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LIFE CYCLE COST ANALYSIS OF PERPETUAL RUNWAY PAVEMENTS; CANADIAN PERSPECTIVE

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ABSTRACT

The principal objective of this project was to evaluate a perpetual runway pavement (PRP) design in a Canadian life cycle cost perspective. Accordingly, this design was compared to a conventional runway pavement (CRP) one by using a life cycle cost analysis (LCCA), represented as a significantly helpful tool of choice evaluation. To compare two accurate designs, the software FAARFIELD 1.42 was used to compute the structural designs for both options as well as the best conventional practices. Data was collected from Toronto Pearson Airport's traffic and from the availability of materials in the Province of Ontario. The LCCA required a calculation of the initial cost, the distribution of the maintenance, rehabilitation, and reconstructions (MRR) during the analysed period of 50 years, and an estimation of the user cost for the two options. The results showed that the PRP was more likely to be a superior option due to the significantly lower cost, in the long run, the greater serviceability, and the reliability that provides to the airport in terms of user cost. All this independently from the fact that the initial cost was considerably higher than that of a CRP. To forward this paper, the environmental assessment should be further investigated as well as the mechanical behaviour of a perpetual design under aircrafts' loads.

1 INTRODUCTION

Sustainability can be measured in numerous different ways, been the main pillars represented by the economic, the environmental, and the social impacts of the subject been evaluated. As a sustainable development, perpetual pavements have gained popularity and present themselves as an appropriate solution. These are long-lasting flexible pavements designed to last approximately 50 years or more, whereas, the design period for conventional flexible pavements is approximately 20 years. Perpetual pavements have a significantly higher initial cost; however, in many cases, they can be considerably more economic-effective than conventional flexible pavements due to their greater lifespan, performance, and maintenance reduction (Mohab El-Hakim, 2012). These long-lasting pavement designs can be envisioned for high volume ways that currently do not count on another parallel route that can satisfy the demand in case of rehabilitation or reconstruction. Thus, perpetual pavement designs could be applied not only for highways but also for runways, especially those that belong to the National Airside System (NAS); therefore, those airports with more than 200,000 passengers per year.

The process of rehabilitating and/or reconstructing airport pavements is an enormously expensive process in comparison to roadways. This is due to an opportunity cost concept as, at the moment of intervention, the airport will not only invest money in time-optimal rehabilitation and/or reconstruction, but also lose functionality as an airport in part or in whole; hence, the intervention time has to be minimized and therefore the cost increases meaningfully. For these and other reasons, the use of a perpetual pavement design on runways could be a suitable cost-effective option, and perhaps, solution. This comparison will be further examined through a life cycle cost analysis (LCCA) using the recommended values for the province of Ontario and the data collected in the literature review. The designs of both options will be made using FAARFIELD 1.42, which is a software created by the Federal Aviation Administration to develop runway pavement designs and by considering the best practices of the airside industry. (FAA, 2017) (Stewart, 2010)

2 LITERATURE REVIEW

During the past decades, the use of life cycle cost analysis to evaluate and decide between competing alternative designs is becoming more popular and significant making of this technique a primary decision tool (Mizan Moges, 2017). The evaluation consists of identifying expected expenditures, when are they going to be effectuated, and how long would they offer a certain level of service (Tighe, 2013). These expenditures can be separated into 3 main interventions, maintenance, rehabilitation, and reconstruction (MRR), that mainly differ on how profound and/or expensive the treatments will be. The cost of the analysis can be considered direct or indirect, been the direct costs those that include the initial construction and MRR for and specific pavement type over the analysis period, and the indirect, those that do not affect directly the owner of the project such as the user cost (ARA, 2011).

A significant review and recommendation guideline for Canadian LCCA was presented at the Transportation Association of Canada's conference of 2017. This review provides information that will be used to build part of the methodology of this project. The considered recommendations are present below:

- The Ministry of Transportation Ontario (MTO) recommends a 50-year analysis period for projects with equivalent single axle loads (ESALs) superior to 1 million (Mizan Moges, 2017). Even though runways do not simplify their traffic on ESALs, this project does fall into this category.
- Among all the options of selecting a discount rate coming from the Office of Management and Budget (OMB), the Federal Highway Association (FHWA), the American Concrete Pavement Association (ACPA), the Asphalt Pavement Association (APA), and others, Ontario Province recommends using a 4% for evaluations from 31 to 75 years (Mizan Moges, 2017).
- For the economic evaluation method, the province of Ontario uses the Present Worth Method where the residual value is considered as well. The total value is calculated by using Eq. 1.

  [1] $NPW = IC + \sum_{j=1}^{k}(M\&R_j\, x[\frac{1}{1+i_{Discount}}]^{n_j}) - SVx[\frac{1}{1+i_{Discount}}]^{AP}$

  Where NPW stands for the Net Present Worth, M&R correspond to the cost of the j^{th} future maintenance and rehabilitation activity, IC is the initial cost, k is the number of future maintenances, preservation, and rehabilitation activities, i correspond to the discount rate, nj is the number of years from the present to the j^{th} future M&R activity, SV is the salvage value, and lastly, AP stands for the number of years of the analysis period.

2.1 Perpetual Pavements and Long-Lasting Flexible Runways

The concept of perpetual pavement was used for the first time in the year 2000 and is lately becoming more popular as a sustainable design alternative (Interactive, 2001). The sustainability of this design raises as it significantly reduces the MRR frequencies which subsequently decreases the energy consumption and Greenhouse Gas (GHG) emissions in the long run. Additionally, it improves the serviceability of the pavement structure and reduces the user cost by the incrementation of the headway between the interventions.

The name perpetual pavement refers to a long-lasting flexible pavement design with 3 different asphalt layers that are designed to provide a design life of 50 years or longer (G. W. Maupin, 2006). A top-renewable surface layer capable of maintaining the level of service by providing a superior skid resistance, a reduced tire-pavement interaction noise, and a greater surface drainage, a rutting resistance layer as it is one of the main distresses in runways, and the rich bottom mix layer with a significant tensile strength in order to protect the pavement from top-bottom cracks and freeze-thaw cycles (Mohab El-Hakim, 2012). The pavement structure is designed to provide a significant level of service without the necessity of a major reconstruction during the entire design life, which means that this last layer of asphalt is intended to last the entire design life period (G. W. Maupin, 2006).

The idea of a perpetual pavement can be considered as well in a runway pavement; nonetheless, there are some significant points that should be clarified:

- The traffic of a roadway is different from a runway as well as the calculation of it. Roadways measures their traffic based on ESALs; however, runways based their calculation on the type of airplane, their annual movement, the assigned growth factor for each airplane or the group of its, among other details.
- The stresses induced by the airplanes are considerably different from those induced by trucks, buses, and cars. airplanes induce high-speed loads, both at the impact of landing or departing, which can be considered as enormous high-speed vertical and shear stresses, and when breaking which also signify substantial shear stresses.
- It is meaningfully important as well to mention that the level of service required by a runway is significantly higher than that of a roadway. Therefore, the frequency of MRRs of a runway are most likely to be shorter than those of a roadway.

2.2 Runway Maintenance

Maintenance is defined as, “a program which is established to maintain aerodrome components in a condition of compliance with standards” (TAC, 2015). Preventative maintenance is defined as “programmed maintenance work done in order to prevent a failure or degradation of facilities and systems” (TAC, 2015). Airports range in size but no matter what, runways play a key role within the airport and it is crucial to keep them in optimal shape to maintain safe departures and landings.

Conventional pavements will deteriorate quicker than perpetual pavements, which will reflect in the Pavement Condition Index (PCI). According to the Pavement Management System report put forth by Transport Canada, if a “pavement condition survey is performed using the PCI index is set out in ASTM D5340, the frequency of condition surveys by PCI index may be extended to three years” (Phipps, 2016). Provided adequate measures are taken to obtain and implement an airport pavement management program, adequate preventative measures can be taken to provide long term cost savings.

2.3 Rehabilitation and Reconstruction

Airport pavement rehabilitations occur when the base level of serviceability is achieved and when performing maintenance activities on the pavement does not represent a significant technique (Rettner, 2015). A reconstruction may be required when there is no redeemable pavement life and rehabilitation is not an option, if major soil improvements are required, if there is a major increase in traffic volume, and so on (Rettner, 2015). The airport can decide to take rehabilitation measures or wait until the pavement reach the minimum pavement condition index (PCI) stated by the airport and whereby, reconstruction is the only solution.

The existing pavement can be assessed by pavement history, conditions/distresses, surface/base/subgrade analysis, and so forth. Various recycling options include full-depth reclamation (pulverization or stabilization), cold in-place recycling, and various overlay options include pre-overlay, mill and overlay, and mill and inlay treatments. Some reconstruction methods could be full depth reclamation, hot in-place recycling, cold in-place recycling, base stabilization, among others. It is essential to note the following: *“with perpetual pavements, the potential for traditional fatigue cracking is reduced, and pavement distresses are typically confined to the upper layer of the structure. This concept is an appealing alternative to airport pavements, where it is desirable to minimize rehabilitation and reconstruction costs as well as minimize closures to traffic”* (Carlos E. Cary, 2018). Hence, having a pavement design that can significantly extend the serviceability of the infrastructure will subsequently make it more efficient.

3 METHODOLOGY

3.1 Design

Airport pavements consist on three main different areas with distinct purposes and different designs. These sections are the runways, the taxiways/taxilanes, and the apron. The runway is that section of the airport pavement where the airplanes arrive and depart, which means that are highly susceptible to massive loads with a superior speed of loading, shear stresses, strong winds due to the turbines, among other loads. The apron is the pavement area where the aircrafts stop to be alighted/boarded by the past/future passengers; therefore, is a pavement structure with a meaningful number of stationary loads. Furthermore, there are the taxiways and the taxilanes which are the part of the airport pavement structure that aim to connect the apron to the runway.

The FAA has developed a software for airport pavement design named FAARFIELD 1.42 updated in summer 2017. The software was envisioned and created to output the structural thickness design of the runway, reason why it was the selected software to be used on this project (FAA, 2018). The inputs required by the software consist on the traffic, the materials, and the design life of the structure. For the purpose of this project, which consist on a comparison of two designs, the only significant variable that was changed was the design life period for both designs, been taken 20 years as the design period for a CRP, and 50 years for the PRP. The traffic and the material properties were assigned based on the last Pearson Airport Traffic Summary of July 2018.

The FAARFIELD 1.42 software requires information on the type of airplane, their annual movement, and the expected annual growth. The annual movement of the aircraft and the growth factor were calculated using the extracted data and analysis of the obtained Pearson Airport Traffic. Some assumptions were required and are described below:

- The total movement of aircrafts was that of the last year from the obtained data.
- According to Kevin Chee on his presentation on the Ontario Asphalt Pavement Council OAPCs' seminar 2018, the busiest runway of Toronto Pearson Airport is 05-33 which manages 45% of the aircraft movements.
- As it can be found on the literature review, the airfield is a sector with an exponential growth and, in order to express that, higher percentages were used for the biggest aircrafts. The assumption consisted on trying to have a similar but higher average growth value as the one that correspond to the total average growth value presented in Table 2.
- As longer trips require bigger and weightier aircrafts, the lighter ones were assumed as domestic flights, the intermediates as transborder, and the weightier as internationals.

Table 1: FAARFIELD 1.42 Traffic Inputs

Airplane Name	Aircraft Class	Consider As (Flight Type)	Gross Taxi Weight (Tons)	%	45% Annual Movement	Annual Growth
DC3	A-B	DOM.	11.5	30%	24078	0
B737-100	C		50.5	35%	28092	1
A320 Bogie	C		74	35%	28092	1.5
DC8-43	C	TRANSB.	144.5	30%	17109	1.5
B787-8	C		228.5	30%	17109	2.5
B777-300 ER	D		352.5	40%	22811	3
B747-8F	D	INT.	450	20%	14442	3.5
B747-8F Belly	D		450	20%	14442	3.5
A380	D		562	30%	21663	3.5
A380 Belly	D		562	30%	21663	3.5
					Average →	**2.35**

To represent how sensitive is the pavement design on the traffic, a sensitivity analysis was conducted on which the traffic was reduced in 50%, 60%, 70% and 80% to see the thicknesses variation of the pavement structure. Both the asphalt layer and the base layer were considered constant, and the change was to be expected in the subbase layer. This to meet the requirements of surface and base layer for the critical aircraft. The results can be seen in Figure 1.

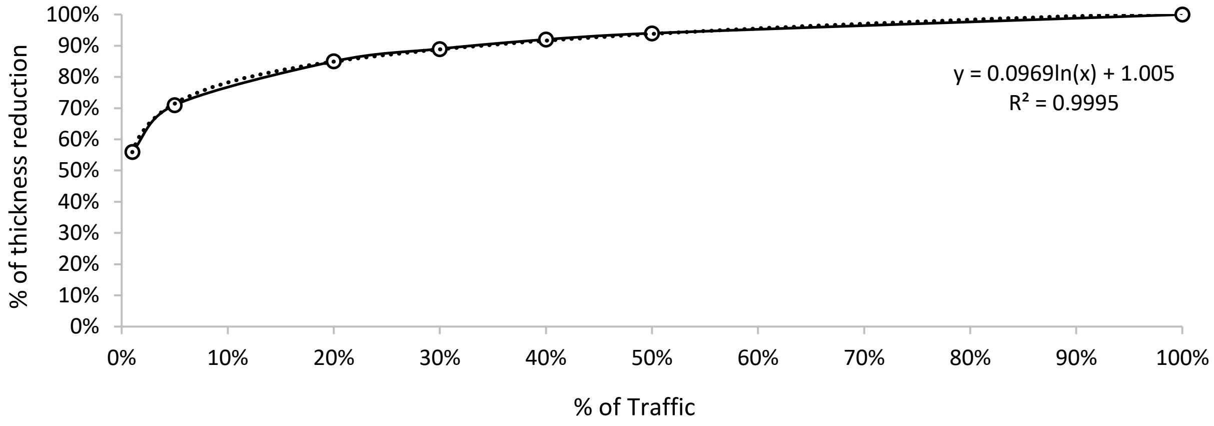
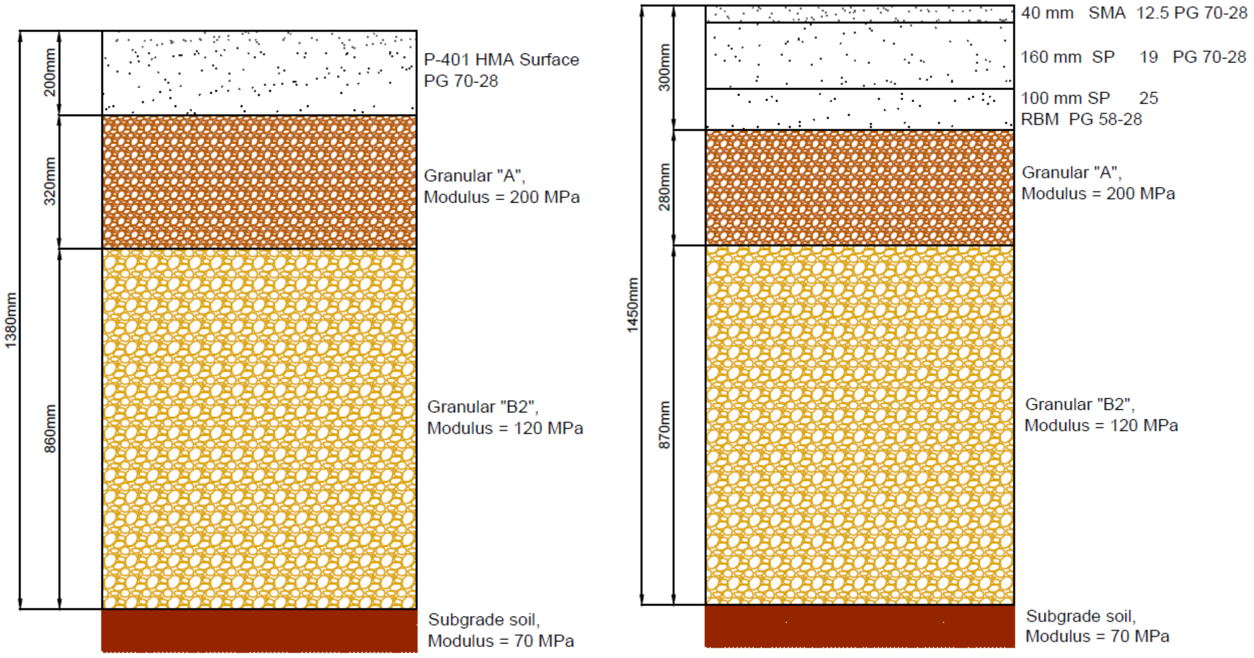


Figure 1. Traffic Sensitivity Analysis on the Pavement Structure

Concerning the materials, as the evaluated designs correspond to flexible pavements, the layers were taken as the existing subgrade, a granular subbase and base, and a hot mix asphalt (HMA) surface. A conventional runway pavement is more likely to use a P-401 mix or a stone mastic asphalt (SMA) mix design (White, 2018); nevertheless, the perpetual design, as described in the literature review, counts on 3 main asphalt layers with different objectives that mainly use superpave (SP) mix design. These layers would principally differ on the gradation of the mix, the performance grade and the percentage of the binder, and the thicknesses which will vary according to the compaction specifications.



a. b.

Figure 2. Final Designs: a) CRP (20 years life); b) PRP (50 years life)

The resilient modulus of the subgrade, according to an assessment of subgrade soils for pavement design for Highway 407, prepared by the Transportation Research Board (Louis D'Amours, 2016) and to the Chapter 3 of the advisory circular (AC) 150/5320-6E prepared by the FAA, was used as 68.7 MPa or 6.7% CBR. The base and subbase layers were considered as Granular "A" and Granular "B" type II which are the main granular materials used in Ontario. The FAA states that the minimum CBR for a base layer of a flexible pavement of a runway must be higher or equal to 80%; therefore, 100% CBR was used which can be translated to a compressive resistance of approximately 200 MPa. The subbase layer has a minimum of 20 MPa; nevertheless, this project assumed a resistance of 120 MPa. The asphalt layer used, as predetermined by the software FAARFIELD 1.42, P-401/P-403 HMA surface which has a modulus of 1,379 MPa. The conventional design was compared/based on the conventional design for runways used in Canada since 2006 due to the change of critical aircraft which is now the Airbus 380 and the Boing 777-300 ER. (Stewart, 2010) The final designs can be found in Figure 2.

4 LIFE CYCLE COST ANALYSIS

LCCA is an engineer technique used to take decisions between different designs providing the most cost-effective option, not only in terms of construction and design, but also contemplating the life span of the structure. In order to proportionate a realistic calculation of both options and considering that the type of traffic for this airport requires a length that can safely allow it to take off or land. The assumptions that were are presented in Table 2 as well as a summary of the structural design presented in the section above.

Table 2: Summary of Runway Dimensions and the Structural Pavement Designs

PAVEMENT DIMENSIONS				STRUCTURAL DESIGNS Layer Thicknesses (mm)			
Pavement Facility	Length (m)	Width (m)	Area (m2 x 1000)	PCC	HMA	B	SB
CRP	3300	60	198	-	200	320	860
PRP	3300	60	198	-	300	280	870

4.1 Direct Costs

The direct costs are those that as the name explains, directly affect the construction and maintenance of the project. In a life cycle cost perspective, the direct costs that must be considered are those that are most likely to vary according to the selected design. Therefore, for the purpose of this comparison, the considered direct cost were the initial cost which only involved the cost of the materials and the excavations as this party was distinct for both designs, and the MRRs cost using the net present worth method which involves the salvage value in the formula. The considerations and results can be found below.

The initial cost of both options was, for the purpose of this analysis, only considering the price of the materials corresponded to each pavement structure plus the cost of excavation as it is different for each design. The price per unit was stablished based on average construction prices used within Southern and Eastern Ontario and updated based on the asphalt cement prices provided by the Ontario Asphalt Pavement Council (OAPC) (Ann Holt, 2011). Quantities are based on square sections and assume density of 2.2 t/m3 for granular base and sub-base material, 2.56 t/m3 for 12.5 mixes, 2.41 t/m3 for 19 mixes, and 2.44 t/m3 for the RBM (Tighe, 2013). Tables 3 and 4 show the results of the initial construction cost of both designs.

Table 3: Initial Construction Cost for the CRP Design

Pavement Layer	Depth (mm)	Description of Pavement Layer	Quantity	Price Per Unit	Cost ($CAN)
HMA	200	P-401 12.5 PG 70-28 (ton)	101,376	$135.00	$13,685,760
Base	320	Granular A (ton)	139,392	$20.00	$2,787,840
Sub-Base	860	Granular B (ton)	374,616	$16.00	$5,993,856
Excavation	1330	Earth Excavation (m3)	579,348	$18.00	$10,428,264
		Total Initial Cost			**$32,895,720**

Table 4: Initial Construction Cost for the PRP Design

Pavement Layer	Depth (mm)	Description of Pavement Layer	Quantity	Price Per Unit	Cost ($CAN)
	40	SMA 12.5 PG 70-28 (ton)	20,275	$135.00	$2,737,152
HMA	160	SP 19 PG 70-28 (ton)	76,349	$125.00	$9,543,600
	100	SP 25 RBM PG 58-28 (ton)	48,312	$110.00	$5,314,320
Base	280	Granular A (ton)	121,968	$20.00	$2,439,360
Sub-Base	870	Granular B (ton)	378,972	$16.00	$6,063,552
Excavation	1430	Earth Excavation (m3)	622,908	$18.00	$11,212,344
		Total Initial Cost			**$37,310,328**

The different options of MRRs were suggested based on best practices (Stewart, 2010) and was helped by a highly useful tool created by the pavement preservation & recycling alliance (PPRA) named road resource (PPRA, 2018). The pay item price per unit were calculated based on best practices and the PPRA tool as well, but as these MRR values are considered for roadways, those were multiple by miscellaneous alternative coefficients varying from 1.3 to 2, representing the cost of working in optimal conditions and night hours as runway MRRs generally require. The discount rate was taken as 4% which is that used by the province of Ontario. Tables 5 and 6 present the direct cost's results for both runway pavement designs.

Table 5: Life Cycle Cost Analysis of the Direct Costs of the CRP Design

Scheduled MR&R (Year)	MR&R Treatment	Amount		Pay Item Price Per Unit	Cost ($CAN)	Discount Rate 4.0%	NPW ($CAN)
0	**Initial Cost**	-		$ 9,968.40	$32,895,720	1.00	**$32,895,720**
4	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.85	$2,821
7	Spot Repairs, Mill / Patch (10%)	330	m	$ 45.50	$15,015	0.76	$11,410
10	Minor Mill & Fill (40 mm)	198000	m2	$ 21.98	$4,351,050	0.68	$2,939,413
13	Crack Rout and Seal (15%)	495	m	$ 10.00	$4,950	0.60	$2,973
16	Spot Repairs, Mill / Patch (10%)	330	m	$ 45.50	$15,015	0.53	$8,017
18	FDR + 8" HMA	198000	m2	$ 83.50	$16,533,000	0.49	$8,161,154
22	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.42	$1,392
26	Spot Repairs, Mill / Patch (15%)	495	m	$ 45.50	$22,523	0.36	$8,124
30	Major Mill and Fill (100 mm)	198000	m2	$ 37.32	$7,389,360	0.31	$2,278,278
34	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.26	$870
37	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.23	$773
40	FDR + 8" HMA	198000	m2	$ 83.50	$16,533,000	0.21	$3,443,643
40	Base Stabilization	198000	m2	$ 19.17	$3,795,000	0.21	$790,457
44	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.18	$588
47	Spot Repairs, Mill / Patch (10%)	330	m	$ 45.50	$15,015	0.16	$2,377
50	Minor Mill & Fill (40 mm)	198000	m2	$ 21.98	$4,351,050	0.14	$612,248
				Total Maintenance →			**$18,264,536**
				Salvage Value	$10,965,240	0.14	**$1,542,948**

Table 6: Life Cycle Cost Analysis of the Direct Costs of the PRP Design

Scheduled MR&R Year	MR&R Treatment	Amount		Pay Item Price Per Unit	Cost ($CAN)	Discount Rate 4.0%	NPW ($CAN)
0	**Initial Cost**	-		$ 188.44	$37,310,328	1.00	**$37,310,328**
4	Crack Rout and Seal (5%)	165	m	$ 10.00	$1,650	0.85	$1,410
6	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.79	$2,608
8	Spot Repairs, Mill / Patch (10%)	330	m	$ 45.50	$15,015	0.73	$10,971
11	Minor Mill & Fill (40 mm)	198000	m2	$ 21.98	$4,351,050	0.65	$2,826,359
15	Crack Rout and Seal (15%)	495	m	$ 10.00	$4,950	0.56	$2,749
18	Spot Repairs, Mill / Patch (15%)	495	m	$ 45.50	$22,523	0.49	$11,118
22	Hot In-Place Recycling + 1.5"	198000	m2	$ 23.08	$4,570,500	0.42	$1,928,547
26	Crack Rout and Seal (15%)	495	m	$ 10.00	$4,950	0.36	$1,785
30	Spot Repairs, Mill / Patch (10%)	330	m	$ 45.50	$15,015	0.31	$4,629
34	Crack Rout and Seal (15%)	495	m	$ 10.00	$4,950	0.26	$1,305
37	Cold In-Place Recycling + 6"	198000	m2	$ 43.17	$8,547,000	0.23	$2,002,535
40	Crack Rout and Seal (10%)	330	m	$ 10.00	$3,300	0.21	$687
45	Spot Repairs, Mill / Patch (20%)	660	m	$ 45.50	$30,030	0.17	$5,141
50	FDR + 12" HMA	198000	m2	$ 117.00	$23,166,000	0.14	$3,259,748
				Total Maintenance →			**$10,059,594**
				Salvage Value	$14,924,131	0.14	**$2,100,014**

4.2 Indirect Costs

The user cost was the only indirect cost considered and it was calculated based on the traffic information that was used for the design. Knowing the annual movement of aircrafts per year, the average of hourly movement was able to be calculated. An assumed percentage (20%) of this value was multiply by the average landing fee of the aircrafts that are intended to arrive at the airport. This was calculated as it is known that airports that belong to the classification of NAS most likely require several runways and therefore, a significant amount of the aircrafts that will not be able to land in the designed runway, during MRRs, are going to be distributed in the other runway/s; nevertheless, not all of them will be able to be distributed due to airport capacity and other reasons. Table 7 summarizes what described above to get the user cost per hour.

Consequently, this value of $CAN 2,934 represents the average cost of one lost hour of operation of the design runway. Therefore, if a maintenance intervention takes 6 hours to be executed, the airport will most likely lose the opportunity to make $CAN 17,600. This explains the opportunity cost concept described in the introduction.

Table 7: User Cost Per Hour

Flight Type	Total Flights Per Year	Flights Per Day	Flights Per Hour	User Cost Per Flight ($CAD)	Cost ($CAN)
Domestic	80262	220	9	$ 500	$ 4,581
Transborder	57028	156	7	$ 600	$ 3,906
International	72210	198	8	$ 750	$ 6,182
			20% of the total user cost →		**$ 2,934**

4.3 Final Results

The final results are an outline of the different calculated costs representing together the life cycle cost of the competitive designs. The last column can be obtained by the summation of the different costs considering the salvage value as a negative one. Below can be find Table 8 which summarizes the results.

Table 8: Life Cycle Cost Analysis Results

Option	Strategy Description	Initial Cost	MR&R Cost	Salvage Value	User Cost	Life Cycle Cost
CRP	50 Year Convent.	$32,895,720	$18,264,536	$1,542,948	$911,847	$50,529,155
PRP	50 Year Perpetual	$37,310,328	$10,059,594	$2,100,014	$747,159	$46,017,068
	Difference →	13.4%	-44.9%	36.1%	-18.1%	-8.9%

5 CONCLUSIONS

The LCCA, based on the FAARFIELD 1.42 designs and the conventional runway design and maintenance practices, suggests an economical approach to evaluating competitive runway pavements, especially those pertaining to the NAS. As pavement technologies advance, more and more options become available, which will update the LCCA process. A LCCA was used to compare a 50-year perpetual versus a 50-year conventional airport runway pavement. As it can be seen in Table 8, there are many differences between the diverse costs during the life cycle of both pavements. As envisioned, the PRP design required a higher initial cost; nonetheless, the direct cost of MRRs for the PRP was significantly lower than that of a CRP. That been said, the salvage value was calculated according to the concepts of residual value and remaining service life for which the PRP had a meaningfully higher value of 36% more than that of CRPs. It can as well be perceived from Table 8 that the PRP requires less user cost as it does not need to provide as frequent MRRs as the CRP. For this evaluated scenario, the difference was 18% of lower user cost if using the PRP design.

The overall LCC for the conventional runway pavement was almost 9% higher than the perpetual design which can be considered as a highly significant difference and therefore, making of a future perpetual runway pavement a promising technology that, regardless of the higher initial cost, can provide higher efficiency to the airport both in serviceability and performance.

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7 REFERENCES

ACI. 2013, June 28. *Guide for maintaining runways in accordance to Annex 14 of ICAO*. (Airports Council International) Retrieved November 2018, from https://cfapp.icao.int/tools/RSP_ikit/story_content/external_files/Guide-for-Maintaining-Runways-in-Accordance-to-Annex-14-of%20ICAO.pdf

Ann Holt, S. S. 2011, September. *Transportation Association of Canada.* Retrieved November 2018, from Life Cycle Cost Analysis of Municipal Pavements in Southern and Eastern Ontario: http://conf.tac-atc.ca/english/annualconference/tac2011/docs/p1/hein.pdf

ARA. 2011. *Life Cycle Cost Analysis for Airport Pavements.* Applied Research Associates Inc. Champaign, Illinois: ARA.

Carlos E. Cary, Z. W. 2018. Effect of Pavement Structure on the Mechanical Response and Performance of Perpetual Pavements at the National Airport Pavement Test Facility. *Transportation Research Board*, 1-9.

FAA. 2017, 09 18. (F. A. Administration, Ed.) Retrieved 09 28, 2018, from http://www.airporttech.tc.faa.gov/Download/Airport-Pavement-Software-Programs/Airport-Software-Detail/ArtMID/3708/ArticleID/4/FAARFIELD-142

FAA. 2018, 06 06. (Federal Aviation Administration) Retrieved 09 30, 2018, from https://www.faa.gov/airports/engineering/design_software/

G. W. Maupin, B. k. 2006. *Design of a High-Binder-High-Modulus Asphalt Mixture.* Virginia Transportation Research Council. Virginia: Virginia Transportation Research Council .

Interactive, P. 2001, August 09. *Perpetual pavements.* Retrieved 11 08, 2018, from www.pavementinteractive.org: https://www.pavementinteractive.org/reference-desk/design/structural-design/perpetual-pavements/#footnote-1

Louis D'Amours, A. C. 2016. *Assessment of Subgrade Soils for Pavement Design for Highway 407, East Extension Pickering to Oshawa, Ontario.* Oshawa: Transportation Association of Canada.

Mizan Moges, A. A.-H. 2017. A Review and Recommendations for Canadian LCCA Guidelines. *Investing in Road Construction: Building Canada's Economy.* St. John's, NL: Transportation Association of Canada.

Mohab El-Hakim, S. L. 2012. Sustainability of Perpetual Pavement Designs, Canadian Perspective. *Transportation Research Record, 02*(2304), 10-16.

Pearson, T. 2017, March 31. Retrieved November 2018, from https://www.torontopearson.com/uploadedFiles/Pearson/Content/About_Pearson/Noise_Management/Noise_Office_Advisories/03-31-2017.pdf

Pearson, T. 2018. *Surface Maintenance*. Retrieved November 2018, from Toronto Pearson: https://www.torontopearson.com/noisemanagement/maintenance/surface/#

Phipps, J. 2016, April. *Transport Canada.* Retrieved from https://www.tc.gc.ca/media/documents/ca-opssvs/AC-302-016-Issue-03.pdf

PPRA. 2018. *roadresource.org*. (Pavement Preservation & Recycling Allience) Retrieved 10 28, 2018, from https://roadresource.org/toolbox/criteria

Rettner, D. L. 2015, April 16. *Airport Pavement Rehabilitation*. Retrieved November 2018, from American Engineering Testing Inc.: http://www.airtap.umn.edu/events/airportsconference/2015/documents/7_rettner.pdf

Stewart, C. 2010. Best Practices in the Design and Construction of Airfield Asphalt Pavements. *Canadian Airfield Pavement Technical Group.* Calgary, Alberta: CAPTG.

TAC. 2015, July 31. *Aerodromes Standards and Recommended Practices 5th Edition*. Retrieved November 2018, from Transport Association of Canada: https://www.tc.gc.ca/eng/civilaviation/publications/tp312-menu-4765.htm

Tighe, N. C. 2013. *Pavement Asset Design and Management Guide.* Ottawa: Transportation Association of Canada.

White, G. 2018. State of arte: Asphalt for airport pavement surfacing. *Pavement Research and Technology, 11*(008), 77-98.