A Multiple Criteria Decision Analysis of Alternative Paving Options for Dalhousie University

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ENVS/SUST 3210 Campus as a Living Laboratory Final Report
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Executive Summary

Halifax, like most cities, is comprised primarily of impermeable surfaces such as buildings and pavement. When precipitation occurs, these impermeable surfaces lead to the development of overland surface runoff, which eventually flows into adjacent water bodies and streams. This surface runoff collects pollutants and contaminants which are then deposited into these water bodies. This leads to a decrease in these waters' ecological integrity and quality. In Halifax, this overland runoff is dumped primarily into the harbour. Moreover, when Halifax's stormwater sewage system becomes overloaded with water during seasons of high precipitation, stormwater is diverted from the treatment system and emitted straight into the harbour.

After being alerted to this unnecessary assault on the environment, we decided to look into how Dalhousie could reduce its impact on the wastewater system in Halifax with the hope of limiting the amount of pollution and contamination that is emitted into the harbour.

We conducted a literature review and contacted various construction companies to gather data through an interview process on alternative pavement options. We learned that pervious concrete, porous asphalt and regular asphalt are available to Dalhousie University to install in its parking lots.

To determine which of these three options were the most economically, environmentally and socially viable for Dalhousie University, we conducted a Multiple Criteria Decision Analysis (MCDA). This MCDA enabled us to compare the various options of alternative pavement using five different measurement criteria: implementation costs, maintenance costs, lifespan, water runoff, and social benefits. We have discovered that the most suitable option for Dalhousie University parking lots is pervious concrete, mainly due to the long lifespan, low maintenance requirements, and fulfillment of Dalhousie's Guidelines as per Facilities Management (2013).

1. Definitions

Pervious Concrete: An engineered pavement through which water can percolate through an interconnected void system. Ideally, voids range from 15% to 25%, enabling water flow-through while still providing strength to support weight loads in areas such as parking lots, walkways, and plazas (EarthCare Landscaping, 2010).

Porous Asphalt: A layer of porous asphalt placed upon a reservoir of broken stone lying above uncompacted earth. Porous asphalt generally has voids of 16% (Dauphin County Conservation District, n.d.). Water percolates through these voids into the stone drainage bed below.

Status Quo Asphalt: Generic paved asphalt with 0-3% air voids (Dauphin County Conservation District, n.d.).

2. Introduction

2.1. Background & Rationale

Halifax is a coastal city that contains many impermeable surfaces that are either paved or occupied by buildings. These impermeable surfaces result in a decrease of stormwater that can infiltrate into the ground after rain or snowfall, leading to surface runoff. This additional surface runoff flows either directly or indirectly into Halifax's surrounding waters, primarily the harbor.

The research question developed for this project's proposal was to identify the best potential paving options for Dalhousie University's campus parking lots. In this final report, we will assess the economic and environmental feasibility and social desirability for the University to install alternative pavement options to improve stormwater infiltration on paved surfaces. The primary focus of this project is the Sir James Dunn parking lot located on Dalhousie University's Studley campus.

The rationale for undertaking this project became apparent when we became aware of the amount of stormwater runoff that is directed into Halifax waterways from impervious surfaces. Dalhousie University has taken measures to install a test plot of porous pavement on Studley Campus, providing the opportunity to test further implementation of permeable pavement. Dalhousie University's Office of Sustainability has shown its commitment to sustainable management of stormwater through implementation of infrastructure such as rain gardens, commercial building rain cisterns and green roofs. This report extends this commitment to sustainably by encouraging the integration of more permeable surfaces and therefore higher infiltration rates through ground surfaces on Dalhousie’s campuses.

2.2. Literature Review

One of the most serious problems that is generated from urbanization is uncontrolled stormwater runoff. Effective drainage systems and the impervious land cover in urban environments can result in higher volume and frequencies of stormwater discharges to nearby water bodies. High volumes of stormwater can result in environmental degradation such as: water pollution, channel erosion, damaged habitats, and negative affects to the riparian environments (Marsh, 2010, p. 168).

Studley Campus is located in the city of Halifax, Nova Scotia (44°51′16″N 63°11′57″W) on Canada's eastern seaboard. The city of Halifax is situated on a small peninsula located within the Halifax Regional Municipality. The ocean borders the peninsula on 3 sides: Halifax Harbour, Bedford Basin, and the North West Arm. The topography in the area was created by a glacial retreat. Most of the city is built on bedrock of pyritic slate, but drumlins are found throughout the region. Both slate and silt can pose environmental and developmental issues when exposed, but the most pressing issue is the lack of water retention on the peninsula. As a result of development, the peninsula lacks wetlands and other stormwater retention features (Manuel, 2003). This, in combination with the steep slopes on the peninsula, creates a space where stormwater vacates the surface very quickly. For the most part, the stormwater runs directly into the sewer or ocean (HRM, 2011), unimpeded by natural barriers.

The Halifax Harbour is contaminated by over 181 million liters of untreated storm-water and wastewater every day (HRM, n.d.). In Halifax, the sewage treatment is primarily a combined sewer system (Halifax Harbour Solutions Advisory Committee, 1998). This means that the sewer system accepts flows of domestic, storm-water, industrial and commercial waste waters (HHSAC, 1998). During seasons of high precipitation, the volume of wastewater entering the sewers exceeds the pipe system’s capacity (HHSAC, 1998). This excess flow bypasses treatment and is dumped directly into the harbour through outflow pipes (HHSAC, 1998). The Halifax Harbour Solutions Advisory Committee (HHSAC) advocates for the integration of source controls to reduce storm-water discharge into the sewer system to avoid this unfortunate overflow into the harbour (HHSAC, 1998). The Committee has pondered the idea of building wastewater storage units to contain overflows, however after considering the abundance of Halifax bedrock, it was decided this would be too costly an endeavor (HHSAC, 1998).

The city of Halifax's weather is dominated by its proximity to the Atlantic Ocean and, as a result, has a humid continental climate (Environment Canada, 2014). The factors that we are concerned with when looking at alternative pavement options are mainly precipitation and temperatures around the freeze-thaw point. The city receives ~1500 mm of precipitation annually, the majority of which is in the form of rain. The summer season, from June to September, is the driest, with ~100 mm of precipitation per month, on average. The fall and early winter, from October to January, receive the most rain, with ~150 mm, on average. Much of the early fall storms are tropical storms, bringing heavy rainfall events. Late winter and spring, from February to May, receives moderate precipitation at ~120 mm on average. Snowfall occurs mainly between December and March, with significant snowfall occurring in January and February. Even though snowfall can be heavy at times, the winter temperature limits the amount of snow accumulation. January and February average -5°C, while the remaining months have average temperatures of above 0°C. These factors combine to create a challenging climate for man made surfaces and infrastructure to withstand.

Halifax's moderate climate limits the amount of snowfall accumulation. Therefore, snow plowing is important, but generally, removal is not. However, as the temperature frequently passes the freeze-thaw barrier, the climate is particularly hard on paved surfaces. This makes icing an issue as well, as standing water will freeze, posing hazards to vehicles and pedestrians. Heavy precipitation causes a large volume of stormwater to enter wastewater collection systems, which results in untreated wastewater and stormwater pouring directly into the Halifax Harbour (HRM, 2011).

Addressing the percentage of impervious land cover in cities has become increasingly important in urban design and zoning criteria in recent years. This is because impervious land cover has one of the greatest impacts on hydrologic systems in urban regions (Hibbs & Sharp, 2012). Flooding generated from storm-water runoff can negatively influence the channel morphology of a river due to excess soil erosion, channel widening and down cutting, sediment degradation and aggradation, and stream relocation (Hibbs & Sharp, 2012). During the process of overland flow, storm-water can pick up significant amounts of pollutants, such as heavy metals, chemicals (such as waste motor oil), and road salts (Freedman, 2010, p. 438). Other pollutants associated with storm-water runoff are accidental spills in residential, commercial, and industrial areas. Domestic wastewater contains fecal material of humans and animals (HRM, 2011). Industrial wastewater may contain toxic chemicals and hazardous wastes, which can be explosive or flammable, as well as dangerous for human and environmental health (Freedman, 2010, p. 438). The impacts on water quality include nutrient enrichment, contamination caused by bacteria, increased organic and hydrocarbon loads and higher metal levels (Hibbs & Sharp, 2012). Other ecological environmental stresses and damage include increasing water temperatures, the destruction of wetlands and riparian buffer zones, negative influences on fish populations, and the reduction in biodiversity of invertebrates and aquatic insects (Hibbs & Sharp, 2012).

A viable method of reducing stormwater flows into the sewer system is to increase the perviousness of the landscape within urban settlements (HRM, 2006). This can be achieved using technologies such as interlocking concrete permeable pavers, macro-pervious pavement systems and pervious asphalt or concrete surfaces. If Dalhousie University is able to integrate alternative, more permeable pavements on campus, stormwater runoff into the sewage system could be reduced. This would reduce the strain on the Halifax sewage system and reduce the amount of untreated sewage diverted to the harbour. We understand that there has been success using alternative paving methods in the United States with warmer climates. However, sites in British Columbia and Ontario also endorse the use of porous pavements as an alternative storm-water practice, especially in parking lots to capture pollutants such as oil (HRM, 2006). Permeable pavement is an innovative approach that improves storm water management in small and large-scale developments.

2.3. Project Objectives

This project was designed to provide information and data on how to reduce stormwater runoff by incorporating alternative paving methods on Dalhousie University's campus. It is our objective to perform a multiple criteria decision analysis of three alternative paving materials and compare them to the baseline pavement used on the Halifax peninsula. Due to time and knowledge constraints, we are limiting the physical extent of our research project to the parking lots found on Dalhousie's Studley Campus. A second objective of our research project is to calculate the amount of stormwater that could be diverted from the sewer system if Dalhousie University was to integrate alternative pavements into campus parking lots. The results of these two objectives will be combined to provide a summary report and identify best potential paving option for Dalhousie University.

This proposed study has the opportunity to test the feasibility of alternative pavers in a cold, wet climate. If the findings show that permeable pavements are a worthwhile investment for Dalhousie University, it is possible that a pilot study could be initiated. If alternative pavements are incorporated into the university and succeed in a pilot program, they could be integrated throughout all three of Dalhousie's campuses. Moreover, the model could become an inspiration to other schools and institutions across Canada.

3. Methods

At the onset of this project, our group members started identifying possible research questions by brainstorming Dalhousie's environmental issues. Our group members have backgrounds in different fields of study and are from different faculties in the university. As such, many interesting research options were suggested, reflecting the environmental science, planning, and sociological lenses that each member brought to the group. Finally, we focused the research topic on stormwater management practices on campus.

We then reviewed the related literature to explore possible solutions for stormwater issues. In the meantime, we also contacted Rochelle Owen, the Director of Sustainability, to ask her opinion on the subject. She helped us understand what has already been implemented on campus to reduce stormwater runoff, and suggested that we research alternative pavers and explore their resilience in cold weather climates. All our group members agreed on this topic and each felt an interest in completing research on the feasibility of incorporating alternative paving methods on the Dalhousie Campus.

After our topic was finalized, a research proposal was completed by the eighth week of classes. This proposal helped us identify the project, understand the background and rationale, determine the research methods, and organize the project through a schedule and a budget. In addition, the proposal highlighted the importance of the study and the environmental benefits of permeable pavement. Furthermore, the proposal indicated some improvements we could use to further develop our methods and how to analyze and obtain more comprehensive findings.

3.2. Literature Review

The literature review plays a significant role in our research project. A large part of our understanding of this project has been dependent on the applied and scientific research that has been done by other academics and governments. This preliminary research focused on topics such as the environmental impacts of stormwater runoff, stormwater issues in the Halifax Regional Municipality, strengths and weaknesses of different pervious paving materials, and the evaluation of those pavements in cold climates. To some extent, our findings are limited due to time, knowledge, and budget. However, we have tried our best to reduce the influences of those factors on the findings that we obtained.

3.3. Contacting Pavement Companies and Facilities Management

In order to get the actual quantitative and qualitative data about the various pervious pavement options, our group also contacted several pavement and construction companies including Dexter Construction, DCT Paving and Ocean Contractors, as well as Dalhousie's Facilities Management. The information we obtained from these sources included implementation costs (i.e. product pricing), lifespans, infiltration rates for parking lots (cm/s), and other information such as the sustainability of the product.

3.3. Multiple Criteria Decision Analysis (MCDA)

Multiple Criteria Decision Analysis is a decision making process and framework. Almost every decision demands an examination of various courses of action or choices (Belton & Stewart, 2002, p. 2). Generally, decisions necessitate the weighting of various factors and options that are sometimes conflicting in nature and often complex (Belton & Stewart, 2002, p. 2). MCDA attempts to ease the decision making process by trying to combine stakeholder values and opinions with impartial measurement to reduce subjectivity in a final decision (Belton & Stewart, 2002, p. 3). This framework does that by taking into account many often conflicting criteria at once, helping to identify the problem, structure the discussion and problem solving (Belton & Stewart, 2002, p. 5). This MCDA process helps to define decisions that are better informed and explainable (Belton & Stewart, 2002, p. 5).

The MCDA process varies depending on the purpose and setting of the problem solving issue, however there are a common set of steps that are used each time:

1. Identify the problem or issue.
2. Structure the problem
   - Identify stakeholder values, set goals, highlight key issues and uncertainties
3. Build a model by defining criteria and eliciting stakeholder values
4. Use the model to inform understanding through the synthesis of information and analysis
5. Develop a plan from the findings (this is out of the scope of this project)

In this project we utilized a value measurement MCDA model. This specific MCDA model uses constructed numerical scores to represent preferences and suitability of various options. These scores are initially developed for individual criterion but are then summed and contrasted during the step of synthesization and analysis.

We chose to complete a multi-criteria decision analysis because of the number of factors that need to be taken into consideration when choosing a paving material. We developed five criteria that were measured using indicators. However, these indicators possessed different values of measurement, making it difficult to see correlations between them or adequately compare them. The MCDA process acknowledges the difficulty of comparing criteria with different methods of measurement and enables stakeholders to convert the criteria to a common scale of measurement. This common scale of measurement allowed us to rank, weight and score the various criteria in a way that was consistent and could be easily compared.

3.3.1. Our MCDA Process

Our MCDA process consisted of five steps that resulted in a final summary score of our three paving options. Firstly, we had to collect data and information from literature reviews as well as researching and contacting companies which specialize in various paving options. Then, we developed criteria against which we measured the suitability of each option. To be able to evaluate the suitability of each option we came up with indicators for each criterion. Thirdly we weighted the criteria to reflect the level of importance of each criterion for our goals. For this project we chose to weight all criteria equally. This was to provide an unbiased and unskewed analysis of the situation and to illustrate that no criterion of our MCDA is deemed more important than another. This also illustrates that even though our project is focused on sustainability, our analysis is not overlooking the importance of economic integrity to the university institution. After weighting the criteria we ranked each option from most preferable (a score of three) to least preferable (a score of one) after assessing indicator measurements. These ranked scores were then inputted into a final decision matrix. This final decision matrix combines the preferability scores with the assigned weights to come up with a final summary score that takes into account the suitability of each criteria for each option. The paving option with the highest summary score after its criteria were inputted into the decision matrix is the option that is most suitable for Dalhousie University.

4. Findings

After researching different types of permeable pavers, we explored three and compared them. In order to determine what option was most suitable for a Dalhousie University parking lot, we analyzed each option based on a set of criteria.

Implementation Costs

Each of the three products range in their implementation and installation costs. After speaking with Dexter Construction, it was found that Pervious Concrete (PC) was the most expensive option at $350/m2 (Dexter Construction, personal communication, 2014). This is due to an intricate process of laying the material, and the complexity of the layers (see Appendix C). This type of concrete has already been installed on the Dalhousie University Studley campus, and this option would be replicated in other areas at the same rate per square meter.

DCT Pavement only offers regular Asphalt (A) paving, and Ocean Contractors provides both Porous Asphalt (PA) and Asphalt (A), and the cost is the same to install (Ocean Contractors, personal communication, 2014). For these pavements to be installed 4 inches thick (recommended thickness for a parking lot), the cost would be $11.55/m2. The main cost difference in these two options lies in the maintenance. These costs do not include labour.

Maintenance Costs

The maintenance costs for Pervious Concrete (PC) are extremely low, and almost non-existent. However, Porous Asphalt (PA) is a product that must be maintained, and for the following reasons, it is not recommended to be used as pavement in parking lots. Porous Asphalt (PA) must be vacuumed bi-annually due to rocks and sand filling in the air voids (Cahill Associates, n.d.). The cost of this maintenance lies in the cost of the vacuum machine itself. The price of equipment, such as the Elgin Whirlwind Vacuum Air Sweeper, would be $4291/year, for 6 years ($18,500 split over 6 years, at a 6% interest rate). This professional street sweeper sucks sand and small rocks that keep the pavement in a permeable state.

To repair both Pervious Asphalt (PA) and Asphalt (A), the cost would be to rip up the pavement and repave small areas, which would cost $11.55/m2, plus the cost of ripping up the pavement, disposing the asphalt, and labour. It could be years before an entire parking lot is repaved (G. Martell, personal communication, 2014).

Lifespan

Some concrete options can last up to 100 years, while Asphalts (both porous and non-porous) may last only 5-10 years. The Pervious Concrete (PC) option explored, like the one already installed, is expected to last at least 20 years, up to 30 depending on conditions of the enviroment. The lifespan of Asphalt depends on a number of factors, according to Dalhousie Facilities Management. For example, areas of a parking lot that are lower than others collect more water, and therefore have more wear and tear. The lifespan of the pavement also depends on how it was installed - some contractors may do a better job than others, and pave smoother or less smooth. When certain areas of the pavement have more wear than others, it is likely to be ripped up and repaved in small sections, rather than replacing the entire area it was installed (G. Martell, personal communication, 2014). For this reason, we were unable to determine a lifespan from Dalhousie Facilities Management for Asphalt (A).

However, from the literary review and database research, we were able to analyze studies done with similar rainfall patterns and climate, and determined that Asphalt (A) could last around 10 years, while Porous Asphalt (PA) has a much shorter lifespan, lasting about 6 years (Henning, 2012).

The reason Porous Asphalt (PA) has a shorter lifespan is due to the air voids that are inside it. Although these air voids let water drain through and helps with storm water run-off, it means that pieces of the asphalt become loose and are worn away. Porous Asphalt (PA) must be repaved and maintained quite extensively.

Water Runoff

Storm water runoff is measured in cm/s, using a cylinder to catch the water. This data is not accessible through construction companies, nor facilities management, and therefore studies were researched through databases. It was concluded that Pervious Concrete (PC) had the best infiltration rates of 0.41 cm/s, according to a study done in a parking lot in Spain. Porous Asphalt had an infiltration rate of 0.22cm/s (Sanudo-Fontaneda, 2014). Asphalt (A) does not allow any water to infiltrate through, therefore its rate is 0cm/s. It is conclusive that Pervious Concrete (PC) has the best infiltration rate, Porous Asphalt (PA) has the second-best, and Asphalt (A) is the worst.

Social Benefits

When analyzing the social benefits of each alternative, we looked at the Dalhousie Natural Environment policy. Section 5.12 of this policy states that “Paving stones and porous paving should be considered as part of a stormwater management program” (Natural Environment Policy, 2013). Since Pervious Concrete (PC) and Porous Asphalt (PA) both are permeable options, they fulfill this requirement. Since Asphalt (A) has an infiltration rate of 0cm/s, it does not meet this requirement.

5. Multi-Criteria Decision Analysis Results

Spreadsheet tables and decision matrix modified from Dalhousie University's SUST 3000 course.

Table 1: Criteria and Indicators

Criteria and Indicators - Permeable Pavement on Dalhousie Campus			
Implementation Costs	**Indicator**	**Best Case**	**Worst Case**
Total costs associated with applying an option on Dalhousie University property. Costs include all materials, labour, and contracts needed for the implementation of the option per square metre. We assume that all options are applied to a current parking lot nearing the end of it's lifespan.	Hundreds of thousands of Canadian dollars: $100, 000 CAD	Cheapest Option	Most Expensive Option
Maintenance Costs			
Total ongoing costs associated with the maintenance of an option. Costs include all upkeep performed on an option over a 10 year period. Costs include: snow removal, salting, surface repair, and surface cleaning.	Hundreds of thousands of Canadian dollars: $100, 000 CAD	Cheapest Option	Most Expensive Option
Lifespan			
The lifespan and durability of an option indirectly affects the total lifetime cost of the option. Since implementation is generally the highest cost associated with a paving option, a long lived paving option will save money in the future by saving on recurring installation costs. An option that is more durable will likely perform better throughout it's lifespan.	Years	Longest Lifespan	Shortest Lifespan
Water Infiltration			
The main purpose the permeable pavement installation plan is to allow storm water to slow and be taken into the water table. A completely impervious pavement will not allow any water into the water table, and would likely divert water into storm drains.	Water infiltration rate. Measured in the proportion of water percolating through the paving surface in centimetres per second of time.	1 or more	0
Social Benefits			
Increasing the environmental reputation of the campus is an important endeavour for Dalhousie University. Stewardship of the environment is also an important issue for the student population. As such, it is important for on campus development to reflect the values held by the parties represented. Dalhousie University has a set of landscaping guidelines that define suitable paving materials for use on campus.	The chosen method's performance in relation to Dalhousie University's landscaping guidelines. (Facilities Management. 2013)	Fully met or exceeded.	Failure to meet the guidelines

Table 2: Decision Options

2.1 Pervious Concrete (PC)

Option 1: Pervious Concrete		
An engineered pavement through which water can percolate through an interconnected void system. Ideally, voids range from 15% to 25%, enabling water flow-through while still providing strength to support weight loads in areas such as parking lots, walkways, and plazas (EarthCare Landscaping, 2010).		
Key Project Parameters		
Implementation Costs		
Capital Costs	$350/m^2	
Maintenance Costs		
Surface maintenance	$0	
Lifespan		
Projected Lifespan	20-30 years	
Environmental Effects		
Infiltration rate	0.41 cm/second	
Social Impacts		
Dalhousie guidelines met	Yes	

2.2 Porous Asphalt (PA)

Option 2: Porous Asphalt		
A layer of porous asphalt placed upon a reservoir of broken stone lying above uncompacted earth.		
Key Project		
Implementation Costs		
Capital Costs	$11.55/m^2	
Maintenance Costs		
Surface maintenance	$4291.92/year	
Lifespan		
Projected Lifespan	6 years	
Environmental Effects		
Infiltration rate	0.22 cm/second	
Social Impacts		
Dalhousie guidelines met	Yes	

2.3 Asphalt (A)

Option 3: Status Quo Asphalt		
Generic paved asphalt with no air voids.		
Key Project Parameters		
Implementation Costs		
Capital Costs	$11.55/m^2	
Maintenance Costs		
Surface repairs	$**/five years	
Lifespan		
Projected Lifespan	10 years	
Environmental Effects		
Infiltration rate	0 cm/second	
Social Impacts		
Dalhousie guidelines met	No	

Table 3: Criteria Weighting

1. Criteria Weighting				
Table 1. Weighting schemes				
	SUST 3502			
Criteria			**Weighting Considerations**	
Implementation Costs	20%		60% = economic viability	
Maintenance Costs	20%		40% = environment/social	
Lifespan	20%			
Water Runoff	20%			
Social Benefits	20%			
	100%			

Table 4: Criteria Scoring

2. Scoring

Preference functions to rank possible outcomes for each criteria indicator on a scale of 1 to 3, with 3 being the most preferable outcome and 1 being the least preferable.

SUST 3502

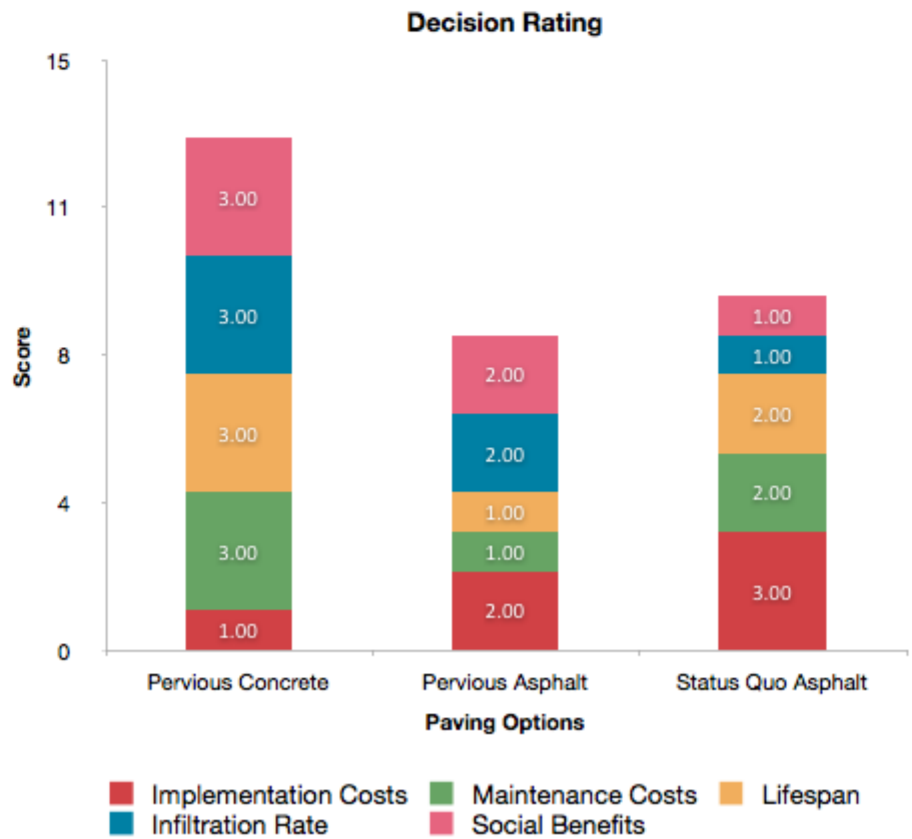
Table 2 - Preference function values	Least desirable		Most preferable
Criteria	1	2	3
Implementation Costs	PC	PA	A
Maintenance Costs	PA	A	PC
Lifespan	PA	A	PC
Environmental Effects	A	PA	PC
Social Impacts	A	PA	PC

Table 5: Decision Rating

DECISION RATING - Permeable Pavement Options for Dalhousie University

CRITERIA	Ratings and scores for: Option 1 Pervious Concrete — Input Rating	Option 1 — Calculated Score	Option 2 Pervious Asphalt — Input Rating	Option 2 — Calculated Score	Option 3 Status Quo — Input Rating	Option 3 — Calculated Score	WEIGHT Input Weighting	Priority
Implementation Costs	1	1.00	2	2.00	3	3	1	0.2
Maintenance Costs	3	3.00	1	1.00	2	2	1	0.2
Lifespan	3	3.00	1	1.00	2	2	1	0.2
Infiltration Rate	3	3.00	2	2.00	1	1	1	0.2
Social Benefits	3	3.00	2	2.00	1	1	1	0.2
		13.00		8.00		9	5	1

Chart 1: Option Scoring



5.1. Results Analysis

The final MCDA summary scores (highlighted in yellow in Table 5) indicates each pavement option's suitability based on the criteria and indicators that we established and the weighting scheme applied to the process. The first option, pervious concrete, receives a final summary score of 13, the highest summary score out of the three choices. The second option, pervious asphalt, earned a summary score of 8, the lowest summary score. Our third option, the status quo asphalt received a summary score of 9, which is the second most preferable choice. These summary scores indicate that the most preferable choice is the pervious concrete option. Pervious concrete received the most preferable score in all categories except for implementation costs. Status quo asphalt received the highest score for implementation costs at a price of \$11.55/m2 in comparison to \$350/m2 of the pervious concrete. However, despite the difference in implementation costs, pervious concrete received higher scores for all the other criteria, thereby outweighing all other options as the most preferable choice.

6. Discussion

As previously stated in our executive summary, Halifax is comprised primarily of impermeable surfaces such as buildings and pavement. When precipitation occurs, these impermeable surfaces lead to the forming of overland surface runoff which flows into neighbouring water bodies and streams. This surface runoff collects pollutants and contaminants which decrease these waters' ecological integrity and quality (HHSAC, 1998). In Halifax, this overland runoff is dumped primarily into the harbor (HHSAC, 1998). Moreover, when Halifax's stormwater sewage system becomes overloaded with water during seasons of high precipitation, stormwater is diverted from the treatment system and is emitted unfiltered into the harbor (HHSAC, 1998).

This mishandling of stormwater and wastewater is an extensive environmental concern. After recognizing this, our research team explored various pavement alternatives which are both economically and environmentally viable for installation on Dalhousie University's Campus. We proceeded to analyze this question through a multiple criteria decision analysis where we compared a status quo pavement product with specific types of porous asphalt and permeable concrete. As you can see from the results above, we compared the paving options in terms of their implementation costs, maintenance costs, infiltration rates, social benefits and their lifespans. Weighting each criterion equally to avoid exhibiting biases that skewed the results based on their preference weighting. We found that pervious concrete was the most viable option for Dalhousie University to install. In terms of the decided-upon decision criteria, pervious concrete superseded the status quo asphalt that is currently in use on campus.

Our project's results indicate that it is a feasible option for Dalhousie University to implement pervious concrete onto Studley campus in the near future. Installation of pervious concrete supports our objective of reducing the school's stormwater runoff contribution into the city's stormwater management system. After a physical evaluation of Dalhousie's Studley campus, our team discovered that many of the paved roads and parking lots around campus are in a state of disrepair. These areas are likely to be repaved in the near future, providing a prime opportunity for Dalhousie to install pervious concrete in their place. As our results indicate, this alternative paving option will cost no more than status quo asphalt yet, will reap many more social and environmental benefits. As outlined in Dalhousie's current Natural Environment and Landscape Policy and Guidelines document, the university aims to conduct future development and maintenance in a manner which upholds the protection and enhancement of the natural environment. The university emphasizes its understanding that landscape materials, plant communities, character and design quality contribute to social, economic, and environmental well-being at Dalhousie and the larger community (Facilities Managment, 2013). In implementing pervious concrete, Dalhousie will be satisfying its personal goals and requirements for both it's campus and the city of Halifax.

7. Conclusion

When traditional asphalt is compared to pervious concrete and porous asphalt against our criteria of cost, future outlooks such as durability and maintenance, pervious concrete is equal to traditional concrete. In many situations, pervious concrete emerges as the best option against criteria. In addition, when other factors such as long-term impact on the environment are considered, pervious concrete once again proves to be superior. The infiltration properties of the material and its ability to remove pollutants from stormwater, illustrate its far greater effectiveness as compared to other popular stormwater management systems. This demonstrates that a paving system which is nearly equal in cost to traditional concrete pays for itself over the long term and is more effective than other stormwater infiltration systems. It is therefore possible to employ an environmentally conscious paving solution while saving money.

Recommendations for Action

Based on the data we procured through researching for this project, we recommend that Dalhousie University talk with a pervious concrete expert about implementing this paving technology into the campus parking lots. An ideal location for this alternative pavement to be initially installed is the Sir James Dunn parking lot on the Studley campus.

Recommendations for Further Research

We recommend that Dalhousie University's College of Sustainability work with facilities management and local pervious concrete experts to gain further expertise on fitting pervious concrete to chosen sites on campus.

8. Acknowledgements

We would like to express great appreciation to the companies (Dexter Construction, DCT Paving and Ocean Contractors) we contacted for their contributions of time and information to enable us to complete this project. We would also like to acknowledge Dalhousie's Facilities Management for their instrumental role in this endeavor. We wish to thank Tim Cashion for his support and guidance throughout the duration of this entire project. Without his constructive suggestions and critiques we could not have finished this project. We extend our thanks to Rochelle Owen for her advocation to pursue research in permeable pavement and the influence she had on the direction of this investigation. We would also like to express our gratitude to Dalhousie University and Professor Hendricus Van Wilgenburg for the opportunity to have this project come to fruition.

Appendix A

Pervious Pavement Inquiry Questions

Upon making contact we will first define our understanding of porous and permeable pavement to be certain we share the same understanding before asking our questions.

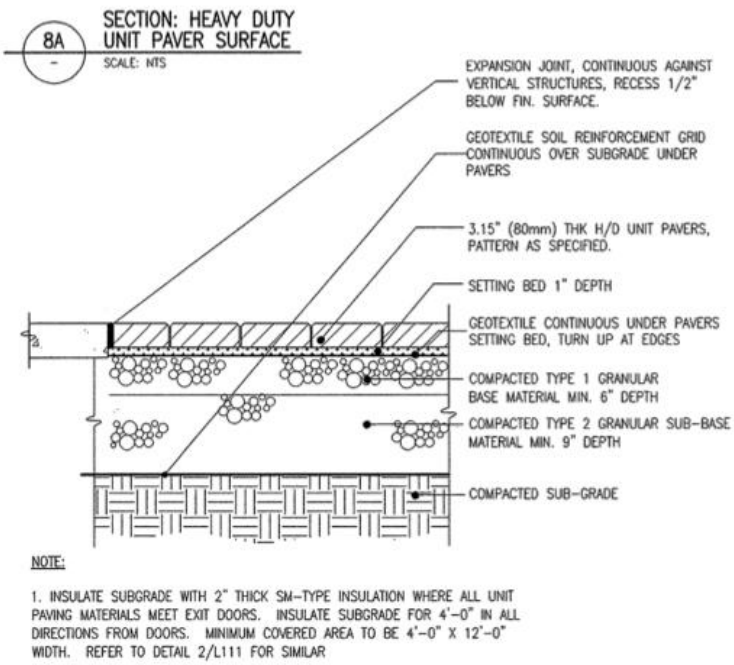
Dalhousie Facilities Management

- What costs are associated with plowing parking lots?
- What costs are associated with laying road salt on parking lots?
- What costs are associated with maintenance of the asphalted parking lots?
- What other factors should we be considering when investigating the potential implementation of permeable pavement in a parking lot?

Concrete Companies

-What types of permeable pavement options do you offer?
-What are the cost associated with removing existing pavement, and laying permeable concrete in a per m^2?
-How much time does it take to install?
-What is the estimated lifespan of your product?
-What are the ongoing maintenance costs for your product?
-Is your product suitable for a climate that receives about 1500mm of precipitation annually?
-How does this pavement react to frequent freeze-thaw events?
-Is this pavement suitable for plowing?
-What is the water *induction/passthrough* rate?

Appendix B



Blueprint of Pervious Pavement layers.
Source: Dexter Construction

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