Improving Airport Pavement Management Using an Analytical Hierarchy Process Decision Making Tool

Samantha T. Pinto, MASc, P. Eng
University of Waterloo, Department of Civil Engineering
200 University Ave. West, Waterloo Ontario, Canada N2L 3G1

Susan L. Tighe, Ph.D, P.Eng
Professor and Norman W. McLeod Professor in Sustainable Pavement Engineering
Canada Research Chair in Sustainable Pavement and Infrastructure Management
Director Centre for Pavement and Transportation Technology
University of Waterloo, Department of Civil Engineering
200 University Ave. West, Waterloo Ontario, Canada N2L 3G1

Submission Date: August 15, 2014

Number of Words: 5219
Number of Tables (2 x 250): 500
Number of Figure (1 x 250): 250
Total Word Count: 5969

ABSTRACT

This paper discusses how an Airport Pavement Management System (APMS) can be used by airport operators to help improve maintenance scheduling and decision making. The steps involved in creating an APMS are outlined from establishing a pavement history to maintaining the system with current information. Opportunities are identified for utilizing the APMS to analyze trends in pavement distresses and evaluate the effectiveness of competing maintenance treatments.

This paper also introduces an Analytical Hierarchy Process (AHP) as a tool that can be incorporated in an APMS and utilized for decision making. An AHP offers a systematic approach to incorporating both qualitative and quantitative factors in the assessment of competing alternatives to provide an innovative solution. A runway surface texture and rubber removal case study is presented. In this case study, it is shown that the state of the art practice testing frequency can be greatly improved with access to data. The importance of runway friction is described and four options for removing rubber accumulation and restoring texture to a runway are presented to provide context for applying this case to an AHP. The paper concludes by showing how an AHP can be incorporated into an APMS to help an operator compare maintenance techniques and select the most suitable alternative based on their airport's needs. The concept of an AHP can be broadly applied to decision making within an APMS.

INTRODUCTION

Background

An Airport Pavement Management System (APMS) considers all pavement assets and is used by airport operators to identify maintenance needs, to prioritize treatments and to justify projects (*1*). An APMS is a valuable tool that helps airport operators track the pavement level of service and identify locations that require maintenance. Considering all components of the pavement network enables long term financial planning to ensure that secondary assets are not overlooked for preventative maintenance treatments. APMS that incorporate asset deterioration modeling can be used to justify performing preventative and rehabilitative treatments. In order to maintain a high level of service on runways, airports must maintain a high quality pavement surface. Pavement texture and contaminant removal are crucial to ensuring safe aircraft landings and takeoffs. Pavement texture is especially important for aircrafts landing in cold climates where snow and ice accumulates on the runway, decreasing the runway friction and the braking effectiveness of a landing aircraft. Rubber accumulation creates slippery conditions for aircrafts and precludes pavement drainage, increasing the risk of aircrafts hydroplaning.

An APMS can be used to track the friction on the runway and determine sections where low friction and rubber accumulation are worst. This information can be used to schedule rubber removal and runway maintenance. Probabilistic modeling that incorporates real-time environmental data and pavement condition can be used to predict the runway level of service. An APMS can also be used to identify low friction areas that are risky for aircrafts landing. This information can be communicated in real time to pilots to provide warning, especially during inclement weather. Finally, an APMS can be used to select a maintenance treatment and provide stakeholders with justification for funding.

Scope
This paper focuses on the importance of pavement texture and how contaminant buildup affects the safe landing of aircrafts. It outlines how to create an APMS, how to incorporate pavement analysis into the system and how to use an APMS for long term strategic planning. This paper presents an Analytical Hierarchy Process (AHP) as a tool that can be incorporated into an APMS to rank alternatives and provide justification for the recommended option. A case study for maintaining runway friction with various rubber removal procedures is included to illustrate how to apply an AHP. Examples are included to further illustrate the practical aspects of incorporating an AHP in an APMS. The goal of this paper is to discuss the significance of Airport Pavement Management Systems (APMS) in operating airports. Figure 1 illustrates the proposed methodology for improving the flow of information using an APMS. This paper also demonstrates that an AHP is a systematic approach that can be used as a tool for decision making and strategic planning.

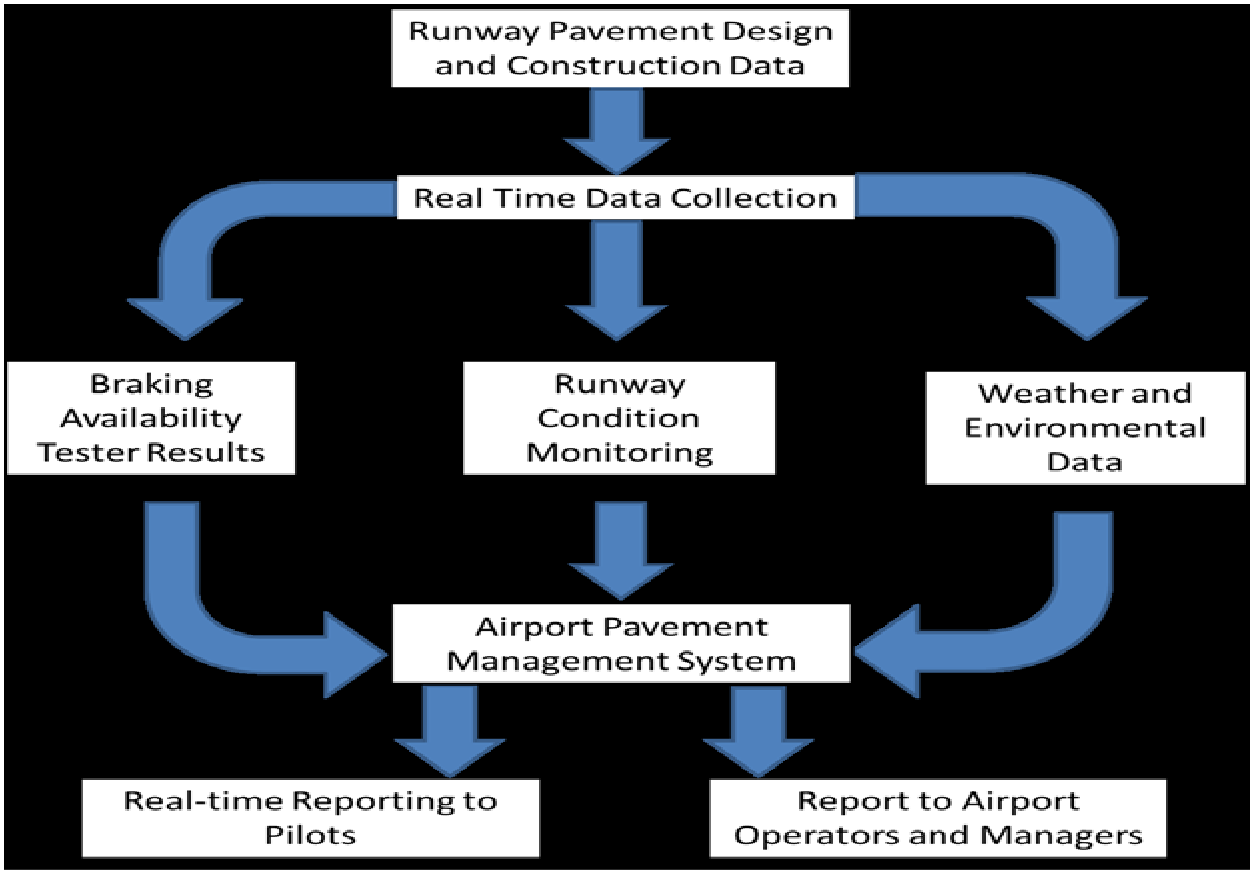

FIGURE 1 Proposed methodology for improved flow of information *(2)*.

PAVEMENT TEXTURE AS A METRIC OF PAVEMENT PERFORMANCE

One of the contributing factors to safely operating runways is maintaining a pavement surface with an adequate level of friction. Pavement friction helps aircrafts safely maneuver the runway and provides a landing aircraft with the traction required to safely stop. Pavement texture is especially important in wet and cold weather climates where runway surface contaminants impact the braking availability of landing aircrafts *(2)*. Pavement microtexture and macrotexture are two factors that contribute to pavement friction. Pavement microtexture is the surface texture and overall roughness of the individual aggregate elements. Although it can be felt, microtexture is not visually discernible as it generally ranges from 0 mm to 0.2 mm *(3)*. Pavement microtexture is important to aircrafts traveling at low speeds.

Pavement macrotexture is a measure of how the profile changes between aggregate elements and the overall pavement surface. Macrotexture is visually discernible and generally ranges from 0.2 mm to 3 mm, as shown in Figure 2 *(3)*. A good pavement macrotexture helps reduce the risk of hydroplaning because the grooving between aggregates provides channels for water to drain off the pavement. If grooving does not naturally exist between the aggregates, texture can be added to the runway by applying a surface treatment or installing grooves into the pavement surface. The macrotexture of the runway is particularly important for aircrafts travelling at fast speeds, especially during landing operations.

Maintaining an appropriate balance between runway pavement microtexture and macrotexture is critical to safe landings. If the pavement texture has worn down, there may be insufficient friction for safe runway maneuvering. In terms of braking action, Transport Canada has identified that a wet runway will provide a level of braking only marginally lower than a dry runway if the runway is equipped with an adequate drainage system and pavement texture *(3)*. Excessively coarse pavement texture increases the risk of damaging aircraft tires, with potentially catastrophic results *(2)*. The coarseness of the pavement surface affects the rate at which rubber accumulates on the runway. A runway with a coarse surface will accumulate rubber faster than a runway with a worn down surface. There is an increased risk for landing aircrafts to hydroplane if the pavement macrotexture is inadequate, as water will pond on the runway surface. Macrotexture can become inadequate as a result of normal surface wearing or rubber accumulation from landing aircrafts.

Impact of Rubber Accumulation

Aircraft tires are made from soft, load absorbing rubber. The heat and friction generated during landing causes the rubber to polymerize, forming a hard, dense rubber that stays on the runway *(4)*. A typical aircraft landing deposits approximately 700 g of rubber on the runway *(5)*. Statistically, the majority of this rubber accumulates within 300 m of the touchdown area. When the runway is dry, the interaction between rubber on the runway and the tires actually leads to increased traction. However, when the runway is wet, the rubber accumulation creates a slick surface for landing aircrafts which significantly decreases the overall runway friction. This loss in friction poses a safety threat for aircrafts landing during inclement weather conditions. Furthermore, rubber accumulation clogs drainage channels in the pavement macrotexture, preventing water from draining off the runway. In addition to altering the pavement texture and friction, rubber accumulation can obscure runway markings.

DEVELOPING AN AIRPORT PAVEMENT MANAGEMENT SYSTEM (APMS)

It is important that airport operators monitor both pavement friction and rubber accumulation so they can schedule surface treatments and rubber removal as necessary. An APMS can be used as a tool in determining when maintenance is required. An APMS can be developed in-house, by an external agency or by purchasing an existing software program *(6)*. An APMS can be used to identify the preferred treatment method by evaluating a wide variety of parameters that should be included in decision making.

The first step in developing an APMS is to divide the airport pavement into manageable sections. The sections should be organized in a way that is meaningful to the airport stakeholders and APMS users. For example, the sections can be divided by functionality (e.g. runway, taxiway, apron etc.), by project type or value (e.g. resurfacing, full depth repair, minor maintenance), or by surface characteristics (e.g. asphalt surface, concrete surface or composite pavement structure). Each section can be further broken down to delineate and identify smaller subsections.

In developing an APMS, it is important to have a good understanding of how the airport operates. This can be achieved by collecting traffic data such as aircraft characteristics (tire configuration, weight etc), the number of landings and takeoffs, and the number of passes made on each section of pavement in the airport network *(3)*. It is also useful to understand and document the environmental conditions at the airport. Historical environmental records such as temperature, precipitation (quantity and type), and wind speed and direction should be entered in the APMS.

The next step in developing the APMS is to understand the pavement history. This can be accomplished by reviewing as-built records and gathering an inventory of the pavement's maintenance and rehabilitation history. It is important to identify the age of the pavement as well as determine the material components and associated thicknesses of the pavement structure. It is helpful to understand the standards as well as the traffic and growth assumptions that were applied at the time of designing the pavement structure. This information should be recorded in the APMS. If available, additional information such as soils reports, and growth planning/strategy documents from the design phase should be included the APMS.

After inputting the pavement design and maintenance history, the APMS should be developed to help airport operators understand the types of pavement distresses historically observed at the airport. Analysis should be performed to identify the root causes of pavement distress. The operators should review how common distresses have been treated and analyze the effectiveness of the solution. Reviewing the maintenance history and determining the frequency of reoccurring maintenance treatments will help operators identify key problem sections. Ideally, the APMS should include a financial component that tracks the costs of initial construction as well as performing maintenance and rehabilitation treatments.

Once the framework for tracking and evaluating past practices has been established in the APMS, it is time to determine the current state of the pavement network. This can be achieved by performing a pavement condition evaluation. There are several industry standardized non-destructive tests that can be performed, including a visual inspection to identify surface distresses, friction testing, skid resistance and roughness profiling. Data can be collected by trained in-house staff or by contracting an external engineering agency. The APMS developers must provide data collectors with a method that enables data collection in a standardized and objective manner.

Resources must be allocated for training front line staff in how to collect data and input it into the APMS.

Destructive tests such as pavement core sampling should be collected if necessary. Core sampling should be collected in areas where distresses repeatedly occur, where subgrade issues are suspected or where geotechnical information does not exist. After gathering and entering data to establish the current state of the pavement structure, it is important to establish a schedule for continuing to collect data. Resources must be budgeted and allocated for ensuring continuous data collection and analysis. Airport operators must keep the APMS current by documenting maintenance and rehabilitation treatments as they are performed. It is important that airport operators and APMS users are trained on collecting and inputting data in a consistent and objective manner.

Case study: Using an APMS to Determine the Rate of Rubber Accumulation

An APMS should be used to store results of friction tests and pavement surface texture inspections. Airport operators can utilize tools within the APMS to analyze data and predict the deterioration rate of the surface texture. This analysis can be extrapolated to predict and plan for maintenance and major rehabilitation. Airport operators can utilize an AHP to evaluate and compare competing maintenance alternatives. The AHP can be incorporated into the APMS. Traffic characteristics such as aircraft size, weight and frequency of landings increases the rate rubber accumulates on the runway. These factors will also contribute to an accelerated wearing of the pavement texture.

The current industry state of practice is to perform friction tests based on the percentage of heavy aircrafts utilizing the runway. Table 1 shows the recommended minimum frequency for testing runway friction based on number of aircraft landings and the percentage of heavy aircrafts. Friction tests can be performed using Continuous Friction Measuring Equipment (CFME). These tests can be performed by the airport operators or by a third party testing agency. When testing the runway, it is important to measure the friction from both approaches of the runway *(2)*.

TABLE 1 Minimum Frequency for Friction Testing *(4)* and *(7)*

Number Of Daily Minimum Aircraft Landings Per Runway End	**Minimum Friction Testing Frequency < 20% Heavy Aircrafts**	**Minimum Friction Testing Frequency > 20% Heavy Aircrafts**
Less than 15	1 year	6 months
16 to 30	6 months	3 months
31 to 90	3 months	1 month
91 to 150	1 month	2 weeks
151 to 210	2 weeks	1 week
Greater than 210	1 week	< 1 week

Once the airport has collected a series of friction tests and incorporated this information into the APMS, operators can use the APMS to analyze trends in the data. Moving to a more state of the art practice, friction tests should be scheduled based on the rate rubber accumulates, as predicted by the APMS. By incorporating environmental factors such as heavy wind or the accumulation of weather related surface contaminants (water, ice, snow etc.) the APMS can identify conditions where pilots are likely to employ aggressive braking. Therefore, the APMS can help operators anticipate periods of higher rubber accumulation. Runway condition information can be communicated in real-time to pilots to enable them to make decisions about their landing technique or whether it is safe to land. The environmental and traffic factors can be modeled by the APMS to determine the rate at which runway friction testing and rubber removal needs to occur.

Methods for Removing Rubber Accumulation and Restoring Pavement Texture

There are four commonly used methods for removing rubber buildup: waterblasting, shotblasting, chemical removal and mechanical removal. Waterblasting is a rubber removal process that entails using a high pressure spray of water. Shotblasting is a process that uses an abrasive material to blast rubber off runway pavement surface. Chemical removal requires the use of a chemical compound to soften and decompose the rubber so it can be gently removed by a broom or vacuum. Finally, mechanical removal is any process not covered by the other three methods, including scraping, grinding, milling or sandblasting to remove rubber buildup *(5)*.

Waterblasting is an increasingly popular technique for rubber removal because it is a more environmental alternative. Waterblasting does not require harsh chemicals to remove rubber from the runway or to separate processed water from the debris. Waterblasting uses a self-contained machine that applies a high pressure stream of water to peel rubber off the runway. Waterblasting units are considered self-contained because they often include a vacuum component that simultaneously collects and separates debris during the cleaning process.

Besides being a more eco-friendly alternative, a key advantage of waterblasting is that this method helps restore macrotexture and microtexture to the pavement. This method is relatively quick, meaning little downtime is required to clean a runway. Additionally, these units can be easily removed from the runway in the event the runway has to accommodate an emergency landing. A key advantage for small airports or airports with limited maintenance staff is that a self-contained rubber removal unit can be operated by one person. Since vacuuming the runway is included in waterblasting, there is a lower risk for leaving foreign object debris (FOD) on the runway. FOD is a major safety concern for operating runways; the smallest debris drawn in by an aircraft engine can have catastrophic results. One of the disadvantages of waterblasting is the risk of an ultrahigh pressure water stream polishing aggregates, leading to a loss in pavement microtexture. Another disadvantage of this method is that it is somewhat seasonal and challenging to utilize in cold weather *(5)*. Shotblasting is a rubber removal method whereby steel balls are shot on the pavement surface to remove the rubber. Shotblasting is often employed as a technique to restore pavement texture, and rubber removal is considered a secondary benefit of this method *(2)*. Vacuums and magnets are used to collect the steel balls and other debris; waste is separated from the steel balls so they can be continuously reused.

Restoring the pavement texture is a key advantage of shotblasting. This method is also considered fairly eco-friendly because it does not require chemicals or large volumes of water. Like waterblasting, shotblasting is not a resource intensive process and can be easily cleared from the runway in an emergency. A significant disadvantage to this method is the increased risk of FOD being left on the runway. Another disadvantage to this method is the possibility of damaging the pavement structure or any runway appurtenances *(2)*. Shotblasting removes material from the surface course of the pavement structure, so this technique should only be applied if the pavement structure includes an overdesigned surface layer. Chemical removal entails applying a detergent compound to the runway to soften the dense, polymerized rubber. After the detergent has permeated and softened the rubber, the detergent and rubber can be rinsed and swept off the runway. Traditionally, rubber and the detergent are either buried adjacent to the runway or left unattended on runway shoulders or in ditches until the accumulation grows large enough to merit an environmental removal *(2)*. Concerns over the effects of the detergent leaching into local watersheds have led to the development of biodegradable and environmentally inert compounds; however, there is still concern regarding rubber disposal as the rubber itself may contain toxins *(4)*.

The key advantage of chemical based rubber removal is that it does not require specialized equipment; airports often already employ staff and own sweepers or similar equipment that can be used to clear the runway. This method is minimally damaging to the pavement; however, literature has shown that chemical rubber removal may not fully restore pavement macrotexture and microtexture *(5)*. The key disadvantage of this technique is that once the detergent has been applied the runway must remain closed until the chemical and rubber have been removed. This means an airport could not accommodate an emergency aircraft landing until the cleaning process is complete. Other disadvantages include the high cost of the detergent, and any fees associated with environmental disposal or environmental permits to operate. The final method of rubber removal is using mechanical means such as scraping, steel brooms or milling machines to remove rubber from the runway. Similar to shotblasting, using mechanical means often leads to improved pavement texture but decreased surface layer thickness. Disadvantages of mechanical rubber removal are the increased risk of causing microcracking, accelerated pavement aging, and the labour intensive nature of the process. Table 2 is a comparison of the processing rate and reported cost of the four previously described methods for removing rubber from a runway. The values shown in Table 2 are based off a study conducted by the Airport Cooperative Research Program.

TABLE 2 Processing Rate and Reported Cost of Rubber Removal [after 4] and *(8)*

Method		Processing Rate (m2/ hour)		Reported Rubber Removal Costs ($/ m2)	
Low	High	Low	Mean	High	
Waterblasting	743	1641	0.31* 0.39**	0.54* 1.20**	3.24* 4.05**
Shotblasting	929	2700	0.60	1.05	1.79
Chemical	743	1641	0.16	0.52	1.43
Mechanical			Varies based on technique applied		

* Cost of airport performing rubber removal
** Cost of contractor performing rubber removal

INCORPORATING AN ANALYTICAL HIERARCHY PROCESS (AHP) IN AN APMS

An Analytical Hierarchy Process is a systematic decision making tool that is useful for comparing multiple alternatives. An AHP can be incorporated into an APMS to objectively compare maintenance alternatives, and provide objective justification for the method selected. This paper shows how an AHP can be included in an APMS to make decisions about the best alternative for removing rubber from a runway. The AHP method was used to develop a tool to help airport operators determine which rubber removal technique is most appropriate for their airport. The AHP includes a variety of criteria (and the option for adding site specific criteria) that are possible factors in the decision making process. The concept of an AHP, can be adapted to any decision where multiple alternatives need to be considered. Examples of possible AHP applications are prioritizing competing projects for funding allocation, selecting pavement maintenance techniques for a particular section of the network and selecting a contractor from a group of competitive bids to complete repair work.

The AHP was structured so that the airport operator assigns a weight 9 between 0% and 100% to each of the criteria being evaluated. A high criteria weight is assigned to criteria deemed exceptionally important to the airport operator; low criteria weights are assigned to less significant factors. The sum of criteria weights assigned by the airport operator for all criteria listed must equal 100%. Next, the airport operator scores each of the criteria as it relates to the alternative being considered. A high score should be assigned to a perceived positive attribute, and a low score should be assigned to a perceived negative attribute. For example, a high score would be assigned to minimizing environmental impact, and a low score would be assigned to a more environmentally risky alternative. The range used for scoring criteria must be applied to each of the alternatives. Using the rubber removal example where there are four alternatives, if startup cost is measured on a scale of 1 to 10 for waterblasting, it must also be measured on a scale of 1 to 10 for mechanical, shotblasting and chemical removal in order for the ranking to be consistent. The simplest method for determining a range is to count the number of alternatives and assign that value as the maximum possible score. If this method is employed, then each alternative should be ranked relative to each other such that the preferred alternative receives a score equal to the number of alternatives, and the least preferred alternative receives a score of 1. Applying this simplified method to the rubber removal example, there are four alternatives therefore the highest score 6 possible is four. If there is a binary criterion (e.g. requiring a permit is a “yes” or “no” decision) then a score of 0 should be assigned for a perceived negative (permit required) and a score of 1 should be assigned for a perceived positive (permit not required). After assigning a score to each of the criteria for all alternatives being compared, multiply the criteria weight by the score assigned to determine a weighted score for each criterion. Finally, calculate the sum of weighted scores to determine an overall score for each alternative. The alternative with the highest score is the recommended method.

Case Study: Using an AHP to select the best rubber removal alternative

This provides an example of how the previously described AHP tool can be applied to determine the best rubber removal technique for an airport to utilize. This sample airport represents mid-volume airport located in a mid-sized suburban town. In this example, airport operators felt that the cost of the operation and the effects on the pavement structure are the most important criteria to be accounted for in deciding the rubber removal alternative. The airport has a small but highly skilled operations staff that is quite flexible in a variety of maintenance roles. The airport is also comfortable contracting work out if necessary. The airport is not located in an environmentally sensitive area, and is primarily surrounded by undeveloped industrially zoned lots. This airport views accommodating an unscheduled emergency landing as a low probability event; however, it does not have a secondary runway that could accommodate an emergency landing. After assigning a weight to each of the criteria, and a score to each of the four alternatives it was determined that the preferred alternative for this airport is waterblasting, followed by mechanical, shotblasting and chemical respectively.

The process was used to show how the operators of a midsized airport might prioritize the cost and pavement elements over other factors. In comparison, a low volume or remotely located airport may be more concerned with factors such as the start-up cost of the operation, availability of skilled workers and availability of equipment and materials. A military airport may be required to accommodate emergency landings, and therefore rate the ability to reopen the runway as a very important factor.

The selection of the preferred alternative depends on the criteria selected and the weights assigned as well as the corresponding score assigned to each alternative. A shift in the weight assigned to the criteria or a shift in the score assigned to the alternatives will affect the overall selection of the preferred alternative. By manipulating these numbers, airport operators can better understand the impact of their rankings.

Advantages of Using an AHP to Make Decisions

One of the advantages of assigning weights to each of the criteria is that the airport operators can perform a sensitivity analysis by changing the score assigned to each criteria weight. In doing so, airport operators can better understand how criteria weights impact the overall selection of the recommended alternative.

Another advantage of using a decision making tool (such as an AHP) in an APMS is that it creates opportunity for strategic planning. With the absence of an APMS, airport operators are likely to make project funding decisions that optimize the annual capital budget. This shortsighted budgeting leaves little opportunity for strategic planning and long term allocation of resources. Additionally, shortsighted planning often leads to overspending to firefight issues that could have been mitigated if proper maintenance had been performed. Performing rehabilitation when the pavement is still in fair condition is considerably less expensive than performing treatment when the pavement condition has deteriorated significantly. It also illustrates that the rate of deterioration is non-linear; there is often a significant drop in condition coupled with a significant increase in the cost of repairing the asset. The AHP is a tool that can be incorporated into an APMS to help identify priorities by ranking and comparing alternatives.

Airport operators are under intense public scrutiny; social perception can be tied to federal funding and permitting for expansion projects. Strategically, this issue can be managed by striking the right balance between the triple bottom line – a combination of social, economic and environmental factors. It is difficult to assign a monetary value to social perception and the environmental impact of maintenance operations. As a result, social and environmental factors are often overlooked in a traditional economic based decision making model. An AHP provides a method for assigning value to social and environmental factors so they can be included in the decision making process.

CONCLUSIONS

Airport operators can use an APMS to determine which pavement sections require maintenance treatments. Information generated using an APMS can also be used to provide justification for project funding and prioritization. This paper showed how an Airport Pavement Management System can be introduced to keep a record of pavement performance and maintenance history. There are several opportunities for an APMS to optimize current practice, including the use of predictive modeling to improve the scheduling of maintenance, testing and repairs. An analytical hierarchy process was also presented as a tool that can be used for comparing several competing alternatives. An AHP uses a weighted score assigned to several factors that can be considered in the decision making process. Using this method, both qualitative and quantitative variables can be incorporated in the decision making process, and the results can be presented to stakeholders as justification for selecting the preferred alternative.

Future Work

This paper presented the framework for incorporating an AHP in an APMS and used the specific example of selecting a rubber removal process as an application to which the AHP can be applied. The next step after implementing an AHP focused on selecting rubber removal techniques is to expand the scope of how AHPs can be used to make decisions in an APMS. AHPs can be expanded to compare and rank maintenance treatments for a specific project, or to compare competing projects to determine which project should receive funding. The process of developing an APMS and implementing AHPs within the system must be iterative. Airport operators must evaluate the performance of the AHP to identify strengths and opportunities, to implement changes and correct any issues that have been identified. Re-evaluation must be completed to determine the effectiveness of these changes.

Data collection must be ongoing to ensure the decisions made by the APMS are based on the most recent data, standards and work practices. As new technology for data collection becomes accessible and adopted by the aviation industry, it should be assessed and incorporated into the APMS if relevant. Airport operators and maintenance staff must be continually trained on how to perform data collection and analysis to ensure consistency of results.

Acknowledgements

The Authors of this paper would like to thank the Centre for Pavement and Transportation Technology and the Department of Civil Engineering at the University of Waterloo for providing resources required for completing this research. Additionally, the authors would like to thank the Ontario Centres of Excellence, Transportation Association of Canada, Team Eagle Ltd. WestJet Airlines Ltd. and the Region of Waterloo International Airport for providing funding and information in support of this research.

REFERENCES

*(1)*Airport Cooperative Research Program (ACRP). (2011). *ACRP Synthesis 22 Common Airport Pavement Maintenance Practices*. Washington, DC: Transportation Research Board
(2 Pinto, S. *Optimizing Airport Runway Performance by Managing Pavement Infrastructure*. Waterloo: University of Waterloo, 2012

(3) Transportation Safety Board of Canada. (2013, June 13). A*viaiton Investigation Report A10H004*. Retrieved July 20, 2013, from http://www.bst-tsb.gc.ca/eng/rapports-reports/aviation/2010/a10h0004/a10h0004.asp

*(4)*Speidel, D. J. (2002). *Airfield Rubber Removal*. 2002 Federal Aviation Administration Technology Transfer Conference.

*(5)*Airport Cooperative Research Program (ACRP). (2008). *ACRP Synthesis 11 Impact of Airport Rubber removal techniques on Runways*. Washington, DC: Transportation Research Board

(6) Tighe, S. *Implementation of an Airport Pavement Management System.* Transportation Research Board Circular E-C127, Washington, DC: Pavement Management Systems for Transportation Research Board Airports Subcommittee, 2008.

(7) Air Force Civil Engineering Support Agency (AFCESA). (2004, May 12). *Engineering Technical Letter (ETL) 04-10 (Change 1): Determining the Need for Runway Rubber Removal*. Retrieved April 28, 2012, from http://www.wbdg.org/ccb/AF/AFETL/etl_04_10.pdf

(8) US Inflation Calculator. 2007 to 2012. http://www.usinflationcalculator.com/

(9) Federal Aviation Administration (FAA). (September, 7 2011). *Airport Obligations: Pavement Maintenance.* Retrieved June 30, 2012, from http://www.faa.gov/airports/central/airport_compliance/pavement_maintenance/