AN EVALUATION OF VARIOUS PRIORITIZATION METHODS FOR EFFECTIVE PAVEMENT MANAGEMENT: A CANADIAN AIRPORT CASE STUDY

By:
Susan Tighe, Ph.D, P.Eng.,
Assistant Professor of Civil Engineering,
University of Waterloo, 200 University Avenue West, Waterloo Ontario,
Canada N2L 3G1 phone (519 888-4567 X 3152, fax (519) 888-6197

Mohammad Karim, MA.Sc.
Pavement Engineer,
EBA Engineering Consultants Ltd.
Edmonton, Alberta, Canada

Alan Herring, P.Eng.
General Manager Facilities Engineering,
Greater Toronto Airports Authority, Lester B. Pearson International Airport,
PO Box 6031 Convair Dr. Toronto AMF, Ontario Canada, L5P 1B2

Kevin Chee, P.Eng.
Greater Toronto Airports Authority, Lester B. Pearson International Airport,
PO Box 6031 Convair Dr. Toronto AMF, Ontario Canada, L5P 1B2

Mounir Moughabghab, P.Eng
Project General Manager, Airside Development
Greater Toronto Airports Authority, Lester B. Pearson International Airport,
PO Box 6031 Convair Dr. Toronto AMF, Ontario Canada, L5P 1B2

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ABSTRACT

Proper Funding for current and future needs has always been a problem for the management of pavements. With the introduction of prioritization it has enabled engineers and managers to identify those pavement sections that need attention. Prioritization of current needs plays an important role in the management system. In short, Prioritization becomes an effective tool for supporting decisions to be taken for effective pavement management. The management system strives to achieve the maximum benefits through prioritization.

Depending on the funding levels, location, and specific conditions of a transportation agency, different methods ranging from a simple subjective ranking of projects based on judgment to comprehensive optimization by mathematical programming models, are being used for determining priorities.

This paper presents a case study for airports, where the Pavement Condition Index (PCI), which has been recognized as an ASTM Standard Test Method for Airfields, has been calculated by entering the distress data of 271 sections in MicroPAVER. Current needs have been calculated and are identified for three different minimum acceptable PCI levels. In addition five treatment alternatives are analyzed based on their life cycle cost and cost effectiveness.

The paper further analyzes three different methods of prioritization, using data from a Canadian airport, to assess how minimum acceptable service levels and performance impact the overall life cycle cost and prioritization. One unique method has been developed in this paper specifically for application in the Canadian environment. The method developed herein is selected based on its advantages over other methods. Inspections for the rehabilitated sections have also been re-entered into MicroPAVER and the effect of changing minimum acceptable level of PCI from 65, 60, and 50 to 70, 65, and 55, and then to 75, 70, and 60 for runway, taxiway, and roadway respectively on network level is calculated in terms of performance. The results show that if minimum acceptable level of PCI for runway 65, taxiway 60, and roadway 50 is increased to 75, 70, and 60 respectively, an enhancement of 62% budget is required.

INTRODUCTION

Pavement Management (PM) is a process for maintaining and preserving pavement assets at a certain level of performance in the most cost effective manner. PM provides agencies and organizations with a tool that can assist in predicting the future performance of pavements. This information can then be used to set budgets and plan future capital programs. The Pavement Management System (PMS) is the working system that enables for coordination of all planning and programming, design, construction, and monitoring in service activities. Every PMS should be able to answer the five basic questions; a) what is the condition of the various sections in a pavement network? b) what sections of the network require rehabilitation? c) what type of treatment should be applied to these sections? d) when should they be rehabilitated? e) what is the cost associated with the rehabilitation?

Proper Funding for current and future needs has always been a problem for the management of pavements. With the introduction of prioritization it has enabled engineers and managers to identify those pavement sections that need attention. Prioritization of current needs plays an important role in the management system. In short, prioritization becomes an effective tool for supporting decisions to be taken for effective pavement management. The management system strives to achieve the maximum benefits through prioritization.

Depending on the funding levels, location, and specific conditions of a transportation agency, different methods ranging from a simple subjective ranking of projects based on judgment to comprehensive optimization by mathematical programming models, are being used for determining priorities.

This paper presents a case study for airports, where the Pavement Condition Index (PCI), which has been recognized as the ASTM Standard Test Method for Airfields [6], has been calculated by entering the distress data of 271 sections in terms of type, quantity, and severity into a computerized PMS, MicroPAVER. Current needs have been calculated using this tool and are identified for three different minimum acceptable PCI levels. In addition five treatment alternatives are analyzed based on their life cycle cost and cost effectiveness.

The paper also describes sensitivity analysis which uses three different methods of prioritization. Data from a Canadian airport is used to assess how minimum acceptable service levels and performance impact the overall life cycle cost and prioritization. One unique method has been developed in this paper which uses weighted system. Inspections for the rehabilitated sections have also been reentered into MicroPAVER and the effect of changing minimum acceptable level of PCI from 65, 60, and 50 to 70, 65, and 55, and then to 75, 70, and 60 for runway, taxiway, and roadway respectively on network level is calculated in terms of performance.

Levels of Pavement Management System

A Pavement Management System (PMS) operates primarily at two different levels, network level, and project level. The project level deals with the details of work coming “on stream”. Very detailed information on the asset condition and performance is obtained. This information is then used to determine the most effective maintenance, rehabilitation or repair strategy in terms of the technical and economic benefits. Other aspects of this include alternative generation and life cycle cost analysis. At the network level, the primary function is to develop the priority program with the asset group. For example, a network level decision will involve the preparation of a rehabilitation and maintenance schedule and the ranking of the priorities within the pavement network.

Each of the two levels of operation is important for the management of the pavement assets. It is also critical to note that different people in the organization require different information and the success of PMS is related to the ability to extract the required information for the various users.

Features of Pavement Management System

The main objective of a PMS is to provide pavement engineers with a tool that can analyze the entire pavement network data and then recommend prioritized maintenance and rehabilitation (M&R) alternatives to the prioritized sections.

Inventory depends on the frequency and consistency of data collection. If the intended use of inventory is only the network level, then more detailed information such as material types are not important. However, this data is critical for project level PMS operation. The network level is important as it determines funding allocations. Project level relates to activities at a specific project or sections level and then requires detailed data for analysis of various M&R strategies. Both levels of operation are important for successful operations, maintenance and engineering.

The scope of this research is restricted to one network, namely airside pavements. The inventory that was included in this analysis is described herein:

i. **Network Identification**: This will identify the network on which the work is being done. Pavements are further subdivided into airside and groundside.

ii. **Branch Identification**: After identifying the network, it is important to recognize the branches of sub network allocations in this network. The entire airside pavements are divided into different branches. They include runways, taxiways, aprons, runway shoulders, taxiway shoulders, service roads, etc. During this analysis no data was available for aprons and shoulders and the whole area of runways, taxiways, and service roads is divided into 31 branches.

   A runway is identified by a suffix RW followed by numbers, which shows the runway orientation. e.g., RW 15L-33R means that the runway orientation is 1500 to the North at one end and 3300 at the other end. Depending upon its importance, usage, or priority of the runway it is also classified as primary, secondary, and tertiary.

   Taxiways are also paved surfaces that are used for taxiing aircrafts from runways to aprons and from aprons to runways. A taxiway is identified by capital letters, e.g., Taxiway A, Taxiway B, Taxiway C, and so on. The letters may be abbreviations of some names, e.g., Taxiway A means Taxiway Alpha, B means Bravo, C means Charlie and so on.

   Aprons are the paved surfaces adjacent to terminals where aircrafts are loaded and unloaded. Aprons are identified by numbers, e.g., Apron 1, Apron 2, etc., which represent the terminal number. Each apron is also divided into sections.

   Service roads are the facilities for automobiles to provide services to aircrafts, runways, taxiways, and aprons. They are named as streets, e.g., Silver Dart Drive, Convair Drive, etc. Each of the runway, taxiway, apron, and service roads are further subdivided into sections.

iii. **Section Identification**: Branches tend to be very large so it is essential to further break them down into sections. This is necessary to represent the fact that the branch is not always consistent throughout its entire area or length. In addition, it is also not always easy to carry out a detailed distress evaluation surveys for the entire branch. Rating of a section is also more objective than rating of a branch from a pavement management perspective. An example of a runway branch divided into sections, in this case twelve, is shown in Figure 1. While dividing branches into sections the following factors are taken into account:

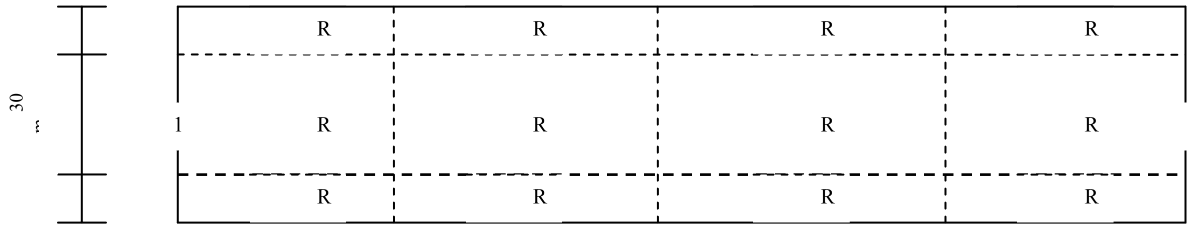

Figure 1. Example Runway (RW 15R-33L) Division into Sections.

a) Pavement Structure: Pavement structure is considered as one of the most important criteria for dividing a branch into sections. A section should consist of uniform thickness of layers and preferable of the same material. The pavement structure analysis considers that similar construction methods are used and that within a reasonable level of variability that the structural layers are of uniform thickness. Subgrade should also be consistent throughout the section. This uniformity of pavement thickness, materials, and subgrade strength will provide a basis for analysis of the pavement behavior. If there is any significant change in layer thickness, material, or strength, the section should be changed.

b) Traffic: Traffic is one of the main causes contributing in pavement deterioration. Therefore volume and load intensity of traffic should be consistent within each individual section. In airfield pavements, a section is defined by traffic channelization. Traffic is normally channelized around the centerline of runway and taxiway. Therefore the central and outside portions are divided into different sections, as noted in Figure 1. Traffic channelization is also considered for aprons. Unlike ESALs for roads, traffic for airfield is counted by the number of departures or can be calculated as equivalent wheel loads (EWL). This is in accordance with current practice at the GTAA.

c) Construction History: Construction history also plays an important role in dividing branches into sections. Each section should have a consistent construction history. Pavements constructed during different time periods, by different contractors, or using different materials or techniques should be considered separate sections. Areas that have received major repairs should also be divided into separate sections.

d) Pavement Rank: Pavements are divided into primary, secondary, or tertiary ranks depending upon functionality. This classification is also termed as functional classification. Any pavement that falls into different rank should be divided into separate section.

e) Drainage Facilities and Shoulders: Drainage and shoulder provision affects pavement performance. Poor drainage facilities result in rapid deterioration of pavement. Similarly this can also be true for shoulder performance. Hence pavements with different types of drainage facilities and/or shoulders should be divided into separate sections.

f) Surface Condition: Surface is an important variable because it reflects many of the factors discussed previously. Surface Condition examines distress and in areas where distress in notably different the section is isolated and repairs are carried out.

g) <u>Other Consideration</u>: Other considerations include length or size of a section, numbering of sections and any unique technical or administrative factors of an agency that might influence performance. A section should not be too small to make management difficult but also not too large to impact the overall evaluation. Sections should be relatively equal in length. Numbering should also be uniform. Sections are typically numbered in increasing order from the North or West end of the branch as shown in Figure 1. Each section should be identified on the agency's network map.

PAVEMENT CONDITION INDEX

Increased customer expectations and accountability in the public sector have helped to focus attention on performance measurement as one of the essential tools for effective management. It is imperative that there is a clear understanding of the goals of the performance measurement and a method available to assess the results in such a way that errors/omissions can be corrected and improvements can be made to the system. Indeed a performance measure can help in improving and standardizing an area of assets.

Pavement Condition Index (PCI) is one of the most widely used performance measures for pavements. PCI in this work is calculated according to ASTM. It uses the recognized test method for roads (D6433) and airfields (D5490) [6]. It is a numerical index ranging from 0 for a failed pavement to 100 for a pavement in perfect condition (Figure 2). Calculation of PCI is based on the results of a visual condition survey in which distress type, severity, and density are identified. The PCI number (0-100) reflects the structural integrity and surface condition of the pavement.

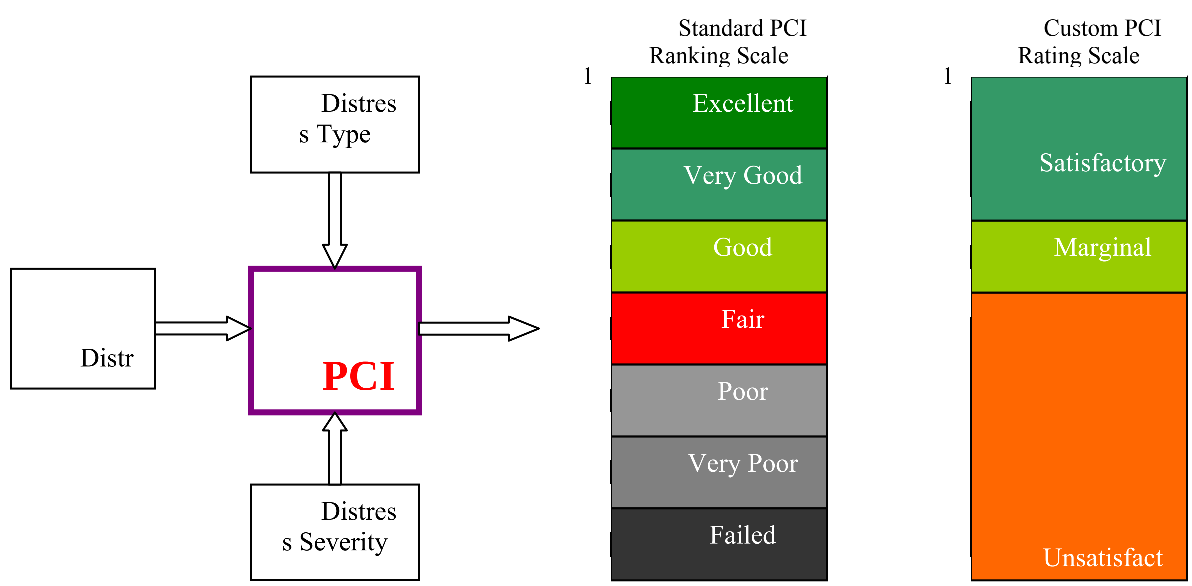

Figure 2. PCI Number Distribution [6].

Surface distress is an objective measurement based on the type, density and severity of the pavement distress. By projecting the rate of deterioration based on the pavement condition history, a life cycle cost analysis can be performed for various M&R alternatives, in which the best alternative and the optimal time for application of this alternative are determined.

Figure 3 represents when a particular pavement section becomes a need. If the minimum acceptable level of PCI is assumed to be 60 for this particular section then in the year 2015 it will need to be considered for rehabilitation.

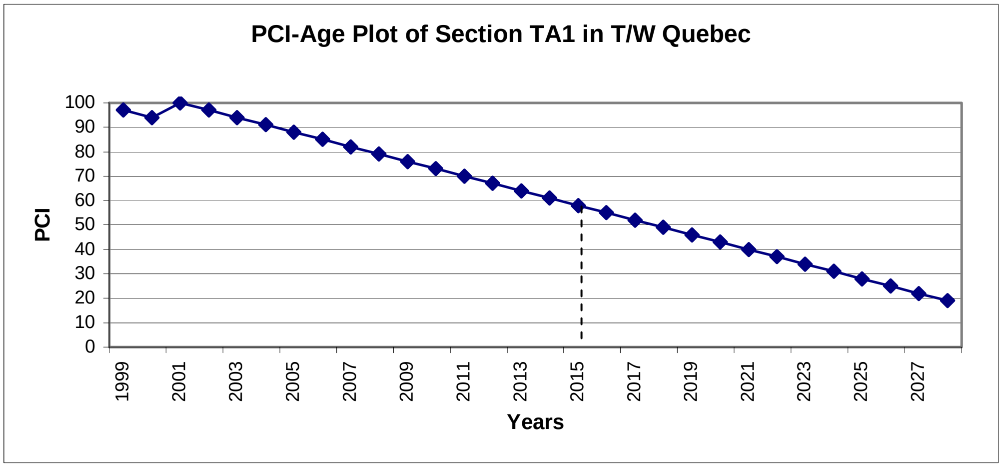

Figure 3. Typical PCI-Age Relationship for a Section.

Calculation of Pavement Condition Index (PCI)

Different methods can be used to calculate the Pavement Condition Index (PCI). One of the most widely used methods is that of MicroPAVER. MicroPAVER calculates PCI automatically after entering the distress data into it. However it can be calculated manually, with a PCI computer program. The PCI calculation is based on the deduct values—weighting factors from 1 to 100 that indicate the impact each distress has on pavement condition [4]. A deduct value of 0 indicates that the distress has no effect on the pavement performance, whereas a value of 100 indicates an extremely serious distress.

The steps involved in calculating PCI are described in ref. [4]. Deduct values have been developed for different types of distresses found on asphalt concrete roads, Portland cement concrete (PCC) roads, asphalt airfields, and PCC airfields. Definitions of distress type, severity (low, medium, high), and method of measuring the quantity (density) are also provided.

Automated PCI Calculation

Manual calculation of PCI can easily be performed with a single sample of pavement. However, the volume of data that must be collected during the visual survey of a road or airfield network is extensive. Consequently, the calculation of PCI can be a time consuming process. The MicroPAVER software can assist with this task. Once the distress information is entered into MicroPAVER, the PCI is calculated automatically for each section, branch, and for the whole network. MicroPAVER was used in this analysis for determining the PCI.

Airside pavements in this case study consist of runways, taxiways, aprons and some service roads. Distress data was available only for runways, taxiways, and two service roads. All the pavements are divided into 271 sections. In total, 839 samples were selected randomly to collect distresses. Selection of samples is based on the fact that 50% of the sample units are surveyed for the central part of runways and taxiways where 95% of the traffic flows. On the outside of the runway or taxiway approximately 25% of the sampling units are selected for the survey. Distresses for these 839 samples were entered into MicroPAVER and the PCI for every section, branch, and network was calculated automatically. MicroPAVER also predicts the condition of the pavement for the coming years based on the history of the pavement. A sample of the resulting PCI-Age relationship curve is given in Figure 3 above.

SENSITIVITY ANALYSIS FOR THE CURRENT AND FUTURE NEEDS

Current or now needs sections in a pavement network are those that have reached the minimum acceptable level of performance, Pavement Condition Index (PCI) in this research. In some cases the section may be below the minimum acceptable level based on limited budgets. If sufficient funds are available, the needs year become the action year. Otherwise the identified sections are deferred to a later point in time when funding is available. In a pavement management system, the future needs are also identified based on the deterioration prediction model. Accordingly budgets are fixed on the criteria established by the organization.

A sensitivity analysis was carried out for the now or current needs by assuming different levels for minimum acceptable PCI for different branches. The airside pavement network in this case study analysis consists of a total of 31 branches which are further divided into 271 sections. Each section is considered as a project level. Of the 31 branches, 4 are runways, 23 are taxiways, 2 roadways, and 2 are holding bays for runways. The minimum acceptable level of PCI for taxiways and holding bays are assumed to be equal. Therefore only three kinds of pavements for different minimum acceptable levels of PCI namely runways, taxiways, and roadways are examined. The now needs year was established as 2003.

Three levels of minimum acceptable PCI were considered and analysis was carried out. The three different levels are as follows:

i. Minimum acceptable level of PCI for runway 65, taxiways 60, and for roadway 50.

ii. Minimum acceptable level of PCI for runway 70, taxiways 65, and for roadway 55.

iii. Minimum acceptable level of PCI for runway 75, taxiways 70, and for roadway 60.

All the distress data for every section was entered in MicroPAVER and the PCI was calculated. The default model was used to predict future performance for each section. The deterioration prediction for a sample section is provided in Figure 3.

Analysis of the prediction models developed for all the sections showed that, by fixing the minimum acceptable level of PCI for runways as 65, for taxiways as 60, and for road ways as 50, there were a total of 39 sections that need to be rehabilitated or in other words 39 sections are the current needs. Out of these 39 sections, 11 are runways, 26 are taxiways, and 2 are roadways.

The surface area of these 39 sections is 232,662.5 m^2 which comprises 16% of the total network area.

Table 1 shows the sensitivity analysis for the current and future ten years needs for the three levels of minimum acceptable PCI. This analysis is based on a "do nothing" policy. It is clear from the table that if this policy is adopted, in ten years the needs sections will increase from 39 to 74 for the first level of minimum acceptable PCI (i above).

If the minimum acceptable level of PCI is assumed to be 70 for runways, 65 for taxiways, and 55 for roadways, the number of sections that need to be rehabilitated immediately goes up to 46 which results in approximately 20% of the total surface area of the network.

By enhancing the minimum acceptable level of PCI further by 5 PCI levels for each runway, taxiway, and roadway, the number of now needs sections jumps up to 58 whose area is 388515.5 m2 resulting in 26.5% of the total surface area of the network.

Table 1.
Needs Analysis for Ten Years with Changing Minimum Acceptable Level of PCI.

Needs Year	Branch Type	No. of Needs Sections when Minimum Acceptable Level of PCI is:					
		65 for Runways 60 for Taxiways 50 for Roadways	Total No. of Needs Sections	70 for Runways 65 for Taxiways 55 for Roadways	Total No. of Needs Sections	75 for Runways 70 for Taxiways 60 for Roadways	Total No. of Needs Sections
2003	Runways	11	39	16	46	25	58
	Taxiways	26		27		30	
	Roadways	2		3		3	
2004	Runways	15	44	23	53	26	66
	Taxiways	27		27		37	
	Roadways	2		3		3	
2005	Runways	20	50	25	59	28	71
	Taxiways	27		31		40	
	Roadways	3		3		3	
2006	Runways	23	55	26	61	29	76
	Taxiways	29		32		44	
	Roadways	3		3		3	
2007	Runways	24	58	27	65	33	85
	Taxiways	31		35		49	
	Roadways	3		3		3	
2008	Runways	25	60	29	70	36	90
	Taxiways	32		38		51	
	Roadways	3		3		3	
2009	Runways	26	61	32	75	42	97
	Taxiways	32		40		52	
	Roadways	3		3		3	
2010	Runways	29	68	33	80	52	111
	Taxiways	36		44		55	
	Roadways	3		3		4	
2011	Runways	29	71	39	88	60	133
	Taxiways	39		45		69	
	Roadways	3		4		4	
2012	Runways	31	74	57	113	62	161
	Taxiways	40		52		95	
	Roadways	3		4		4	

Figure 4 is developed showing the distribution of needs sections of the airside pavements in the case study for a ten year period. Figure 5 details the total percentage of pavement surface area that require rehabilitation. When the minimum acceptable level of PCI is changed to 75 for runways, 70 for taxiways, and 60 for roadways the percent of needs dramatically increased as would be expected. Thus, if the "do nothing" policy is applied to the network, 56% of the total surface area will need to be repaired after ten years.

If the unlimited funds scenario is adopted and all the needs sections can be rehabilitated once they reach their minimum acceptable service level, the distribution of needs for ten years will dramatically fall. Such a scenario is summarized in Figures 6 and 7. Table 2 provides a summary of all the needs sections in terms of number of sections, surface area, and percent of the total network surface area for all the three levels of minimum acceptable PCI in both the unlimited and no funds scenarios.

As all the sections are not of the same area, it is not recommended to use the number of sections for fixing budget. Thus, needs in terms of surface area can be used to determine the final list of sections requiring repair. Table 2 shows that the number of needs sections for the first series of minimum acceptable level of PCI in years 2004 and 2006 is five. However, the area associated with these needs varies. Similarly in year 2007, 2011, and 2012 there are three needs sections for each of these years. However, the surface area ranges from 6138 m^2 to 14005 m^2. Hence almost 2.5 times more budget will be required to fix the three needs sections in year 2011 than the three sections in year 2012.

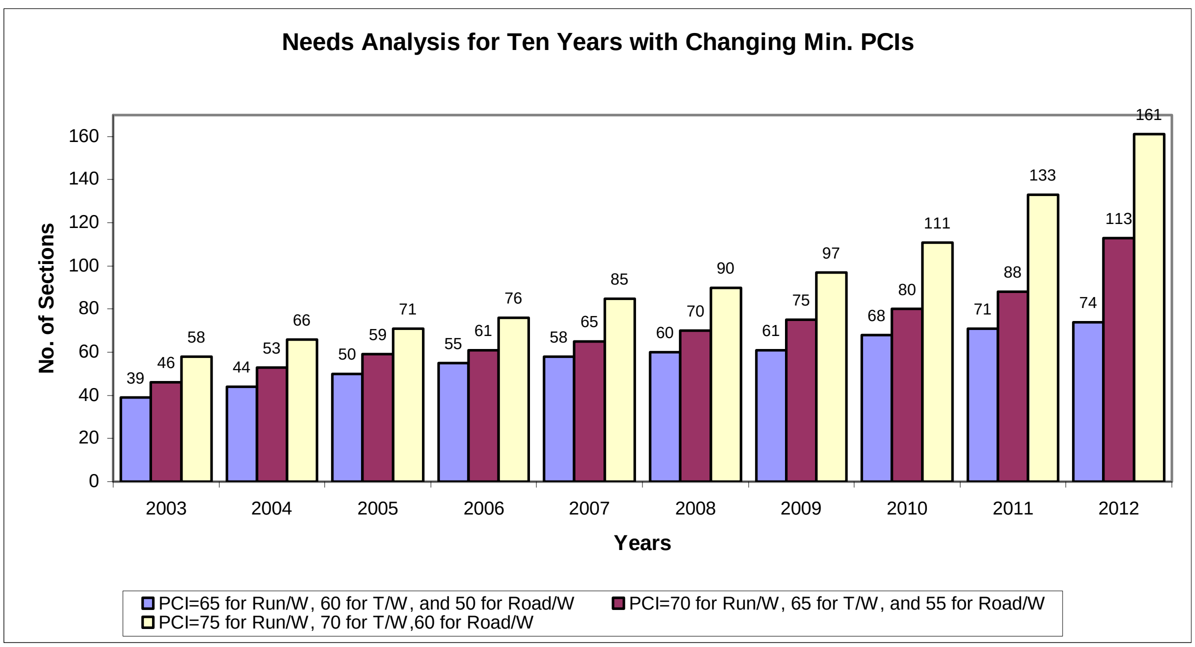

Figure 4. Comparison of Needs for Ten Years with Different Minimum Acceptable Level of PCI.

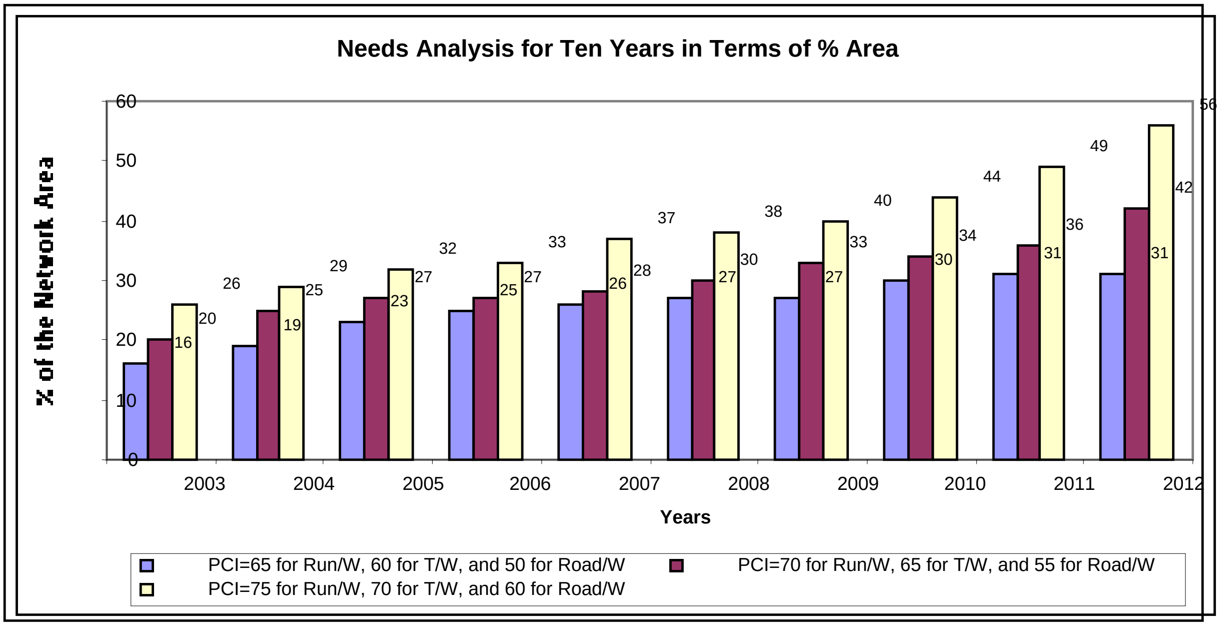

Figure 5. Comparison of Needs for Ten Years in Terms of Percent Area.

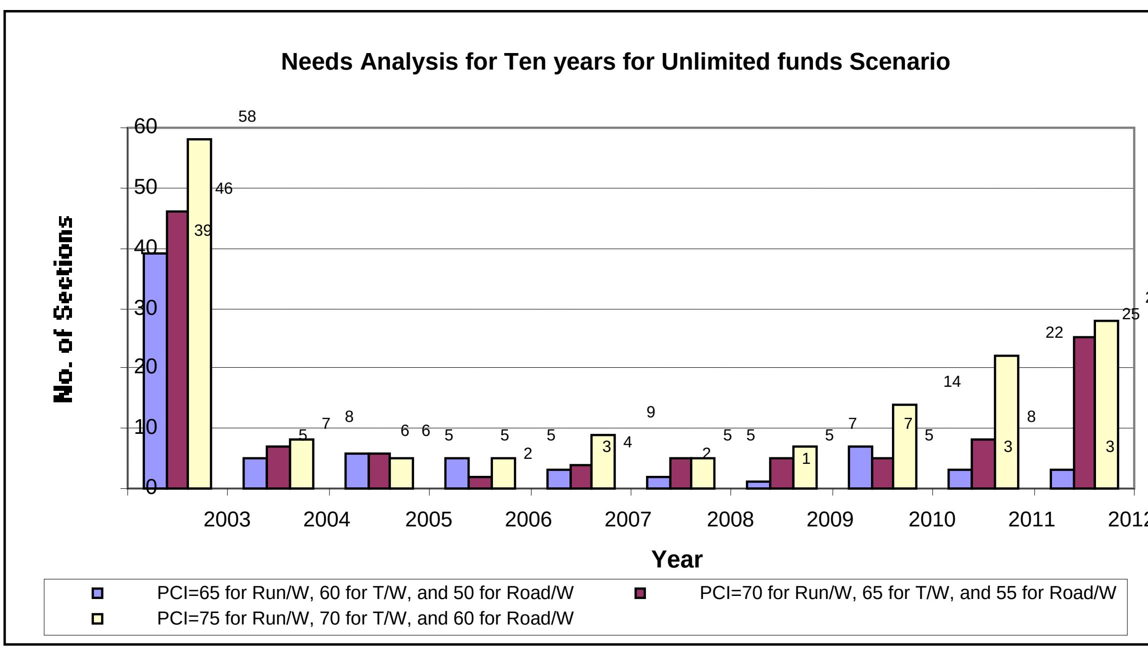

Figure 6. Needs Analysis for Ten Years in Case of Unlimited Funds (In terms of No. of Sections).

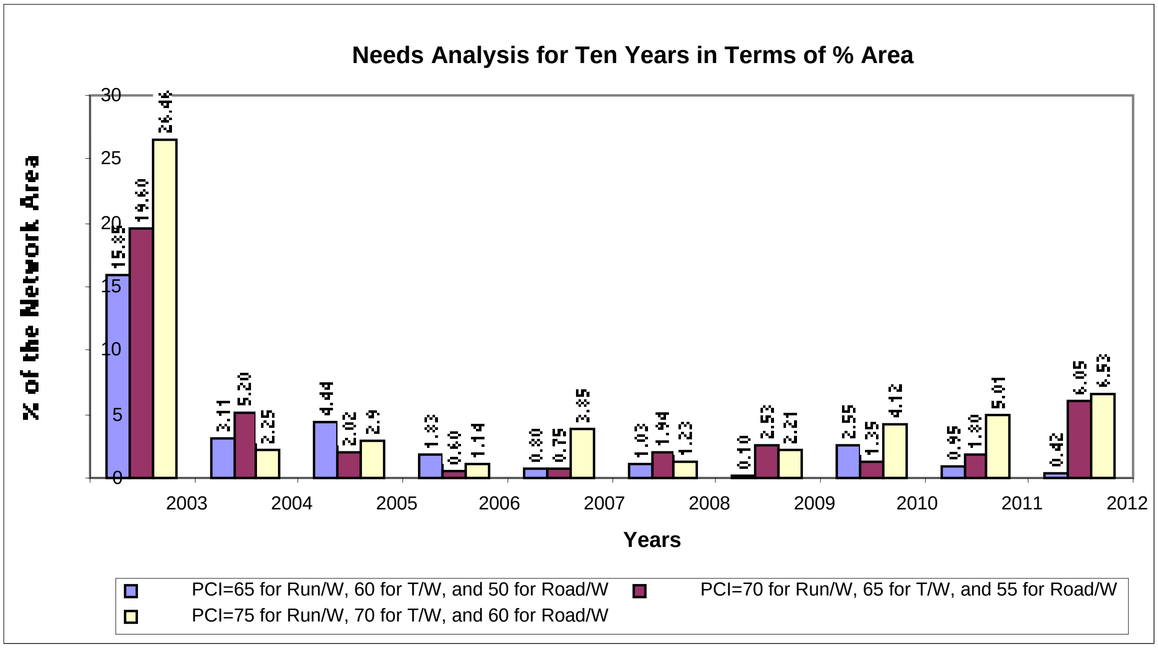

Figure 7. Needs Analysis for Ten Years in terms of Percent Area (Unlimited Funds Scenario).

DETERMINING THE LIST OF PRIORITIES

Proper funding for the current and future needs has always been a problem for the management of pavements. With the introduction of prioritization it has enabled engineers and managers to identify those pavement sections that need attention. By fixing priorities the available budget can be diverted to the sections that need to be rehabilitated first.

Prioritization of needs sections is based upon the policy and resources of agency. The factors that need to be considered while assigning priorities are; deterioration index (in this case PCI), branch use (runway, taxiway, apron, or service road), and pavement rank (primary, secondary, or tertiary). Prioritization also depends on traffic conditions, subgrade conditions, drainage condition etc.

Depending on the funding levels, location, and specific conditions of a transportation agency, different methods ranging from a simple subjective ranking of projects based on judgment to comprehensive optimization by mathematical programming models, are being used for determining priorities. Each method has specific features such as the pavement rating parameters and type of economic analysis [5]. Every method follows almost the same basic principles of the framework presented in Figure 8. Whatever the agency chooses as the preferred method of priority programming, it should be able to answer the following:

Table 2.
Summary Distribution of Needs for Ten Years in Case of Both No Funds and Unlimited Funds.

Total Surface Area of the Airside Pavement Network: 1468041 SM													
Needs Year			2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
		Funds Scenario											
Number of Sections when Minimum Acceptable Level of PCI =	65 for Run/W 60 for T/W 50 for Rd/W	No Funds	39	44	50	55	58	60	61	68	71	74	271 Sections
		Unlimited Funds	39	5	6	5	3	2	1	7	3	3	
	70 for Run/W 65 for T/W 55 for Rd/W	No Funds	46	53	59	61	65	70	75	80	88	113	
		Unlimited Funds	46	7	6	2	4	5	5	5	8	25	
	75 for Run/W 70 for T/W 60 for Rd/W	No Funds	58	66	71	76	85	90	97	111	133	161	
		Unlimited Funds	58	8	5	5	9	5	7	14	22	28	
Needs in terms of Area (SM) when Minimum Acceptable Level of PCI =	65 for Run/W 60 for T/W 50 for Rd/W	No Funds	232663	278286	343536	370335	382085	397220	398720	436092	450097	456235	1468041 m^2
		Unlimited Funds	232663	45623	65250	26799	11750	15135	1500	37372	14005	6138	
	70 for Run/W 65 for T/W 55 for Rd/W	No Funds	287691	364056	393800	402500	413492	441978	479230	499023	525349	614261	
		Unlimited Funds	287691	76365	29744	8700	10992	28486	37252	19793	26326	88912	
	75 for Run/W 70 for T/W 60 for Rd/W	No Funds	388516	421458	464104	480791	537264	555339	587741	648355	721852	817634	
		Unlimited Funds	388516	32942	42646	16687	56473	18075	32402	60616	73497	95782	
Percent of the total Airside Pavement Network area when Minimum Acceptable Level of PCI =	65 for Run/W 60 for T/W 50 for Rd/W	No Funds	15.85	18.96	23.4	25.23	26.03	27.06	27.16	29.71	30.66	31.08	100 %
		Unlimited Funds	15.85	3.11	4.44	1.83	0.80	1.03	0.10	2.55	0.95	0.42	
	70 for Run/W 65 for T/W 55 for Rd/W	No Funds	19.60	24.80	26.82	27.42	28.17	30.11	32.64	33.99	35.79	41.84	
		Unlimited Funds	19.60	5.20	2.02	0.60	0.75	1.94	2.53	1.35	1.80	6.05	
	75 for Run/W 70 for T/W 60 for Rd/W	No Funds	26.46	28.71	31.61	32.75	36.60	37.83	40.04	44.16	49.17	55.70	
		Unlimited Funds	26.46	2.25	2.90	1.14	3.85	1.23	2.21	4.12	5.01	6.53	

i. Identify the sections of the network that need to be rehabilitated or maintained (i.e., identifying the now needs).

ii. Identify the type of treatment that should be applied to a certain section (i.e., within project treatment alternative).

iii. Determine when each section should be rehabilitated (selection of timing).

iv. Determine how much the selected treatment for the selected section will cost.

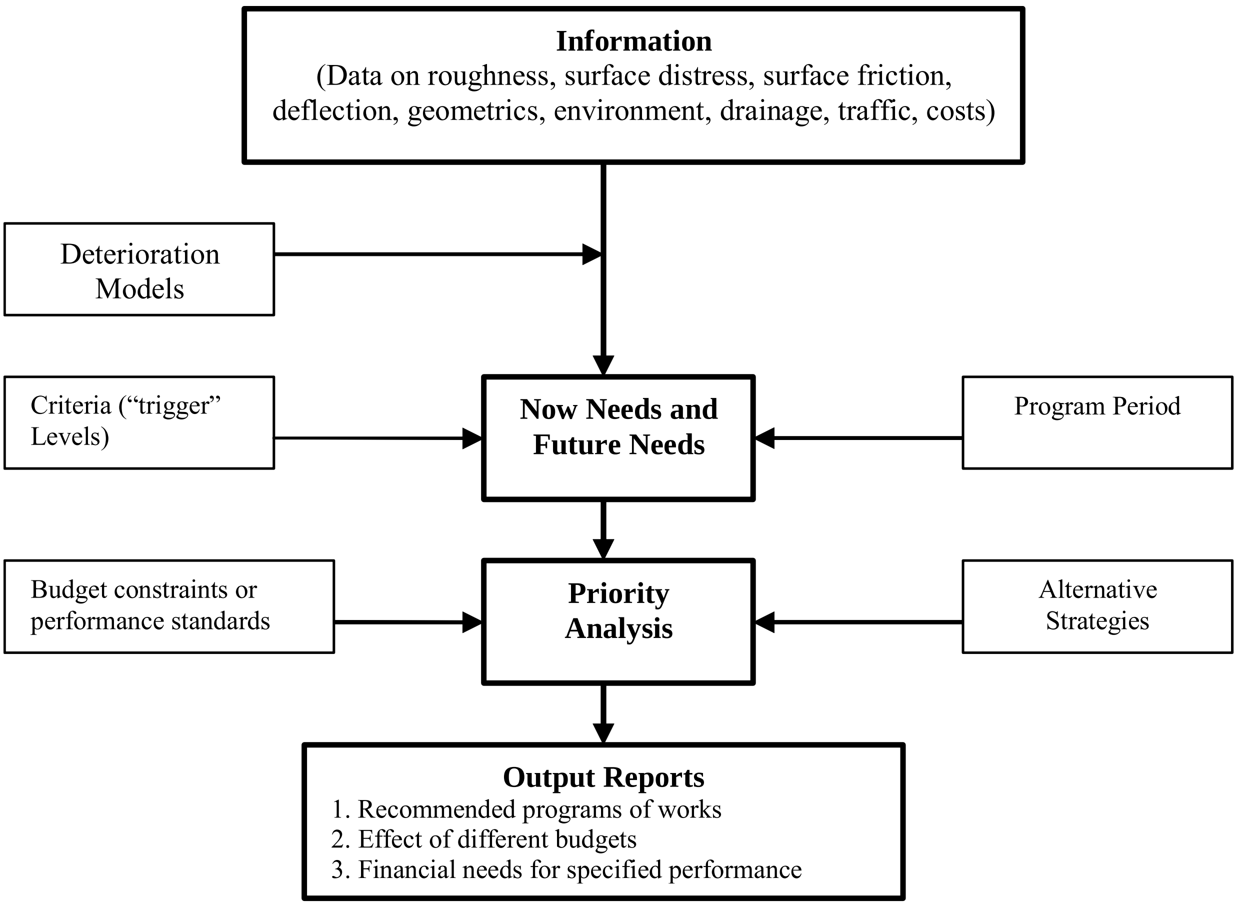

Figure 8: Framework for the Priority Programming Process [5]

The M&R alternative that should be selected for a section should be the most cost-effective. The main role in this portion of the analysis framework is to examine how it relates to the Life Cycle Cost Analysis (LCCA) of the M&R alternative and available budget. Generally there are two budget scenarios, an unlimited budget scenario and a restrained budget. In the first case, the alternative with highest benefit- Cost (B/C) ratio is selected. While in the case of constrained budget, if the funds are not enough for the first priority, the second one is selected. If funds are still not sufficient for the second alternative, the third one will be selected until all constraints are satisfied. For example, A, B, and C are the three alternatives. After the prioritization process, alternative A is selected as the most cost-effective alternative for a prioritized section of pavement, but due to budget limitations, this alternative can not be implemented; therefore the next most cost effective alternative B is selected. If the cost associated with this alternative is also greater than the cost allowed by the budget then C is selected.

In the prioritization process, the expertise of the engineers and managers should always be used to ensure there is balance in the management system. This allows for the advancement or deferral of sections based on the various operational, engineering and maintenance considerations.

Methods Used for Prioritization of Sections

Three methods of prioritization for current needs are being discussed in this section. When the minimum acceptable level of PCI for the runways is 65, for the taxiways 60 and for the roadways 50, then the current needs for the year 2003 are 39 sections with an area of 232663 m^2. In the case of the second and third levels, the numbers of sections are 46 and 58 with area of 287691 m^2 and 388516 m^2 respectively.

Prioritization on the basis of PCI only

This method of prioritization is based on the worst condition of sections. A section with the least PCI value in the network will be the top priority and the second least will be the second priority and so on. It does not take the operational or functional classification of the sections into account. If the current PCI for a service road is 20 and for a runway it is 50, by applying this method the roadway has to take priority because of the poor PCI value. But in reality, the runways would usually take precedence over the roadway based on priorities. This method would focus on the worst condition basis. Prioritization of the current needs of 39 sections for the first level of minimum acceptable PCI, 46 for the second level and 58 sections for the third levels for airside pavements were identified for this case study using this method. Calculations for all the needs sections for the three different minimum acceptable level of PCI were carried out and sample calculations are shown in Table A1 in the Appendix. Overall, this method can result in an unacceptable decision.

Furthermore, this can result in selecting sections that are functionally less important by selecting secondary sections over more important primary sections (Refer to Table A1 in the Appendix). Based on this rational this method is not very effective for a larger network. However this method can work for a small network where all other conditions are the same or if there are minimal differences in the functional or operational classification.

Prioritization Through Near Optimization Method

This method has been used for prioritization by a number of States Department of Transportations (DOT's) and some Canadian provincial DOT's. This method is considered as the basis for a comprehensive and integrated pavement management system [1]. This method includes the following steps:

i. Consider each combination of section, treatment alternative, and year in the program period.

ii. Calculate the Effectiveness, E, of each combination (which is the area under the performance curve, multiplied by ADT, and section length).

iii. Calculate the cost, C, in net present value terms, of each treatment alternative in each combination.

iv. Calculate the cost-effectiveness, CE, of each combination as the ratio of E/C (i.e., a ratio inverse in concept to the benefit-cost ratio method).

v. Select the combination of treatment alternative and year for each section which has the best CE, until the budget is exhausted.

Determination of Feasible Rehabilitation Treatment Alternatives

There are more different treatment alternatives available for rehabilitation of a pavement section. Thus, it is very important to examine the specific needs of the section and the associated life cycle cost of the alternative. For example if a thin asphalt concrete overlay is selected for a pavement that has severe load related distresses, the decision will likely not be cost effective. On the other hand if a section exhibits construction or material related deficiencies such as raveling, a thin overlay would work well in this case.

It is also very important to consider the timing of the rehabilitation. Rehabilitation funding restrictions may make it necessary to defer or advance the placement of the rehabilitation for several years. For example, if an investment is deferred, during this period of time, the distresses will increase and the original thin overlay treatment will not be the cost-effective treatment alternative. Table 3 details typical service lives and relative costs for various treatments [5]. In addition a decision tree is presented in Figure 9, which provides advice on how to relate distresses to treatments. The following rehabilitation treatment alternatives are considered for this case study analysis;

i. Thick hot mix overlay (3 lift)

ii. Reclamation (3 lift) hot mix overlay

iii. Milling and resurfacing with 3 lift hot mix overlay

iv. Hot-in-place recycling

v. Cold-in-place recycling

The condition index used in the decision tree in Figure 9 is based on a Pavement Serviceability Index (PSI). To convert the PSI to PCI, the PSI has been multiplied by 10 (i.e., PSI 4 is equal to PCI 40). The expected and calculated PCI for the selected rehabilitation treatment alternatives and their unit costs are provided in Table 4. These values are based on the Ministry of Transportation Ontario (MTO) practices [7]

Table 3.
Normally Expected Pavement Rehabilitation Treatment Service Lives and Relative Cost [5].

Rehabilitation Alternative	Expected Service Life (Years)	Relative Cost
<u>Flexible Pavements</u>		
Reconstruction	Up to 12 – 15	High
Resurfacing (Thin Overlay)	Up to 8 – 10	Low
Resurfacing (Thick overlay)	Up to 12 – 15	High
Milling and resurfacing	Up to 10 – 12	Medium
Hot in-place recycling	Up to 10 – 12	Medium
Cold in-place recycling	Up to 10 – 12	Medium
Full depth reclamation (Pulverization and resurfacing)	Up to 12 - 15	High
<u>Rigid Pavements</u>		
Asphalt concrete surfacing	Up to 12 – 15	Medium
Diamond grinding	Up to 8 – 10	Low
Joint stabilization	Up to 5 – 10	Low
Crack, seat, and resurfacing	Up to 12 – 15	High
Rubblizing and resurfacing	Up to 12 – 15	High
Bonded concrete overlay	Up to 15 – 20	High
Unbonded concrete overlay	Up to 25 – 30	High
<u>Surface treated Pavements</u>		
Surface treatment reapplication	Up to 2 – 5	Low
Pulverization or scarification and resurfacing	Up to 8 – 10	Medium

Distress Presence	**Combination of Distress (Read Vertically)**																	
PSI < 4	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cracking Major	No	No	No	No	Yes	Yes	Yes	Yes										
Rutting>30%	Yes	No	No	No														
Ravelling>30%		Yes	No	No														
Bleeding >30%			Yes	No														
Allig. Cr. > 30%					No	No	No	Yes										
Edge Cr > 30%					No	No	Yes											
Long. Cr > 30%					No	Yes												
Excess crown Maj.									Yes	No	No							
AADT > 5000										No	Yes	No	Yes	No	Yes		No	Yes
Allig. Cr. Maj												No	No	Yes	Yes			
Rutting Maj.																No	Yes	Yes
Feasible Rehabilitation Actions	3 4 6 11	1 5 7 12	1 8 12	2 4 5	2 5 7	3 4 6 9 10	2 6 9 11	3 6 11	4 10	1 4 10	2 9 11	2 4 5 9 10	3 4 9 11	2 4 6 10	3 9 11	2 4 5 8	3 4 5 8 10	3 6 9 11

REHABILITATION CODES

1. 25 mm overlay	5. Recycle 25 mm + 25 mm overlay	9. Heater Plan 25 mm + 75 mm overlay
2. 50 mm overlay	6. Recycle 25 mm + 50 mm overlay	10. Reconstruct 50 mm AC/ 100 mm ABC
3. 75 mm overlay	7. Heater Plan 25 mm + 25 mm overlay	11. Reconstruct 50 mm AC/ 150 mm ABC
4. Mill 25 + Chipseal	8. Heater plan 25 mm + 50 mm overlay	12. Chipseal

Figure 9. Decision Tree Used to Select Feasible Rehabilitation Treatment Alternatives [5].

Table 4.
PCI, Life and Unit Costs of Selected Treatment Alternatives [7].

No.	Rehabilitation Alternative	Actual PCI	Expected PCI	Life (Years) Min/Expected/Max	Unit Cost $/m^2$
1.	3 Lift Hot mix overlay	95	100	12/ 12.5/ 15	17
2.	Reclamation + 3 Lift Hot mix Overlay	95	100	12/ 13.5/ 15	18
3.	Mill and resurface with 3 lift hot mix overlay	95	100	10/ 12.5/ 15	19
4.	Hot in-place recycling	90	92.9	9/ 10.6/ 12	14
5.	Cold in-place recycling with overlay	90	92.9	10/ 12.5/ 15	12.50

The aforementioned five treatment alternatives are selected because of their high expected PCI values. Cold in-place recycling and Hot in- place recycling are also included in the analysis.

If the cold in-place recycling or hot in-place recycling are determined to be more cost-effective, they will utilize minimal quantities of new material which provides benefits to the environment. These methods also treat the existing pavement distresses and have the ability to reprofile as well as rejuvenate the pavement surface. Table 4 describes the impact of various treatments in terms of performance (PCI), expected life and unit cost. Note, values have been modified to determine the expected life of the rehabilitation treatments in the airport context and these are presented in Table 5.

The values of expected life are slightly higher due to differences in traffic and overall climatic conditions. The primary reason for this is that arriving aircrafts are lighter than departing aircrafts because of the lighted fuel loads. With regards to assessing ADT in the analysis, a general value was included which reflects the type and size of aircrafts travelling at the Toronto Airport as the site specific (i.e. specific gate information) was not available. A sensitivity analysis was performed to determine the impact of variation but due to the scope of this paper, the full analysis is not included.

Table 5.
PCI, Life and Unit Costs of Selected Treatment Alternatives for Airport Case Study.

No.	Rehabilitation Alternative	Actual PCI	Expected PCI	Life (Years)	Unit Cost $/m^2$
1.	3 Lift Hot mix overlay	95	100	16	17
2.	Reclamation + 3 Lift Hot mix Overlay	95	100	20	18
3.	Mill and resurface with 3 lift hot mix overlay	95	100	18	19
4.	Hot in-place recycling	90	92.9	12	14
5.	Cold in-place recycling with overlay	90	92.9	15	12.50

Life Cycle Costing of the Selected Treatment Alternatives

Investing significant amounts of money in building new pavement structures, or improving those that already exist requires careful appraisal to ensure that optimum use is being made. The adoption of higher design standards normally results in a higher initial cost, but may result in lower costs to the agency in terms of future costs of renewal and maintenance. Life Cycle Costs are taken into account to make the investment decisions objective.

In general, life cycle cost analysis is done for new construction. In this paper the objective is prioritization of sections that need early rehabilitation. The best treatment alternative is selected on the basis of its expected life, performance, and the minor or routine maintenance needs during its life cycle.

Present worth method was selected for analysis which is described in [5]. The rehabilitation alternative that meets the design requirements for a desired level of functional service at a lowest cost over time (present worth cost) is selected as the optimum rehabilitation treatment.

Net present value of a rehabilitation alternative can be calculated by the following equation:

$$NPV = (IRC)_{x_1} + \sum_{t=0}^{t=n} PWF_{i,t}\left[FRC_{x_1,t} + MC_{x_1,t}\right] - (SV)_{x_1,n} \times PWF_{i,n} \qquad (1)$$

Where:

NPV = Net Present Value
$(IRC)_{x1}$ = Initial Rehabilitation Cost of Alternative x_1
$(FRC)_{x1,t}$ = Future Rehabilitation Costs of Alternative x_1 in year t
$MC_{x1,t}$ = Maintenance Costs of Alternative x_1 in year t
PWF = Present Worth Factor = $1/(1+i)^n$
i = Discount rate
n = Year when the cost is incurred
$(SV)_{x1,n}$ = Salvage Value of Alternative x1 at end of the analysis period

Initial rehabilitation costs are taken from Table 5 that were obtained from MTO. The costs have been calculated based on a standard measure of 100 m^2. The routine maintenance costs for rout and seal, mill and patch etc. were also obtained from MTO [7]. The analysis period is selected as twenty years as the expected life of one of the alternatives is twenty years.

Discount rate is used to reduce the future expenditures to present day values. In this analysis a discount rate of 6% is used. Costs of routine maintenance such as pothole repair are not included in the analysis. However major maintenance such as routing and sealing, and patching were included. The selected quantities and year of applications are based on engineering best practice combined with actual data from maintenance records.

Salvage value is the value of material in place at the end of the service life of the pavement. This is a benefit and it is therefore a negative cost. Salvage value is included in the analysis because it is significant in the case of pavements. Calculation of salvage value was based on the remaining service life at the end of the twenty years analysis period. Salvage Value can be calculated from the following equation:

$$SV = \frac{FC_{LR} * SL_R}{SL_T} \quad (2)$$

Where:

SV = Salvage Value
FCLR = Future Cost of the last rehab prior to year 20
SLR = Service Life remaining at year 20
SLT = Total Service Life expected after the rehabilitation

Engineering costs, management costs and user costs are neglected in the analysis as it is assumed they will not vary significantly for all of the various treatment alternatives.

After carrying out the complete Life Cycle Cost calculations, using the discount rate of 6% for all the five rehabilitation treatment alternatives, the costs obtained in terms of net present value are summarized in Table 6 below.

Table 6.
Comparison of Life Cycle Cost for the Five Treatment Alternatives.

Alternative No.	Alternative Name	Cost ($) / 100 m^2
1.	3 Lift Hot mix overlay	2202.81
2.	Reclamation + 3 Lift Hot mix Overlay	1898.42
3.	Mill and resurface with 3 lift hot mix overlay	2194.53
4.	Hot in-place recycling	2183.34
5.	Cold in-place recycling with overlay	1723.11

Based on the results obtained from the life cycle cost of the five rehabilitation alternatives, Alternatives 1, 3, and 4 are eliminated from the analysis due to the high cost. These alternatives are very expensive compared to other two alternatives and are therefore not considered. Among the remaining two, Alternative 2 is selected. Although Alternative 5 is more cost-effective as compared to Alternative 2, alternative 2 is selected based on the airport engineering experience. Also, the expected value of PCI after rehabilitation is higher for Alternative 2 than the one expected for Alternative 5.

Overall, based on engineering best practice, Alternative 2, i.e., “Reclamation with 3-lift hot mix overlay” is selected for rehabilitating the now needs sections in this case study. The cost of this treatment is used in the calculation of cost-effectiveness method of prioritization.

Calculation of Effectiveness

Effectiveness of a section of pavement is defined as the area under the performance curve multiplied by ADT and length of the section. This definition is valid for highways because in highways generally width (lane width) of all the sections is same and therefore only length is considered. In airfields different pavement sections have different lengths, widths and areas are typically based on geometric differences associated with the three types of airport pavements. In terms of traffic, the routine practice and data that is primarily available is the annual departures count. Departures are considered because they have heavier wheel loads than arrivals due to the full fuel tank. Hence in the airport context the definition of effectiveness is modified as "area under the performance curve multiplied by volume of traffic (annual departures) and area of the section."

A typical schematic illustration for a rehab alternative deferred from its need year is given in Figure 10. Effectiveness *E*, according to the above definition can be given as;

$$E = \left[\sum_{\mathrm{Re}\,habYear}^{PCI_R \geq PCI_M} (PCI_R - PCI_M) - \left(\sum_{PCI_N \geq PCI_M}^{\mathrm{Re}\,habYear} (PCI_M - PCI_N) \right) \right] * [AD] * \text{Area of the section} \qquad (3)$$

Where:

E	= Effectiveness
PCI_R	= Pavement Condition Index after rehabilitation (i.e., for the implementation year) and for each year until PCI_M is reached
PCI_M	= Minimum acceptable level of PCI
PCI_N	= Yearly PCI from the Need year to the implementation year
[AD]	= Annual Departures
Area of Section	= Square metre area of pavement section

Annual Departures were calculated from the data available. In this example 1200 arrivals and departures are accommodated every day. The assumptions that were made for calculation of effectiveness are listed below:

i. Arrivals and departures are equal and therefore are 600 each.

ii. Each of the four runways gets the same amount of traffic, therefore annual departures for every runway are = 600 * 365 / 4 = 54750

iii. Every one of the 25 taxiways is also exposed to the same amount of traffic, hence the number of departures for taxiways = 600 * 365 / 25 = 8760

The total area of all of the 271 sections was known from the data provided.

Calculation of Cost in Terms of Net Present Value

Net present value of cost per 100 m^2 has already been calculated in the preceding sections. The rehabilitation treatment alternative that has been selected on its life cycle cost analysis has a unit cost of $1898.42 based on Table 6. As every section has a different area, the cost associated with every need section is also different.

Calculations of Cost Effectiveness

Cost effectiveness of a pavement section is the ratio of effectiveness to cost (*E/C*). It is calculated as dividing the effectiveness of a section by the cost in terms of a net present value.

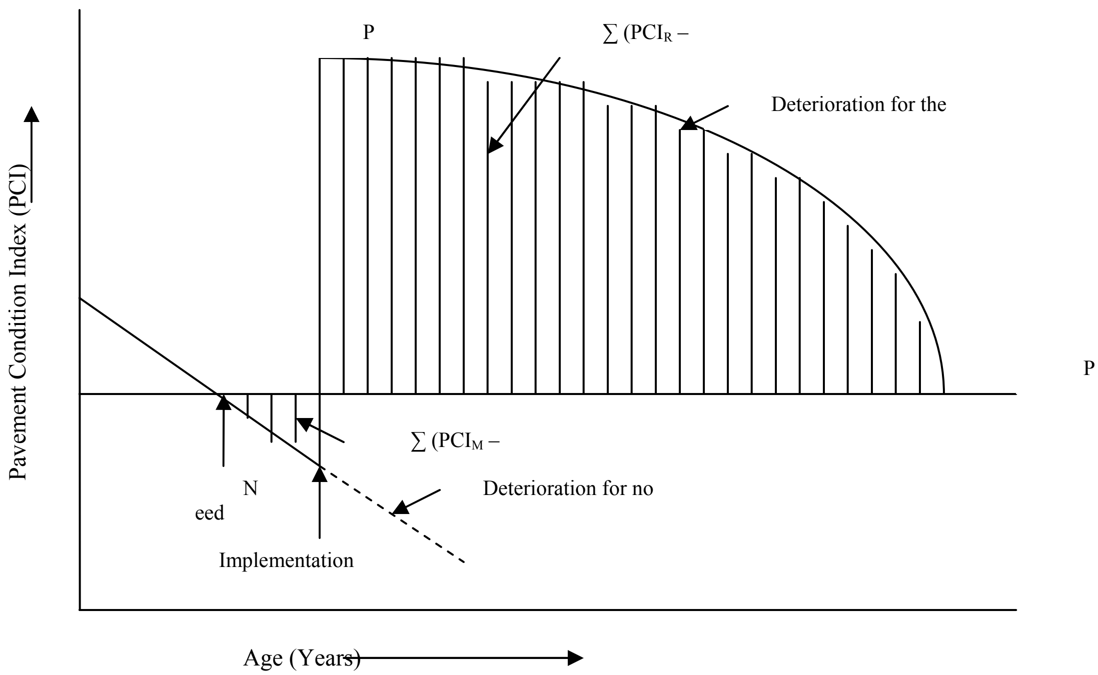

Figure 10. Schematic Illustration of Effectiveness for a Rehabilitation Alternative [5]

Calculations of cost, effectiveness, and cost-effectiveness for all the needs sections at three different levels of minimum acceptable PCI were carried out and prioritization of the sections on the basis of cost-effectiveness was made which are shown in Table A2 in the Appendix.

Prioritization by assigning weights to factors affecting the list of priorities

A unique method for prioritization of airfield pavement sections is described in this section. The method assigns a numeric score to different factors affecting the list of priorities. A score of 1 (least priority) to 10 (highest priority) is used in this research. The major factors that contribute to the prioritization analysis are categorized as Pavement Condition Index (PCI), Traffic (Annual Departures), Operational Sensitivity (OS), and Functional Classification (FC). Using engineering best practice and judgment, a score to these contributing factors is assigned as shown in Table 7.

The Pavement Condition Index (PCI) has the highest weighting factor in prioritization program. Thus, if a section has a lower value of PCI, it will indicate a higher weighting in calculating a priority score and vice versa. Traffic on the airfield pavement is counted as the annual departures taking off from a particular section of pavements. This is based on the maximum traffic weight that is usually about 75% of the maximum take off weight of the aircraft. Aircraft weight and frequency impact the performance of pavements. Different weightings are assigned to different traffic levels as shown in Table 8.

Operational Sensitivity (OS) refers to the importance of a section in the entire network. OS of a section indicates how much is this important in terms of operation? Weighting on the scale of 1-10 is given for runways, taxiways, Aprons, and roadways. Using some engineering judgment a weight of 10 is given to runway, 7 to taxiway, 4 to apron, and 2 to roadway. Relative weighting of operational sensitivity is given in Table 9.

Table 7.
Relative Importance of Contributing Factors in the Prioritization Program (Weighting 1 to 10).

Factors	Very Important	Important	Somewhat Important	Less Important	Not Important
	Weighting =10	Weighting=8	Weighting=5	Weighting=3	Weighting=1
Pavement Condition Index (PCI)	X				
Traffic in Terms of Annual Departures			X		
Operational Sensitivity			X		
Functional Classification		X			

Table 8.
Relative Weightings Given to Annual Traffic in the Prioritization Program.

Contributing Factor	Traffic Level	Weighting (1-10)
Annual Traffic in Terms of Departures	High (> 10,000)	10
	Medium (5,000 to 10,000)	6
	Low (<5,000)	2

Table 9.
Relative Weightings of Operational Sensitivity in the Prioritization Program

Contributing Factor	Pavement Type	Weighting (1 to 10)
Operational Sensitivity	Runway	10
	Taxiway	7
	Apron	4
	Roadway	2

Functionally every pavement is classified as either primary, secondary, or tertiary. For example, a runway can be a primary runway, secondary runway, or tertiary runway depending upon its functional importance. Similarly, this is the case for taxiways, aprons and roadways. This factor is also considered in the prioritization program to help in quantifying the prioritization within a class of pavements and also among classes of pavements. Functional classification determines whether a primary runway has priority over a secondary runway or a priority of primary runway over primary taxiway or primary apron and so on. Table 10 is developed to quantify the order of priority of each facility by using engineering judgment and some past work in this respect.

Based on the priority numbers indicated in Table 10, relative weightings on a scale of 1 to 10 are assigned to the different functional classes of pavements. Based on previous work [3] and combining this with airport engineering experience Table 11 was developed. This table shows the relative weightings of the functional classification for the priority programming. Table 11 exactly reflects the priority order of Table 10.

All the above four contributing factors and their relative weightings are used to calculate the priority score (PS_i) in equation 4 below,

Table 10.
Priority Number of Functional Classification.

Functional Classification (Weighting 1 to 10)[a]	Type of Pavement	Primary	Secondary	Tertiary
	Runway	1	3	7
	Taxiway	2	5	8
	Apron	4	6	9
	Roadway	6	8	10

[a]1 represents top priority while 10 indicates the least priority

Table 11.
Relative Weightings of Functional Classification for the Prioritization Program.

	Primary	Secondary	Tertiary
Runway	10	8	4
Taxiway	9	6	3
Apron	7	5	2
Roadway	5	3	1

$$PS_i = [w_1 * (100 – PCI)/10 + w_2 * (Traffic) + w_3 * (OS) + w_4 * (FC)] / W \quad (4)$$

Where:

PS_i	= Priority Score of section i
PCI	= Pavement Condition Index
Traffic	= taken as annual departures
OS	= Operational Sensitivity
FC	= Functional Classification
w_1, w_2, w_3, w_4	= are the corresponding weightings of PCI, Traffic, OS, and FC respectively and are derived from Table 8.
W	= $w_1 + w_2 + w_3 + w_4$

With regards to traffic, OS, and FC, a weighting scale of 1 to 10 is also used. The PCI is then normalized to a scale of 1 to 10 to provide a uniform range.

Calculations for all the needs sections for the three different minimum acceptable level of PCI were carried out and sample calculations are shown in Table A3 in the Appendix. The priority score ranges from 1 (least priority) to 10 (highest priority). The sections are presented in their descending order priority number.

COMPARISON OF THE THREE METHODS OF PRIORITIZATION

The results of the three methods for the entire airside network level pavements are compared. Based on this analysis a section of taxiway was shown to take priority over a runway section in both the PCI method and cost-effectiveness method (Tables A1 and A2). Results of both of these methods are almost similar and do not seem to be logical. The method developed herein gives reasonable results as it takes other factors into consideration. This method of prioritization which assigns weights to different contributing factors needs comparatively less effort and time involved in fixing priorities. In addition, it provides results that appear to be more logical and accurate. The results obtained by this method are selected for further analysis to determine the budgets.

The cost-effectiveness method of prioritization which is more often used in highways did not work well for this case study. This could be related to the following [2]:

1. Calculating area under the performance curve sometimes gives a negative value which can not be compared to other sections.

2. Before fixing the priorities, one has to perform the life cycle cost analysis for all the rehabilitation treatment alternatives, select the best alternative, find the cost of the sections, and apply the rehabilitation to determine the performance curve for calculating area. This procedure can be time consuming.

3. Area or length of a section is an important input in calculations of effectiveness (Effectiveness = area under the performance curve * traffic * length or area of the section) which may guide the management towards wrong decisions. For example if one section (i.e. section 1) is larger in area than another one (i.e. section 2), then section 1 may take priority over section 2

even if section 2 has more distresses than section 1. This idea can be illustrated by a worked example as follows:

Consider two different sections of pavements A and B in the same location. If both sections are exposed to the same traffic and the minimum acceptable level of PCI for both of the sections is 60 then the performance curves for both sections could be represented by Figure 11. Suppose section A has a surface area of 300 square metres and the surface area of section B is 3000 square metres. Both the sections have equal annual departures of 2000 and the same rehabilitation treatment is applied to both sections. Thus, the area under the performance curve after rehabilitation is the same (e.g., 200). If the cost of rehabilitation is $18 per square metre then the effectiveness is calculated as follows:

Effectiveness of section A = (200 – 80) * 300 * 2000 = 7.2 * 107

Cost of section A = 18 * 300 = $5400

Cost effectiveness of section A = 7.2 * 107 / 5400 = 13333.33

Effectiveness of section B = 200 * 3000 * 2000 = 1.2 * 109

Cost of section B = 18 * 3000 = $54000

Cost effectiveness of section B = 1.2 * 109 / 54000 = 22222.22

The results show that section B is more cost effective and should be given 1st priority but actually section A has priority over section B due to the fact it has a lower PCI value. This example further demonstrates the drawbacks to using this method of cost-effectiveness.

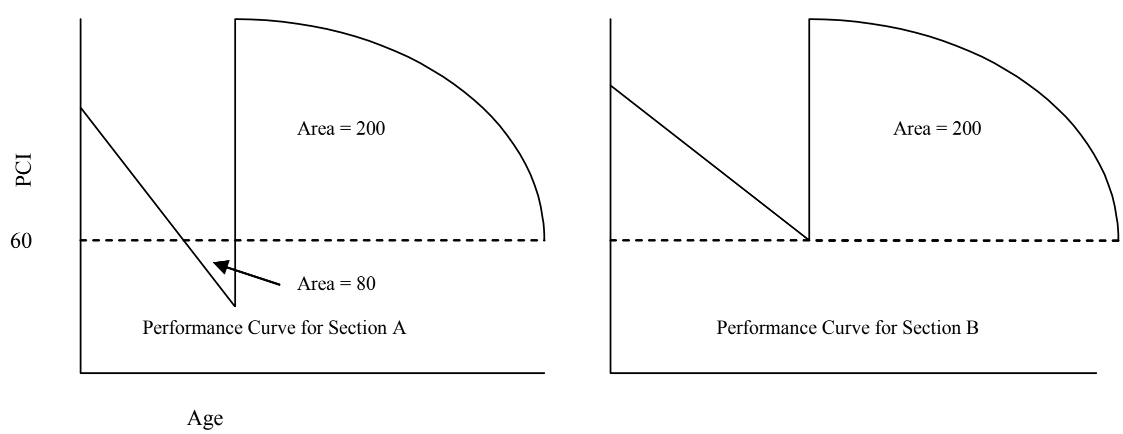

Figure 11. Performance of two pavement sections in the same location with different surface area.

DETERMINING BUDGETS FOR THE NOW NEEDS

An annual budget must be established to keep the pavements above their minimum acceptable level of PCI. Alternatively, deterioration will continue over time and eventually pavements will fail and reconstruction will be necessary. The now needs were based on the most effective prioritization combined with the various PCI levels. Budgets were subsequently determined.

When the minimum acceptable level of PCI is assumed to be 65 for runway, 60 for taxiway, and 50 for roadway, the needs for year 2003 were found to be 39 out of 271 sections. Surface area for these sections is 232,663 m2. As stated earlier, the best treatment alternative for rehabilitation has been selected as "reclamation with three lifts of a hot mix." Unit price in terms of net present value have been calculated as $1898.42 per 100 m^2. Hence the budget required to fix all the 39 sections is calculated as $4.417 million.

By increasing the minimum level of serviceability for each runway, taxiway, and roadway by five PCI levels, this resulted in seven more sections that required rehabilitated by the year 2003. The total area of all the 46 sections is 287,691 m2 and the budget required is $5.462 million, which shows an increase of almost 24% budget for just seven more sections.

Further raising the level of service by 5 PCI levels i.e., 75 for runways, 70 for taxiways, and 60 for roadways, the number of now needs sections jumped up to 58 with a total surface area of 388,516 SM. The budget required to fix these needs is calculated as $7.376 million which is further enhanced by more than 35% of the previous level.

Table 12 shows that a total of 67% more budget is required if it is desired to increase the minimum acceptable level of PCI from 65 to 75 for runways, from 60 to 70 for taxiways, and 50 to 60 for service roads on the airside in this case study.

EFFECT OF CHANGING PCI ON THE NETWORK LEVEL MANAGEMENT

After determining the now needs for the first set of minimum acceptable level of performance and budget, inspections were entered for 39 sections in MicroPAVER to see how sensitive the rehabilitation needs sections are in terms of the overall network level condition of pavements. It was also desirable to check the effect of changing minimum acceptable level of PCI based on the different scenarios. For this purpose, the inspections for 46 and then for 58 needs sections were entered into MicroPAVER. Every entry of the data was run three times to examine the impact of the scenarios. These results were then exported into Excel. The resulting curves are shown in Figure 12.

It was observed from Figure 12 that if no rehabilitation is applied to any section, the expected PCI for the network in year 2004 would be 78. After applying rehabilitation to 39 sections for the first set of minimum acceptable level of PCI, the network level PCI for the year 2004 jumped up to 88 thus improving the network level condition by 10 PCI levels. However for the second and third sets of the minimum acceptable level of PCI the effect on network level is not significant. It was improved only by one PCI level for every higher set of minimum acceptable level of PCI. Hence even after spending an additional 67% of the budget for first set of minimum acceptable level of PCI, the expected improvement in network level condition is only two PCI levels (from

88 to 90). Table 12 summarizes the effect of changing minimum acceptable level of PCI on the network condition.

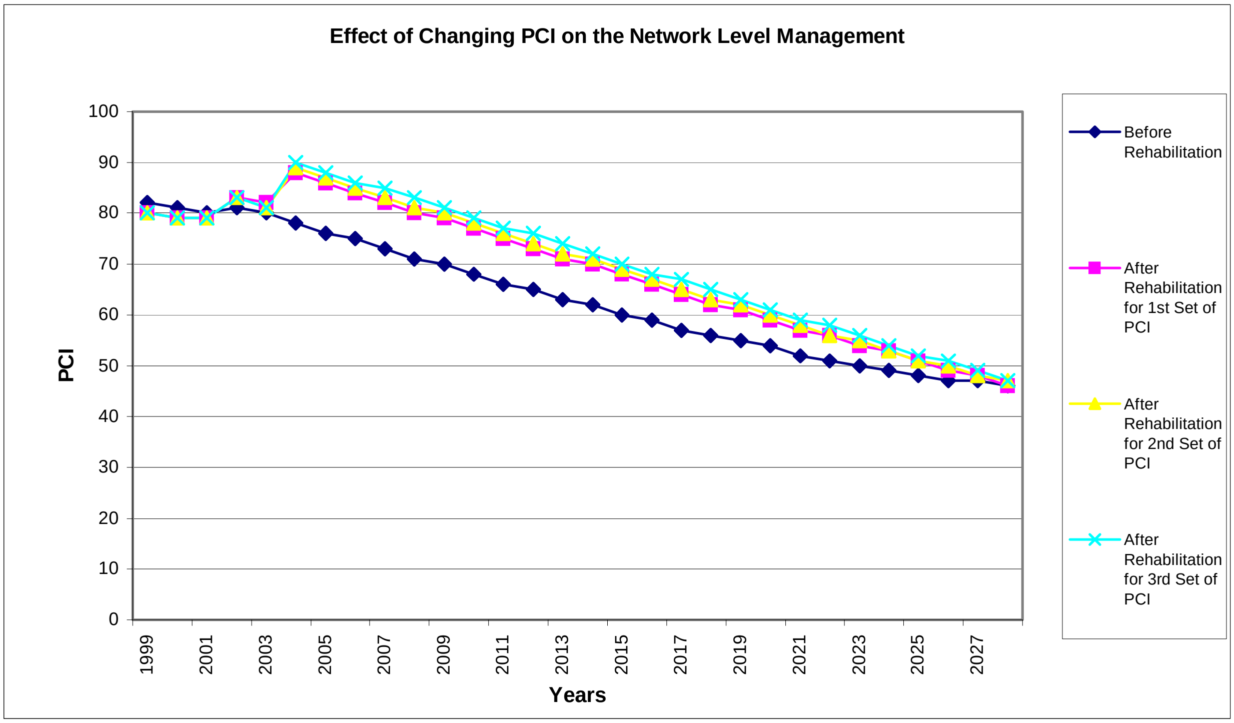

Figure 12. Effect of Changing PCI on the Network Level Management.

Table 12.
Impact of Changing Minimum Acceptable Level of PCI on the Network Level Pavements.

Minimum Acceptable Level of PCI	Number of Now Needs Sections	Area of Now Needs Sections (SM)	Budget Required to Fix the Needs ($ Million)	Enhancement in Budget from the 1st set of Minimum Acceptable Level of PCI (%)	Network Level Condition (PCI)
Before Rehabilitation (Do Nothing)	Not Applicable	Not Applicable	Not Applicable	Not Applicable	78
Runway = 65 Taxiway = 60 Roadway = 50	39	232,663	4.417	Not Applicable	88
Runway = 70 Taxiway = 65 Roadway = 55	46	287,691	5.462	24	89
Runway = 75 Taxiway = 70 Roadway = 60	58	388,516	7.376	67	90

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The purpose of the paper was to examine how tools can be used to optimize the management of pavements especially in the airport context. Pavement Condition Index (PCI) was calculated for all the airside pavement sections by entering the distress data into MicroPAVER. Current and future needs were identified and analyzed based on three different sets of minimum acceptable levels of PCI. Five treatment alternatives were analyzed for their life cycle cost and cost effectiveness. Available methods of prioritizing sections were analyzed and it was found that they were not suitable to the airport environment. Hence, a unique new method of prioritization was developed. Budgets required for the needs sections at three different sets of minimum acceptable PCI levels were calculated and their effect on the network level management was determined. Conclusions and recommendations drawn from this study are summarized as:

1. MicroPAVER can not assign different minimum acceptable level of PCI to different branches.

2. MicroPAVER can make calculations of predicted condition based on the history of pavement section for as many years as desired, for example 5, 10, 15, 20, 30 etc. years.

3. MicroPAVER can calculate how many sections of the network are in what condition in a specific year.

4. Prioritization of pavement sections at airports can best be done by the method developed in this research, where different weights are assigned to different contributing factors.

5. For the minimum acceptable level of PCI (i) 65 for runways, 60 for taxiways, and 50 for roadways, (ii) 70 for runways, 65 for taxiways, and 55 for roadways, (iii) 75 for runways, 70 for taxiways, and 60 for roadways, the now needs sections are 39, 46, and 58 respectively.

6. The results of this research show that if minimum acceptable levels of PCI for runways are 65, for taxiways are 60, and for roadways are 50 and then they are increased to 75, 70, and 60 respectively, an additional 67 percent budget is required.

7. When the effectiveness is calculated, the annual departures were taken as constants. However, in practice they should be assigned a ratio to represent increase. If this increment of annual departures is incorporated into the calculation of effectiveness, the list of priorities might change.

8. An assumption that departures for all runways are the same was made. In addition, all the taxiways were assigned the same number of departures. However, ideally, actual data of traffic distribution on different branches should be assigned so that priorities are based on actual measurements. This data should be monitored as part of future evaluation.

9. Based on the fact that all pavement sections are not of the same area size, it is not recommended to use the number of sections for fixing budgets.

10. The deterioration prediction model should not be based on two or three data points as the prediction errors might affect the list of priorities. The prediction model, and subsequently the

needs year lists should be periodically updated. After entering a new inspection for a section that has been recently rehabilitated, MicroPAVER recalculates the new PCI value. The rate of deterioration for the default model is represented by a straight line.

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APPENDIX A

Table A1: Priorities for the First Set of Minimum Acceptable Level of PCI on the basis of PCI Only

No.	Network ID	Branch ID	Section ID	Use	Rank	Length	Width	Area (SM)	(PCI)	Priority #
1	AS	C3	SB2	TAXIWAY	S	95	12	1140	0	1
2	AS	D East	TA6	TAXIWAY	P	73	185	13505	0	2
3	AS	B	SB6	TAXIWAY	S	103	12	1236	1	3
4	AS	B	TA4	TAXIWAY	P	106	23	2438	19	4
5	AS	B	TA5	TAXIWAY	P	121	23	2783	21	5
6	AS	SDD	SDD	ROADWAY	T	635	17	10795	24	6
7	AS	H	SB1	TAXIWAY	S	850	12	10200	27	7
8	AS	B	TA6	TAXIWAY	P	310	23	7130	32	8
9	AS	05HB	SA1	OTHER	S	190	12	2280	34	9
10	AS	D4	TA1	TAXIWAY	P	385	23	10955	34	10
11	AS	W	TA2	TAXIWAY	P	490	22	10780	34	11
12	AS	CD	CD2	ROADWAY	T	535	7.5	4012.5	34	12
13	AS	06R-24L	RA4	RUNWAY	P	432	23	9936	39	13
14	AS	H	SA1	TAXIWAY	S	770	12	9240	40	14
15	AS	H4	SA1	TAXIWAY	S	280	12	3360	41	15
16	AS	B4	SA1	TAXIWAY	S	270	12	3240	42	16
17	AS	G	TA2	TAXIWAY	P	195	61	11895	42	17
18	AS	H	SB3	TAXIWAY	S	297	12	3564	42	18
19	AS	B	TA1	TAXIWAY	P	400	23	9200	43	19
20	AS	05-23	RC10	RUNWAY	P	119	15	1785	44	20
21	AS	B	TA2	TAXIWAY	P	131	23	3013	46	21
22	AS	H	TA11	TAXIWAY	P	275	23	6325	48	22
23	AS	15L-33R	RA14	RUNWAY	P	185	15	2775	50	23
24	AS	05-23	RB2	RUNWAY	P	868	30	26040	51	24
25	AS	H	SA3	TAXIWAY	S	297	12	3564	51	25
26	AS	05-23	RC11	RUNWAY	P	220	15	3300	55	26
27	AS	15L-33R	RC14	RUNWAY	P	185	15	2775	55	27
28	AS	A	SA6	TAXIWAY	S	119	12	1428	55	28
29	AS	H4	SB1	TAXIWAY	S	280	12	3360	55	29
30	AS	C2	TA2	TAXIWAY	P	340	25	8600	56	30
31	AS	H	SA11	TAXIWAY	S	475	12	5700	58	31
32	AS	C2	SB2	TAXIWAY	S	150	12	1800	59	32
33	AS	H	SB2	TAXIWAY	S	113	12	1356	59	33
34	AS	H	SA10	TAXIWAY	S	88	12	1056	60	34
35	AS	05-23	RA11	RUNWAY	P	220	15	3300	62	35
36	AS	05-23	RB12	RUNWAY	P	115	30	3450	63	36
37	AS	06R-24L	RC6	RUNWAY	P	620	23	14260	64	37
38	AS	06R-24L	RA5	RUNWAY	P	147	23	3381	65	38
39	AS	06R-24L	RC3	RUNWAY	P	335	23	7705	65	39

Table A2: Priorities for the 1st Set of Minimum Acceptable Level of PCI with Cost-effectiveness Method

No	N/W ID	Br. ID	Sect. ID	Area under the Curve	Departures	Section Area (SM)	Effect.	Cost/ 100SM	Sec. Rehab Cost	Cost Effect.	Priority No.
1	AS	C3	SB2	-27.00	8,760	1,140	-2.6963E+08	$1,898.42	$21,641.99	-12,458.78	1
2	AS	D East	TA6	-27.00	8,760	13,505	-3.1942E+09	$1,898.42	$256,381.62	-12,458.78	2
3	AS	B	SB6	8.00	8,760	1,236	8.6619E+07	$1,898.42	$23,464.47	3,691.49	3
4	AS	SDD	SDD	308.00	1,000	10,795	3.3249E+09	$1,898.42	$204,934.44	16,224.02	4
5	AS	CD	CD2	358.00	1,000	4,013	1.4365E+09	$1,898.42	$76,174.10	18,857.79	5
6	AS	B	TA4	93.00	8,760	2,438	1.9862E+09	$1,898.42	$46,283.48	42,913.58	6
7	AS	B	TA5	103.00	8,760	2,783	2.5110E+09	$1,898.42	$52,833.03	47,527.94	7
8	AS	H	SB1	132.00	8,760	10,200	1.1794E+10	$1,898.42	$193,638.84	60,909.60	8
9	AS	B	TA6	153.00	8,760	7,130	9.5562E+09	$1,898.42	$135,357.35	70,599.76	9
10	AS	D4	TA1	159.00	8,760	10,955	1.5259E+10	$1,898.42	$207,971.91	73,368.38	10
11	AS	05HB	SA1	163.00	8,760	2,280	3.2556E+09	$1,898.42	$43,283.98	75,214.13	11
12	AS	W	TA2	173.00	8,760	10,780	1.6337E+10	$1,898.42	$204,649.68	79,828.49	12
13	AS	H	SA1	193.00	8,760	9,240	1.5622E+10	$1,898.42	$175,414.01	89,057.22	13
14	AS	H4	SA1	198.00	8,760	3,360	5.8279E+09	$1,898.42	$63,786.91	91,364.40	14
15	AS	H	SB3	202.00	8,760	3,564	6.3066E+09	$1,898.42	$67,659.69	93,210.14	15
16	AS	B	TA1	205.00	8,760	9,200	1.6521E+10	$1,898.42	$174,654.64	94,594.45	16
17	AS	B4	SA1	216.00	8,760	3,240	6.1306E+09	$1,898.42	$61,508.81	99,670.25	17
18	AS	B	TA2	220.00	8,760	3,013	5.8067E+09	$1,898.42	$57,199.39	101,516.00	18
19	AS	G	TA2	225.00	8,760	11,895	2.3445E+10	$1,898.42	$225,817.06	103,823.18	19
20	AS	H	TA11	241.00	8,760	6,325	1.3353E+10	$1,898.42	$120,075.07	111,206.16	20
21	AS	H	SA3	242.00	8,760	3,564	7.5554E+09	$1,898.42	$67,659.69	111,667.60	21
22	AS	H4	SB1	261.00	8,760	3,360	7.6822E+09	$1,898.42	$63,786.91	120,434.89	22
23	AS	C2	TA2	264.00	8,760	8,600	1.9889E+10	$1,898.42	$163,264.12	121,819.20	23
24	AS	A	SA6	265.00	8,760	1,428	3.3150E+09	$1,898.42	$27,109.44	122,280.63	24
25	AS	H	SA11	271.00	8,760	5,700	1.3532E+10	$1,898.42	$108,209.94	125,049.25	25
26	AS	H	SB2	272.00	8,760	1,356	3.2310E+09	$1,898.42	$25,742.58	125,510.69	26
27	AS	H	SA10	273.00	8,760	1,056	2.5254E+09	$1,898.42	$20,047.32	125,972.12	27
28	AS	C2	SB2	275.00	8,760	1,800	4.3362E+09	$1,898.42	$34,171.56	126,895.00	28
29	AS	05-23	RC10	120.00	54,750	1,785	1.1727E+10	$1,898.42	$33,886.80	346,077.26	29
30	AS	05-23	RB2	142.00	54,750	26,040	2.0245E+11	$1,898.42	$494,348.57	409,524.76	30
31	AS	06R-24L	RA4	146.00	54,750	9,936	7.9423E+10	$1,898.42	$188,627.01	421,060.67	31
32	AS	05-23	RC11	172.00	54,750	3,300	3.1076E+10	$1,898.42	$62,647.86	496,044.08	32
33	AS	15L-33R	RA14	179.00	54,750	2,775	2.7196E+10	$1,898.42	$52,681.16	516,231.92	33
34	AS	15L-33R	RC14	188.00	54,750	2,775	2.8563E+10	$1,898.42	$52,681.16	542,187.71	34
35	AS	05-23	RA11	194.00	54,750	3,300	3.5051.E+10	$1,898.42	$62,647.86	559,491.58	35
36	AS	05-23	RB12	196.00	54,750	3,450	3.7022E+10	$1,898.42	$65,495.49	565,259.53	36
37	AS	06R-24L	RC6	197.00	54,750	14,260	1.5380E+11	$1,898.42	$270,714.69	568,143.51	37
38	AS	06R-24L	RA5	198.00	54,750	3,381	3.6652E+10	$1,898.42	$64,185.58	571,027.49	38
39	AS	06R-24L	RC3	198.00	54,750	7,705	8.3526E+10	$1,898.42	$146,273.26	571,027.49	39

Table A3: Priorities for the 1st Set of Minimum Acceptable Level of PCI by the Method of Assigning Weights to Different Contributing Factors

No.	Network ID	Branch ID	Section ID	Use	Rank	w1	PCI	w2	Traffic	w3	OS	w4	FC	W	PS	Priority #
1	AS	06R-24L	RA4	RUNWAY	P	10	39	5	10	5	10	8	10	28	8.61	1
2	AS	D East	TA6	TAXIWAY	P	10	0	5	6	5	7	8	9	28	8.46	2
3	AS	05-23	RC10	RUNWAY	P	10	44	5	10	5	10	8	10	28	8.43	3
4	AS	15L-33R	RA14	RUNWAY	P	10	50	5	10	5	10	8	10	28	8.21	4
5	AS	05-23	RB2	RUNWAY	P	10	51	5	10	5	10	8	10	28	8.18	5
6	AS	05-23	RC11	RUNWAY	P	10	55	5	10	5	10	8	10	28	8.04	6
7	AS	15L-33R	RC14	RUNWAY	P	10	55	5	10	5	10	8	10	28	8.04	7
8	AS	B	TA4	TAXIWAY	P	10	19	5	6	5	7	8	9	28	7.79	8
9	AS	05-23	RA11	RUNWAY	P	10	62	5	10	5	10	8	10	28	7.79	9
10	AS	05-23	RB12	RUNWAY	P	10	63	5	10	5	10	8	10	28	7.75	10
11	AS	B	TA5	TAXIWAY	P	10	21	5	6	5	7	8	9	28	7.71	11
12	AS	06R-24L	RC6	RUNWAY	P	10	64	5	10	5	10	8	10	28	7.71	12
13	AS	06R-24L	RA5	RUNWAY	P	10	65	5	10	5	10	8	10	28	7.68	13
14	AS	06R-24L	RC3	RUNWAY	P	10	65	5	10	5	10	8	10	28	7.68	14
15	AS	C3	SB2	TAXIWAY	S	10	0	5	6	5	7	8	6	28	7.61	15
16	AS	B	SB6	TAXIWAY	S	10	1	5	6	5	7	8	6	28	7.57	16
17	AS	B	TA6	TAXIWAY	P	10	32	5	6	5	7	8	9	28	7.32	17
18	AS	D4	TA1	TAXIWAY	P	10	34	5	6	5	7	8	9	28	7.25	18
19	AS	W	TA2	TAXIWAY	P	10	34	5	6	5	7	8	9	28	7.25	19
20	AS	G	TA2	TAXIWAY	P	10	42	5	6	5	7	8	9	28	6.96	20
21	AS	B	TA1	TAXIWAY	P	10	43	5	6	5	7	8	9	28	6.93	21
22	AS	B	TA2	TAXIWAY	P	10	46	5	6	5	7	8	9	28	6.82	22
23	AS	H	TA11	TAXIWAY	P	10	48	5	6	5	7	8	9	28	6.75	23
24	AS	H	SB1	TAXIWAY	S	10	27	5	6	5	7	8	6	28	6.64	24
25	AS	C2	TA2	TAXIWAY	P	10	56	5	6	5	7	8	9	28	6.46	25
26	AS	05HB	SA1	OTHER	S	10	34	5	6	5	7	8	6	28	6.39	26
27	AS	H	SA1	TAXIWAY	S	10	40	5	6	5	7	8	6	28	6.18	27
28	AS	H4	SA1	TAXIWAY	S	10	41	5	6	5	7	8	6	28	6.14	28
29	AS	B4	SA1	TAXIWAY	S	10	42	5	6	5	7	8	6	28	6.11	29
30	AS	H	SB3	TAXIWAY	S	10	42	5	6	5	7	8	6	28	6.11	30
31	AS	H	SA3	TAXIWAY	S	10	51	5	6	5	7	8	6	28	5.79	31
32	AS	A	SA6	TAXIWAY	S	10	55	5	6	5	7	8	6	28	5.64	32
33	AS	H4	SB1	TAXIWAY	S	10	55	5	6	5	7	8	6	28	5.64	33
34	AS	H	SA11	TAXIWAY	S	10	58	5	6	5	7	8	6	28	5.54	34
35	AS	C2	SB2	TAXIWAY	S	10	59	5	6	5	7	8	6	28	5.50	35
36	AS	H	SB2	TAXIWAY	S	10	59	5	6	5	7	8	6	28	5.50	36
37	AS	H	SA10	TAXIWAY	S	10	60	5	6	5	7	8	6	28	5.46	37
38	AS	SDD	SDD	ROADWAY	T	10	24	5	2	5	2	8	1	28	3.71	38
39	AS	CD	CD2	ROADWAY	T	10	34	5	2	5	2	8	1	28	3.36	39