3 shows the 93 sections, each one a different colour, that have been created for the WIA.



Figure 3.3: Results of Section Level Classification on Winnipeg Airfield

Time and budget constraints prohibit the inspection of every component of the network, so each pavement section is further divided into sample units for inspection purposes. The sample units are sized such that each AC unit has an area of $450\text{m}^2 \pm 180\text{m}^2$ and each PCC unit consists of 20 ± 8 slabs.

Using the above guidelines a sample unit map was created using the existing site base plan and air photos. In AutoCAD each section was manually divided into an appropriate number of sample units. The resulting map contains 1844 sample units and is presented as Figure 3.4. Attention was paid to ensuring the sample units were uniformly sized and kept within the allowable ranges. The reasoning behind this is to allow for pavement condition information at the section level to be reported as the average of the sample units that were inspected. If the sample units were drastically different in size and a weighted average was not used, the reported section level pavement condition may not be representative of the actual condition.

Table 3.2 summarizes the network classification completed for the Winnipeg International Airport. The table can be used to identify branch names, sections within each branch, the number of sample units each section contains and what surface type each section is. It should be noted that a portion of a section of pavement (half of former section Rwy0725-01) was removed during 2005, and this is why the number of sample units in Table 2 does not add up to 1844, but 1828 as it reflects the new total number of sample units on the airfield. The remaining portion of section R0725-01 has been renamed to TaxiG-02 in Table 2.