2015

Assessing the energy and financial viability of heated pavement systems for airports

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Recommended Citation

Anand, Pritha, "Assessing the energy and financial viability of heated pavement systems for airports" (2015). *Graduate Theses and Dissertations*. 14748.
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Assessing the energy and financial viability of heated pavement systems for airports

by

Pritha Anand

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Civil Engineering Materials)

Program of Study Committee:
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Ames, Iowa

2015

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ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor and committee chair, Professor Halil Ceylan for letting me be a part of his excellent research team and his un-parallel support during my Master’s study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Master’s study. I have been fortunate to have worked under the guidance of Professor Ceylan.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Kasthurirangan Gopalakrishnan, Dr. Sunghwan Kim, Dr. Peter Taylor and Professor John Miranowski, for their insightful comments and encouragement. I would specially thank Dr. Kasthurirangan Gopalrishnan and Dr. Sunghwan Kim for their invaluable and unceasing supervision. I am hugely indebted to their encouragement, direction and persuasion.

My sincere thanks also go to Dr. Konstantina Gkritza and V. Dimitra Pyrialakou who were a part of this research team. Without their knowledge and support it would not be possible to conduct this research.

I thank my fellow lab mates for the stimulating discussions in terms of research and coursework, for the sleepless nights working together before deadlines, and for all the fun we have had in the last two years.

Last but not the least, I would like to thank my family. My parents and my brother for supporting me throughout writing this thesis and my life in general.

ABSTRACT

Ice and snow impacts on transportation infrastructure systems add significant costs to the American economy in the form of snow removal, damaged pavement and lost productivity due to travel delays. Due to environmental and logistics concerns associated with traditional pavement deicing strategies, the use of heated pavement systems (HPS) at airports are continually gaining attention as a desirable alternative. The main objective of this research was to examine the financial viability of installing HPS at aprons and ramps for different categories of airports. The apron is the busiest part of the airport where vehicles and airplanes share the same space. Snow removal operations are challenging and time consuming for the ground staff involved as they are exposed to rough weather. In addition, due to immense activity and asymmetric (skewed) geometric designs, small sized snow removal equipment (SRE) is used in aprons. These factors together contribute to delays. In order to study the feasibility of HPS, two economic analysis techniques, the Net Present Value (NPV) and Benefit Cost Ratio (BCR) were employed. The required data for economic analysis were collected through airport site visits, email surveys, government websites (Bureau of Transportation Statistics and Bureau of Labor Statistics), reports, etc. The costs incurred due to melting snow by hydronic heated pavements and its potential benefits were calculated and compared with the operating costs of conventional snow removal methods under specific case scenarios. Due to the inherent uncertain nature of weather-related delays, an in-depth sensitivity analysis (SA) was carried out to represent contrasting scenarios. It was found that HPS, despite the high installation costs, may be economically viable at commercial airports. The feasibility depends on the size of the airport in terms of operations and area of installation. As the heated pavement technology continues to evolve with time,

especially with the use of renewable energy sources and advanced construction methods, their benefits are far likely to outweigh the existing high initial installation costs.

CHAPTER 1

INTRODUCTION

Background

In the northern U.S., Canada, and other cold-climate regions, snow and ice control operations are required to ensure the safety, mobility, and efficiency of highways where the driving conditions are often aggravated by inclement wintery weather. As air travel is the only means of a rapid transport connecting large geographical locations in a short period of time, it is crucial to keep airports functional during severe winter months. Airports typically employ chemical deicers in combination with heavy-power snow removal equipment (SRE) like snow plows or brooms, to remove snow and ice from ramps, runways and taxiways. However, snow removal operations are challenging for the ground staff as they are exposed to rough weather. They have to be trained to deal with varied levels and types of precipitation and understand the effects of wind speed and direction on snow clearing operations (USA Today 2014). According to the FAA Advisory Circular (FAA, 2011), most transport category aircraft are prohibited from operating on runways covered by untreated ice or by more than ½ inch of snow or slush, although the limits vary with aircraft types. Common practices for removing ice and snow from transportation infrastructure surfaces include spraying large quantities of anti-ice chemicals on the ground and deploying a great number of snowplowing vehicles. However, these methods are labor intensive and have environmental concerns with possible contamination of nearby water bodies for highway and airport pavements. Furthermore, traditional methods for deicing using road salt and chemicals might cause damage to concrete, corrosion of reinforcing steel in concrete bridge decks and drainpipe, and damage to the ecological environment (Zhao et al., 2010).

Many airports conduct trials during summer to identify the most effective and accelerated way to clear snow (Michaels 2014). A large fleet of equipment is essential for rapid snow removal but it is expensive, and such large costs may not be justifiable (Merkert and Mangia 2012). As time plays a crucial role in clearing airports, the Federal Aviation Administration (FAA) has established guidelines for the time that can be taken to clear snow. According to these guidelines, commercial airports with annual airline operations of more than 40,000 in number are required to clear snow/ice from the Priority 1 areas within half an hour of 1 inch of snowfall. Areas that are included under Priority 1 are primary runways with taxiway turnoffs, access taxiways leading to the terminal, terminal and cargo ramps, airport rescue and firefighting (ARFF) station and emergency service roads, and navigational aids (FAA 2008).

In the aprons, specifically, there is a lot of activity in the form of baggage handlers, ground staff and oil refueling operations. Due to the use of smaller sized equipment, snow clearing operations are time consuming and inefficient which propagates delays. Additionally, the mix of machinery and human activity at aprons poses safety concerns. These factors motivate the use of heated pavement systems (HPS) at aprons. Heating runways might not be practical as they are subjected to thrust and high temperature, which may damage the heated pavement. Moreover, costs and energy requirements may not be justifiable for such a large area, as pointed out by the Airports Council International (ACI). Airports usually have reduced number of daily operations in winter. If the number of daily operations can be increased, the operating revenue can increase greatly benefitting the airport. Assuming that this reduction is related with the delays caused by snowfalls, alternate snow removal strategies like heated pavement systems may have the potential to alleviate the aforementioned problems and keep airports operational during severe winter months.

Heated pavement surfaces may be achieved by circulating hot fluid through a series of pipes running through the pavement or by using electrical methods. Heated fluid can be supplied from boilers operated by natural gas, geothermal energy or electricity depending on the location of the airport. The use of heated airport pavement systems as a means of removing ice and snow has reportedly been successful in European airports. The benefits of using such a system include a reduction in environmental effects of deicers, cost of fuel and energy, reduced labor requirements, and fewer impacts to travelers. However, before such approaches are implemented in the United States (U.S.), it is essential to study the cost and energy impacts of such systems. Note that heating aprons and ramps is the primary focus of this study. Runways, being long straight strips are relatively easier and faster to clear than ramps and aprons by using heavy equipment and so may not be the main contributing factor for flight delays in a typical airport.

To assess the financial viability of heated pavements, economic analyses were conducted involving benefit cost analysis (BCA) and net present value (NPV) method. The purpose of benefit cost analysis is to compare the benefits and costs associated with a policy or investment; this methodology is commonly used for the assessment of proposed public projects. If the sum of the benefits of a project or policy exceeds the costs, then there is an economic argument supporting the investment in the project. In BCA all the possible costs and benefits associated with the concerned parties are monetized (FAA 1999). In this study, BCA was applied to evaluate whether heated pavement systems are financially viable at certain prospective airport locations and also, whether it is expected to generate more benefits than conventional snow removal strategies in terms of reduced delays. The results of this study will provide a better understanding of the various benefits and costs associated with each strategy and serve as a decision making tool for airport managers to adopt the alternative technology.

Research Objectives

Heated pavement systems have gained attention as desirable alternatives to current ice and snow removal practices, and make practical and economic sense for airport pavements frequently impacted by snow/ice during winter months.

The over-arching objectives of this research are three-fold:

- To assess the amount of energy required to heat a slab to above freezing temperature during a winter precipitation event, and compare it with the energy consumed using conventional approaches. Conventional approaches include plowing, use of chemicals (such as potassium acetate) and hauling off site.
- To appraise the initial installation costs of a heating system and ascertain how they may be absorbed over a period of time under operation.
- To investigate the economic advantages of a heated pavement, this will include factors such as operational savings and improved safety along with staffing needed to operate snow removal equipment. In addition, to examine any differences in these benefits between high traffic airports and small general aviation airports.

This study focuses on the financial viability of hydronic heated pavement systems on aprons and ramps. The apron is the busiest part of the airport where vehicles and airplanes share the same space. Snow removal operations are challenging and time consuming for the ground staff involved as they are exposed to rough weather. In addition, due to immense activity and asymmetric (skewed) geometric designs, small sized snow removal equipment (SRE) is used in aprons. These factors together contribute to delays. On the other hand, runways being long straight strips are relatively easier and faster to clear than ramps and aprons by using heavy equipment and so may not be the main contributing factor for flight delays. Heating runways might also not be cost effective as pointed out by the Airports Council International (ACI) (ACI, 2010). In this analysis, it is assumed that areas apart from aprons and ramps will still be cleared using SRE.

Thesis Organization

This thesis consists of eight chapters. Chapter 1 will introduce the background and objectives of this study. Chapter 2 presents a comprehensive literature review of conventional strategies of snow removal and advances in heated pavement system of snow removal. Chapter 3 deals with the Methodology followed which discusses the data collection process, determining energy requirements to melt the slab and development and identification of various cost and benefits related to the conventional and alternative methods of snow removal. Chapter 4 through 6 describes the case studies on three commercial airports. Data collection, estimation of costs and benefits and in depth economic analysis results are presented here. Chapter 7 discusses the case study on general aviation airports and analyzes situations where the use of HPS would be necessary in smaller airports like general aviation. Chapter 8 summarizes the conclusions, limitations and recommendations from this study. Figure 1 is a flow chart representing the thesis structure.

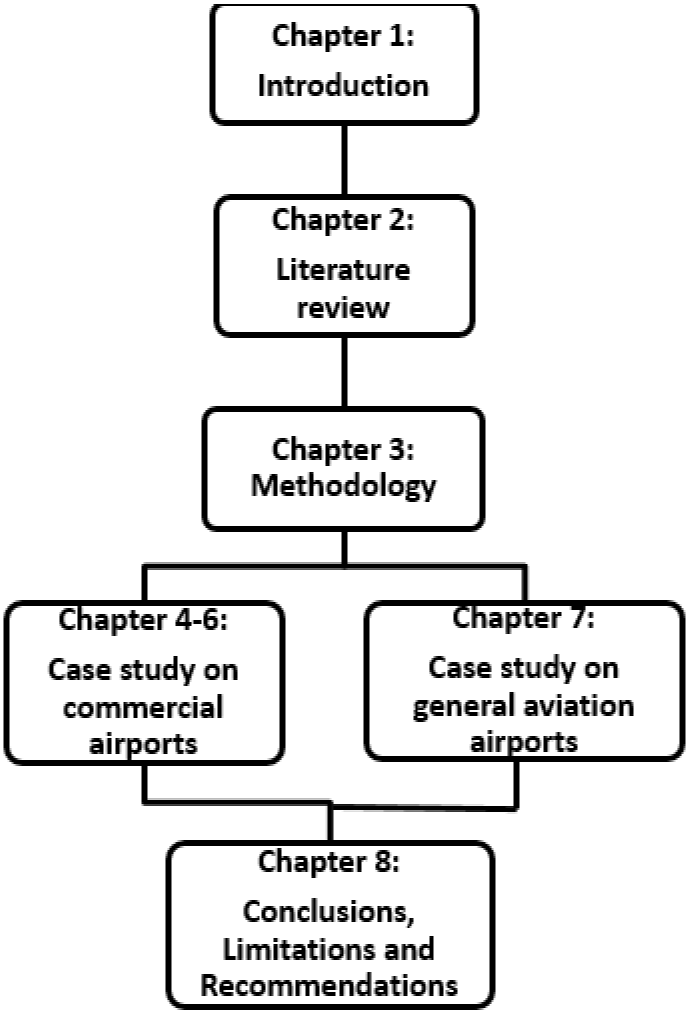

Figure 1. Thesis organization flow chart

CHAPTER 2

LITERATURE REVIEW

In this section, a comprehensive literature review is presented. The section starts with discussing the conventionally used snow removal methods. These include common practices like using chemicals and high power equipment to aid in snow removal. This leads to discussing the use of heated pavements for snow removal. A brief overview of the FAA advisory circular AC 150/5370-17 on heated pavements is also presented.

Conventional Strategies

Ice and snow removal activities require expensive machinery, significant manpower and detailed planning. De-icing is defined as the removal process of existing snow, ice, or frost from a trafficked surface. It includes both mechanical methods and application of ice melting chemicals after the snow event. Anti-icing is the treatment with ice melting chemicals before or during a storm to prevent or delay the formation or adhesion of ice and snow to the surface.

Conventional snow removal strategies include both mechanical and chemical methods. Mechanical methods include the use of snow plows/blowers, snow brooms, and sweepers. Snow plows basically push aside the snow and ice towards the shoulders and disposed of later. Mechanical methods of snow removal might be very time consuming as they operate at relatively slow speeds, and thus may interfere with aircraft operations. In addition, wet snow and ice can develop a strong bond with the pavement reducing greatly the efficiency of snow removal equipment. Another major drawback of mechanical snow removal methods is that they remove snow from the surface and do not focus at the point of bonding (FAA 2011). Mechanical methods can also damage the pavement and the embedded lighting fixtures.

Chemical treatments include solid chemical dispersal and liquid spraying equipment using a variety of de-icing and anti-icing chemicals. This approach can reduce or prevent ice bonding to the pavement surface. Some airports limit the use of chemical agents because of environmental restrictions and the cost of remediation efforts such as detrimental effects to the aquatic life and plants. Other disadvantages include the time for chemicals to become effective, as well as impacts on pavements, electrical systems and aircraft braking performance. Chemical sprayer trucks can be utilized for these purposes.

The purpose of deicer chemicals is to suppress the freezing point, and so, prevent ice formation. The products used most widely at U.S. airports include potassium acetate, urea, sodium acetate, sodium formate, and propylene glycol. Acetate is gradually replacing other deicers. However, acetate can impact aquatic environments through consumption of dissolved oxygen in the water (EPA 2010). Acetates do not have widespread effects on plants, but can be detrimental if used in high concentrations. Acetates, such as potassium acetate (KAc) and calcium magnesium acetate (CMA), are used for anti-icing and they are generally more expensive than chloride based products. However, they can be more effective, less corrosive to carbon steel, and not as environmentally harmful as chlorides (EPA 2012, Fay and Shi 2012). Pavement deicers specified by the FAA do not pose environmental hazards and do not require special methods for purification and thus the storm water purification costs have not been considered a part of the analysis. Airport managers usually limit the use of such substances as they are very expensive and can cause tremendous changes in the budget.

Current State of Practice - Heated Pavements

Hydronic heated pavement has been used in practice since the completion of the Klamath Falls Bridge in 1948 (Lund 2000) as shown in Figure 2. Hydronic heated pavement has since spread globally with high concentration of use in Nordic countries and Japan. Hydronic heated pavement is primarily used in bridges, but it has recently been utilized to heat aircraft parking stands in Nordic countries (Barbagallo 2013). In 1948, the first application of heated pavement in the United States resulted in a hydronic heating system constructed into a 137 m long (450 ft.)

bridge deck in Klamath Falls, Oregon. A half ethylene-glycol-half-water solution circulated through 19 mm-diameter (3/4 in) iron pipes located 7.5 cm (3 in) below the pavement surface and 45 cm (18 in) on center. Ethylene glycol acted as antifreeze for the fluid. The solution was heated by a 62 °C (143 °F) geothermal well through a heat exchanger before being pumped through the deck. The pump, which required electricity to run, was the only operation cost of the heated pavement. The Klamath Falls hydronic system initially had the heating capacity to keep the bridge clear for a snowfall intensity of 76 mm per hour at an air temperature of -23 °C (3 in per hour at -10 °F). In 1992 the temperature of the geothermal well dropped from 62 °C to 37 °C (143 °F to 98 °F), and the well was rehabilitated. In 1997, the hydronic system failed from leaks in the iron pipes caused by corrosion. A replacement geothermal-powered hydronic system was installed into the bridge after the failure. The new system used 19 mm (3/4 in) diameter cross-linked polyethylene (PEX) tubes imbedded 7.6 cm (3 in) deep in an 18 cm (7 in) thick concrete layer. The PEX tubes were placed 36 cm (14 in) on center in a double overlap pattern. In 1999, the total cost of the reconstruction project was approximately $430,000, and the annual operation and maintenance cost was $3,000 and $500 respectively (Lund 2000).

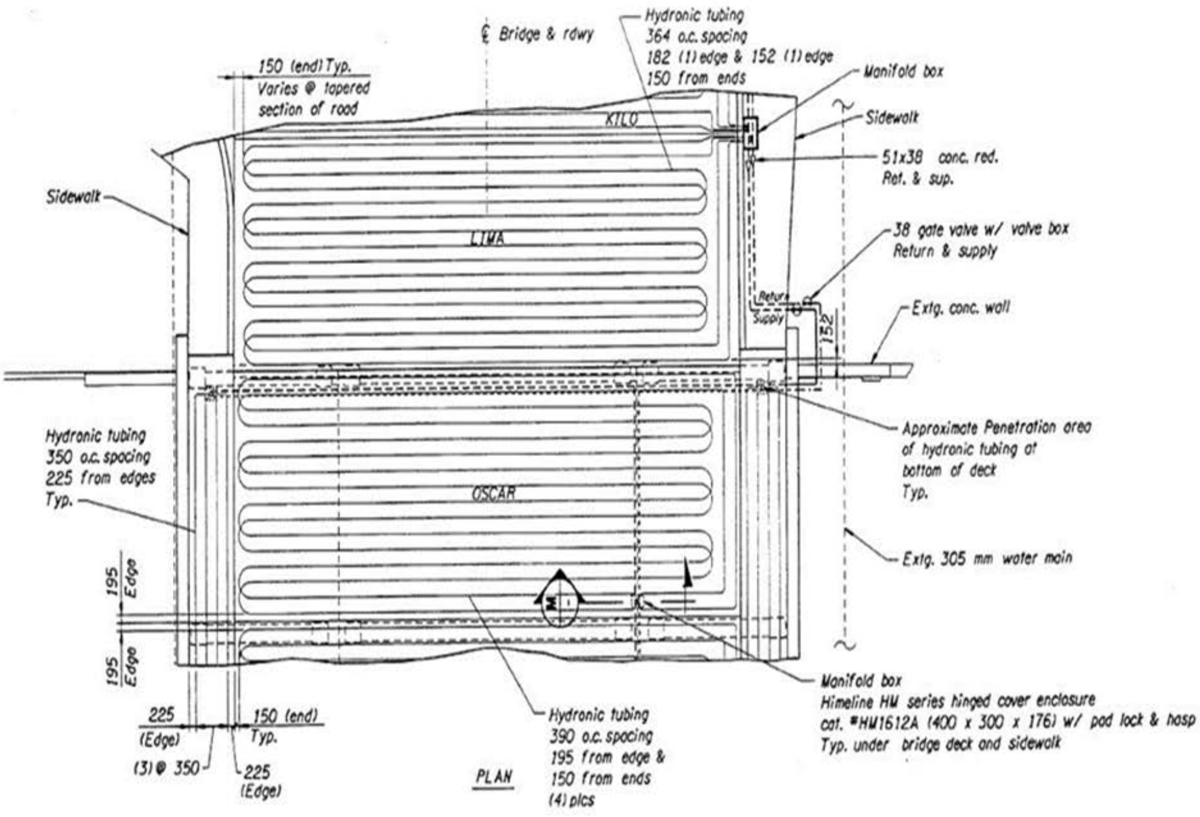

Figure 2. Replacement hydronic system for Klamath Falls (Lund 2000)

Today, the United States has hydronic and heat pipe bridges in operation in Oregon, Nebraska, Texas, Virginia, Wyoming and New Jersey. The Gardermoen International Airport contains 35 hydronic heated aircraft parking stands ranging from 600 m^2 to 780 m^2 (6,500 – 8,400 ft^2) in size. The hydronic system is geothermally-heated through Aquifer Thermal Energy Storage (ATES) as shown in Figure 3, which also heats and cools the terminal buildings as shown in Figure 3. The hydronic system is also supplemented by one electric and four oil fired and boilers to reach the design heating performance of 248 w/m2 (79 BTU/(hft^2)). ATES operates when temperatures fall between -8 °C and 2 °C (18 °F and 35 °F) and takes about four hours to start up. The hydronic heated aircraft parking stands averaged from $275,000 to $375,000 to build, and the annual operation cost for each stand amounted to around $16,500.

Gardermoen International Airport considers the heated stands a necessity because of quicker aircraft turnaround times and safety of ground crews and passengers. Gardermoen currently has 10 larger heated stands under construction, which would increase their heated pavement area to 36,836 m^2 (396,500 ft^2) (Barbagallo 2013). Arlanda International Airport, located in Stockholm, Sweden, also uses ATES to heat 54 aircraft parking stands, which cover an area of over 92,900 m2 (Barbagallo 2013).

Figure 3. Schematic of ATES heats the airport terminal and the aircraft parking stands (Wigstrand 2010)

The Greater Binghamton airport constructed a prototype two way geothermal heated pavement at the concrete aprons. According to the report (Chris Kopec, 2015), it increased the efficiency of the cooling system by 50% and reduced greenhouse gas emissions. The project consisted of heating a 4,000 ft^2 of apron area. The construction budget was set as $1,300,000 and it incurred an estimated annual operation costs of $15,000. This system went in operation from 2013-2014.

Overview of Advisory Circular- Hydronic Heated Pavements

An overview of airport heated pavement systems is provided in the FAA Advisory Circular AC 150/5370-17 (FAA 2011). Heated pavement systems use the heat provided by embedded electric cables or hydronic tubing. The heat requirement for designing and sizing any kind of deicing systems and equipment depends mainly on atmospheric factors (such as humidity and air temperature), thermal conductivity of the pavement surface, and the classification of heat expectations (FAA, 2011). Convection and radiation loss from the melted snow depends on the film coefficient and the difference in temperature between the surface and air. The film coefficient is a function of wind speed alone, and since the pavement temperature is fixed, convection and radiation losses vary with changes in air temperature and wind speed (ASHRAE Handbook 2003; Lund 2000).

Heating airfield pavements from within the pavement structure can be accomplished by passing electric current through the pavement or by circulating warm fluids through pipes embedded in or below the pavement structure. Hydronic refers to the use of heated fluid as the transfer mechanism. Hydronic heating systems utilize heated fluid carried by pipes embedded in or below the pavement in a serpentine pattern to warm the pavement through conduction.

Hydronic pavement heating

Hydronic heating systems are typically closed loop systems, where, after the fluid releases heat into the pavement, it returns to the heat source to be sent through the pipes again (Lund 2000). Hydronic heating systems use metal or PEX pipes. The fluid can be heated by a variety of sources from burning fossil fuels to more environmentally friendly options like natural gas, geothermal wells and waste heat from local industries. Geothermally-heated hydronic systems tend to incorporate a heat pump to obtain a higher range of heat as in many places the ground temperature might not be high enough to melt the snow (Minsk 1999).

The issue of surface runoffs from the heated pavement is a major design consideration. Commonly the design of drainage systems considers a maximum design storm depending on the geography and climate. The water drainage from melted snow might exceed the design capacity, affecting the traffic, causing damages to the facilities and others. Thus, measurements for the proper drainage or storage/removal of the water should be also considered.

Electrical heating system

Electrical current encounters resistance when flowing through a conductor. The resistance to current flow converts electrical energy to heat energy. The heat produced is a function of the current flowing through the conductor and the composition of the conductor that offers resistance to the current flow. Two forms of electric heating are used for in-pavement snow melting applications (FAA 2011).

Insulated conductors are embedded in the pavement, such as heating cables or grid/mesh mats. Conductive materials are added to the pavement material mix, electrical energy is applied through uninsulated conductors, and the pavement serves as the heat source.

Heat requirements

The calculations related to design heat requirement take into account atmospheric factors including rate of snowfall, air temperature, relative humidity, and wind velocity. The detailed equations for each of the parameters are available in FAA Advisory Circular AC 150/5370-17 (FAA 2011). Heat requirements for snow melting installations are classified as Class I, II or III. Class I systems have a snow free area ratio of 0 and are designed not to melt snow while it is falling but later. Class III systems have a snow free area ratio of 1 and are designed to melt snow and ice while it is falling and keep the surface dry Class II expectations are for areas that must be kept clear of accumulating snow, but the pavement may remain wet. Class II systems are designed for a snow free area ratio of 0.5. Class III systems have been selected for the study. The required heat design load should be based on expected rate of snowfall, air temperature, humidity, wind speed, dimensions, and characteristics of the pavement

The heating system must be capable of:

- Maintaining a surface condition of “no worse than wet”,
- Attaining surface temperature above the freezing point before the start of expected snow accumulation, and
- Maintaining surface temperature above the freezing point until snow accumulation has ceased.

CHAPTER 3

METHODOLOGY

This chapter discusses the methodology followed in this study and is illustrated in Figure 4. The basic strategy is simple and starts with selecting airports that had an annual snowfall of at least 35 inches and icy conditions prevailing for the most part of the winter. Data was then collected from these airports through email surveys and on-site visits. In addition, weather conditions, passenger and delay statistics were gathered by means of publically available data. Direct and indirect costs (and benefits) related to the collected data were then monetized and analyzed for a 20 year period. The costs and benefits of installing HPS were finally compared with the conventionally used methods of snow removal to investigate their economic feasibility.

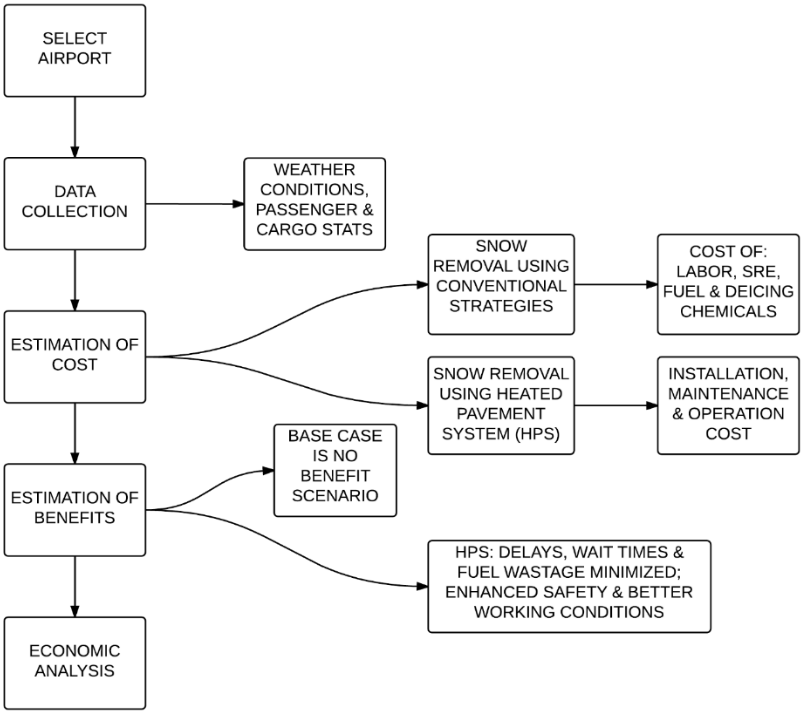

Figure 4. Flow chart of the general methodology followed in the study

Airport Site Selection

Commercial and general aviation (GA) airports within the United States that would benefit from heated pavements during winter operations were identified.

According to the FAA (FAA 2014), Commercial Service Airports are publicly owned airports that have at least 2,500 passenger boardings each calendar year and receive scheduled passenger service. Passenger boardings here refer to all revenue passenger boardings on an aircraft in service in air commerce, whether or not in scheduled service. This also includes passengers who continue on an aircraft in international flight that stops at an airport in U.S. for a non-traffic purpose, such as refueling or aircraft maintenance rather than passenger activity. General aviation airports is the largest single group of airports in the U.S. system. This category also includes privately owned, public use airports that enplane 2,500 or more passengers annually and receive scheduled airline service. Figure 5 illustrates the various airports shortlisted for the study.

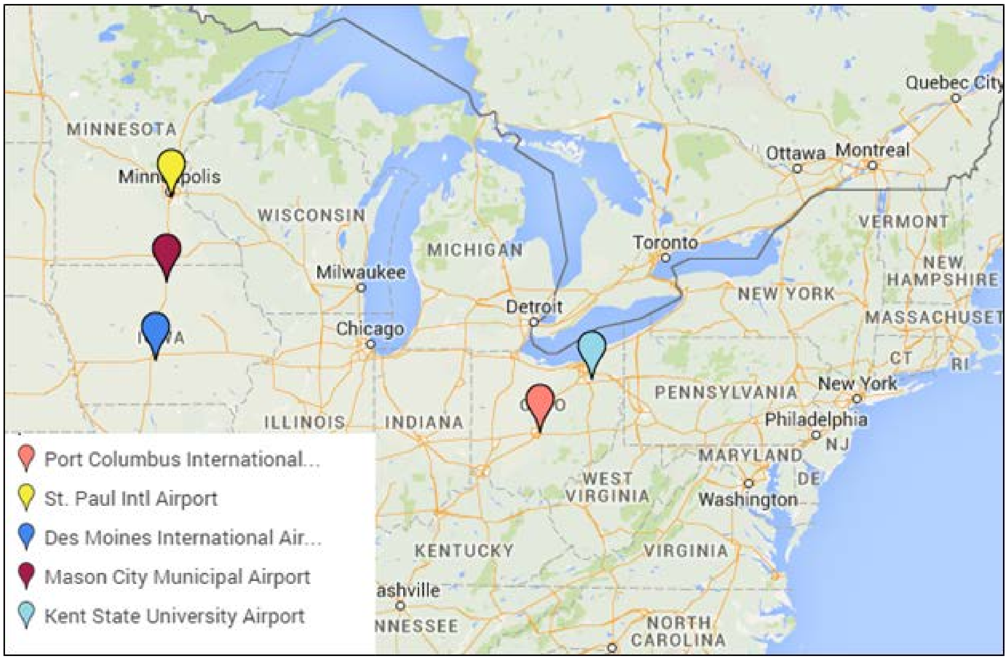

Figure 5. The airports considered in the analysis

The following criteria were used for selecting the airport sites:

- Airports with average annual snowfall greater than 35 inches per winter season.
- Snow/ice clearing operations on average at least 20 days per winter season.
- Airports with plans for installing new pavement due to airport expansion or rehabilitation within the next ten years.

An extensive list of airports based on the aforementioned criteria was made and their snowfall history and number of enplanements was extracted and analyzed. The airport managers were contacted and the most suitable airports for the study were finalized.

The three commercial airports which are a part of the research study are:

- St. Paul International Airport, Minneapolis, MN (MSP)
- Port Columbus International Airport, OH (CMH)
- Des Moines International Airport, Des Moines, IA (DSM)

The two GA airports which are a part of the research study are:

- Kent State University Airport, Kent, OH (1G3)
- Mason City Municipal Airport, Mason City, IA (MCW)

Data Collection

A detailed survey questionnaire (refer to Appendix D) was sent to all the commercial and general aviation airports to gather information on various aspects like operations and maintenance costs during snow removal, staffing levels, purchasing costs of the snow removal equipment and the challenges faced during snow removal operations. Note that the survey does not need approval from the Institutional Review Board. The summary of the responses can be seen in Appendix E. Site visits were made to MSP and DSM in July 2014 to understand the operation of snow removal in depth; some pictures of the sites are shown in Figure 6. We note here that there were some limitations in the collected data on conventional snow removal operations because the operation costs and usage could not be separated down to per unit level. Due to this, costs were assumed to be a function of the area considered. This assumption was further supported by discussions with the airport managers.

Figure 6. Pictures taken during the MSP site visit

There were attempts to collect data on the number of delays occurred in the airport and their root cause from the airports directly, but such data is unavailable. Data collection for the current study was thus a challenge and most of the data was collected from the Bureau of Transportation Statistics (RITA 2014) or by conducting interviews with the airport managers. A flight is considered to be delayed if it arrives 15 or more minutes later than the schedule (RITA 2014). As seen in Figure 7 (created using data from RITA 2014), there can be many causes of scheduled air service delays like severe weather delays, air carrier delays, security delay, national aviation system delay or the aircraft arriving late. Weather related delays can be due to high winds, low visibility, and extreme snowfall. In this study, we are only concerned with delays due to snowfall. Figure 8 (created using data from RITA 2014) depicts the on-time arrival performance and delay causes for all airports and all domestic carriers in U.S for 2014.

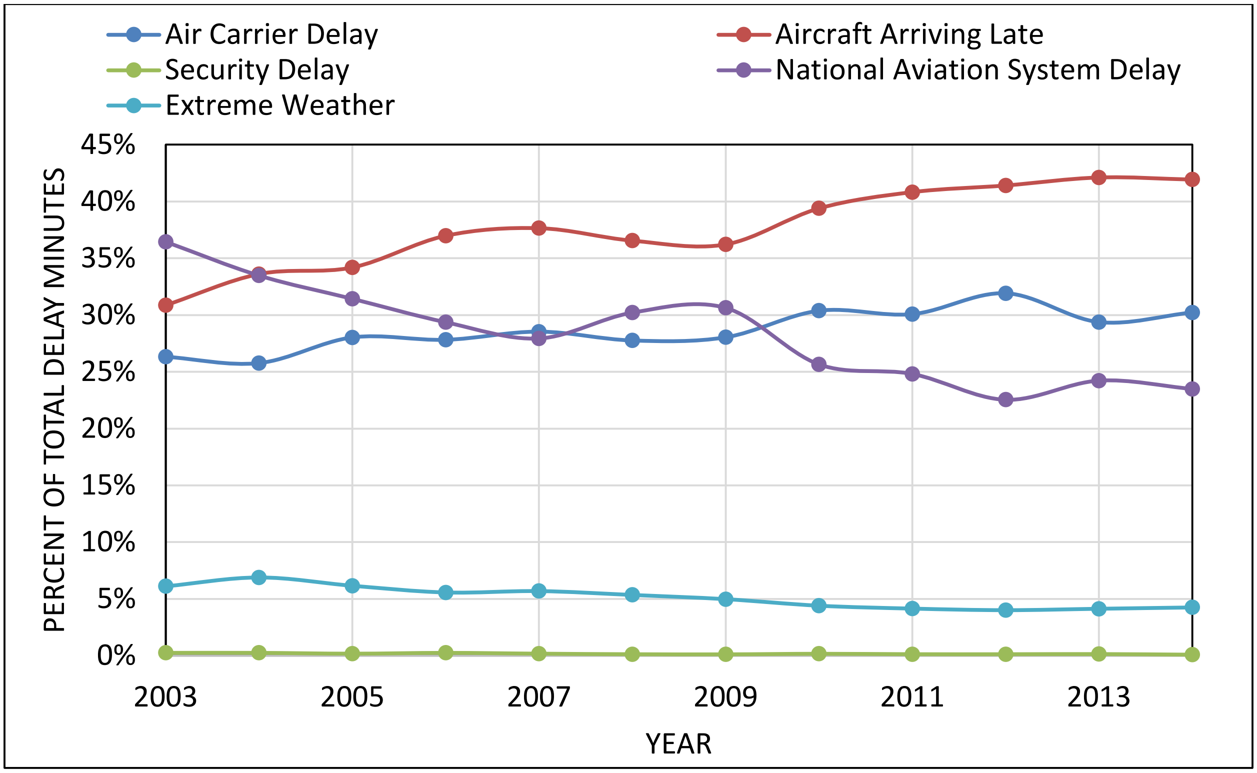

Figure 7. Factors contributing to aircraft delays

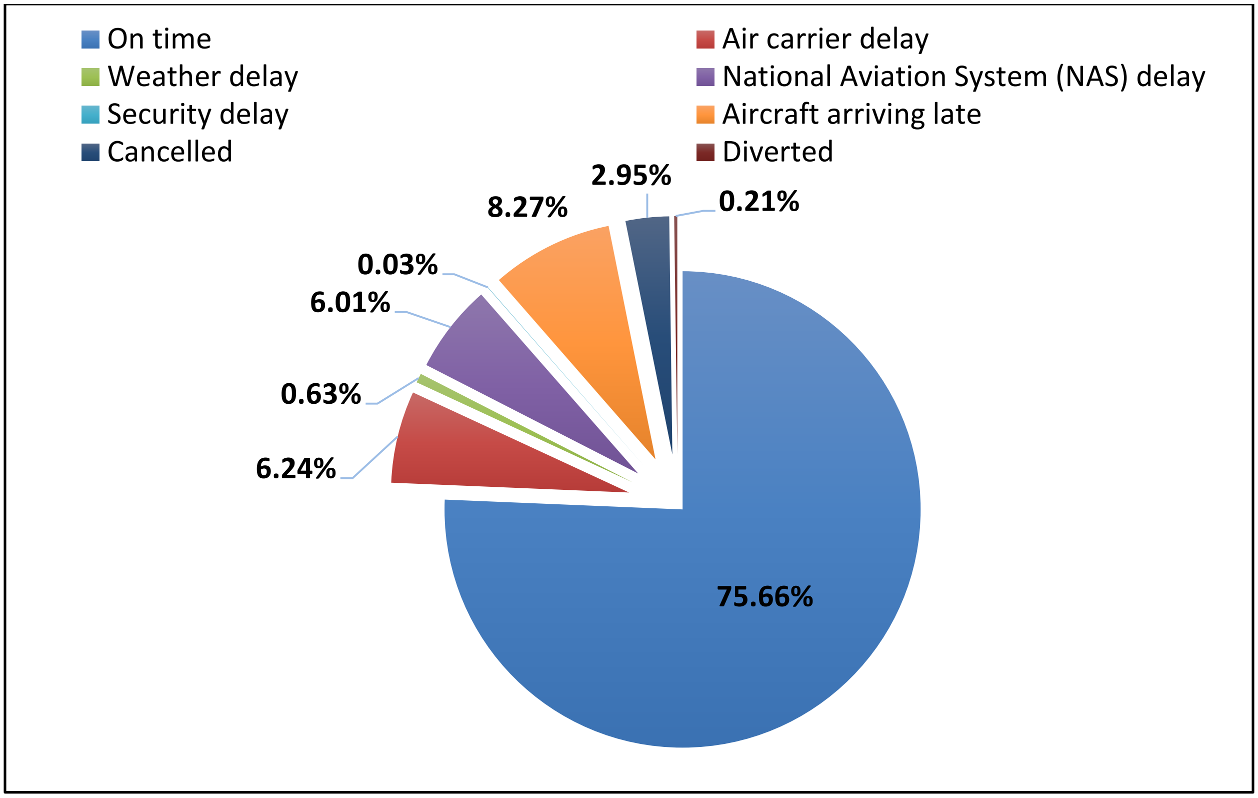

Figure 8. On-time arrival performance and delay causes for all airports and all domestic carriers in U.S for 2014

Weather related delays were assumed to be approximately 2% of the total operations. This conservative value was used as the base case, but sensitivity analysis was carried out. Airports do not keep track of the number and causes of aircraft delays and, at the same time, the delay-related data reported from the airlines, is not detailed. Thus, publicly available data pertaining to the total operations reported by the U.S. Department of Transportation (RITA, 2014) was used instead with some assumptions. There can be many causes of scheduled air service delays like severe weather delays, air carrier delays, security delay, national aviation system delay or the aircraft arriving late; a flight is considered to be delayed if it arrives 15 or more minutes later than scheduled (RITA, 2014). Weather related delays may further be due to high winds, low visibility, and extreme snowfall. In this study, we are only concerned with delays due to high amounts of snowfall, such that keeping up with snow clearing operations is not possible. However, data for flight delays related to snow are not explicitly recorded, and airlines do not report the specific causes of late-arriving aircrafts, but rather if the delay was due to severe weather conditions or another general reason.

Usually, the number of operations in a day during winter months is far less than the summer months. For example, operations in MSP in August were nearly 2.5 times as much as January (MSP, 2014). Assuming that efficiency loss and delays due to snowfall is one of the causes of such reduction, with an increase in efficiency the number of operations can be increased, which will directly affect the revenues as well. The loss of these operations can be quantified using direct and indirect costs as discussed in the later sections.

Determining Energy Requirements for Selected Airport Sites

This step involved data collection on energy and cost requirements for the identified airport sites. After selecting airports that could benefit from the installation of heated pavement, pavement areas to be considered for heating were identified. Using guidance provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 2003), the required amount of energy (Watts/ft^2) necessary to melt snow and leave a wet residue 90% of the time for the geographic area where the airport is located was calculated.

General Equation to Calculate Heat Load

According to Chapman (1952), the general equation for the required pavement heat output (q_o) in Btu/h.ft^2:

$$\boldsymbol{qo = qs + qm + Ar\,(qe + qh)} \tag{1}$$

Where:

qs = sensible heat transferred to the snow (Btu/ h·ft^2)

qm = heat of fusion (Btu/ h·ft^2)

Ar = snow-free area ratio must equal 1 for areas with aircraft operations

qe = heat of evaporation (Btu/ h·ft^2)

qh = heat transfer by convection and radiation (Btu/h·ft^2)

The parameters in Equation 1 take into account atmospheric factors including rate of snowfall, air temperature, relative humidity, and wind velocity. The detailed equations for each of the parameters are available in the FAA Advisory Circular AC 150/5370-17 (FAA 2011). The ratio of the uncovered, or free area A_f to the total area A_t is the free area ratio A_r. To maintain A_r = 1, the system must melt the snow so rapidly that accumulation is zero. This may not be practically possible in all situations. When determining the solution for general equation qo, the snow-free area ratio A_r can be assumed as 1. This is a conservative measure in order to get the maximum heat required heat load.

For hydronic heating systems, the temperature of the fluid can be calculated using Equation 2 (ASHRAE 2003)

$$\boldsymbol{tm = 0.5qo + tf} \qquad \textbf{\textit{(2)}}$$

Where:

tm = average fluid temperature, °F

tf = water film temperature (°F), accepted as 33°F

It is expected that the heated pavement will be operated from just before the winter season until after the last winter storm event. A run of precipitation free days may mean that the system may be turned off, depending on how long it takes for the pavement to be re-heated in advance of the next storm. Additionally, a fixed maintenance plan should be followed, for the maximum life expectance, and measurements should be taken in order for efficient emergency repair.

Total Heat Output Requirement Estimations

Depending on the energy source and required equipment to operate the system being analyzed, an estimated cost for equipment maintenance was calculated. These values are based on the weather conditions of the airports under study. The ambient temperature and wind speed have been assumed to be the same for all airports. Inspections will be required before and after the winter season to check for damage to and repair the delivery system.

The energy source was taken as natural gas. According to the 2003 ASHRAE handbook HVAC Applications, Minneapolis receives on average 199 hours of snowfall per year respectively (ASHRAE Handbook 2003). Using this, costs required to melt snow using natural gas were approximated. Values of total heat output requirement, as calculated from Equation 1 for each of the snowfall case scenarios are shown in Table 1. The recurring costs related to natural gas are summarized in the Section Case Studies.

Table 1. Energy requirement and annual snowfall events in the concerned airports

Airport	State	No. of annual snowfall events (ASHRAE 2003)	Energy requirement (btu/hr)
St. Paul International Airport	MN	31	256
Des Moines International Airport	IA	29	162
Port Columbus International Airport	OH	26.2	136
Mason City Municipal Airport	IA	28.2	159
Kent State University Airport	OH	28.2	141

Development of Benefit Cost Analysis Framework

In order to achieve the research objectives, it is necessary to develop a set of criteria, which can be used to objectively evaluate the benefits and costs of heated pavement systems. The goal is not necessarily to prove that heated pavements are cost effective but rather to give a realistic assessment of the true cost and benefit that could be realized as well as the payback period. The basic benefit cost analysis framework is outlined in Figure 9 (FAA 1999).

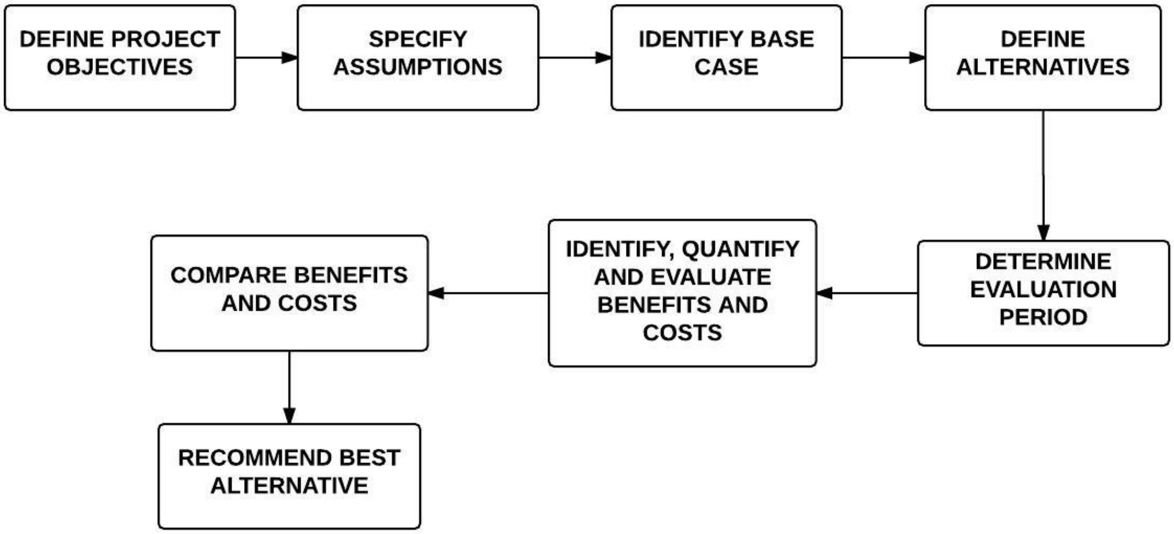

Figure 9. Benefit-cost analysis framework

Define BCA Project Objectives

The BCA project objectives were to investigate the economic advantages of a heated pavement, which included factors such as operational savings by reducing staffing requirements to operate snow removal equipment and improved safety. The next objective was to appraise the initial installation costs of a heating system and ascertain how they may be absorbed over a period of time under operation. The last objective was to compare the potential net costs and benefits of installing a heated pavement system.

Identify BCA Base Case

In general, the BCA base case represents the best course of action that would be pursued in the absence of a major alternative to obtain the specified objectives. The BCA base case represents the reference point against which the incremental benefits and costs of various possible investment alternatives will be measured. In the current study, the use of conventional methods, i.e., Snow Removal Equipment (SRE) and deicing chemicals to clear snow/ice is taken as the base case.

Identify BCA Alternatives

This step involves the identification of all reasonable ways/alternatives to achieve the desired objective. The alternative in this study is use of hydronic heated pavements. The heating may be achieved by means of natural gas, electricity or geothermal energy. In this study, natural gas has been taken as an example to illustrate the methodology proposed.

Determine Evaluation Period

The analysis period for a BCA must be sufficiently long such that each alternative pavement strategy includes at least one future rehabilitation event. FAA pavement design practice requires the use of a 20-year design life period (FAA, 1999). 2014 has been taking as the year 0 and all values correspond to 2014 USD.

Identify, Quantify and Evaluate Benefits and Costs

A few relevant terms and concepts used to identify, quantify, and evaluate the benefits and costs involved are briefly outlined in the following sections.

Initial Costs

A project's initial costs are those that are incurred during the design and construction process. They usually include costs related to planning, preliminary engineering, and project design, project-related staff training, final engineering, and land acquisition, construction costs, including improvements to existing facilities, equipment and vehicle purchases, equipment required for project operation etc. The initial costs considered here refer to the cost of installation of hydronic HPS and the purchasing cost of SRE.

Operations and Maintenance Cost (O&M)

O&M costs are the recurring costs required to operate and maintain the proposed investment project. Expenses associated with O&M may occur annually or periodically. The recurring costs are annual costs and include maintenance, operation and labor costs. Conventional snow removal strategies involve fuel costs, labor costs, and cost of deicing agents and maintenance of SRE as their recurring costs. Hydronic systems on the other hand involve no labor costs and cost of deicing chemicals. Cost of natural gas required to heat pipes and maintenance of the system are the recurring costs associated with the HPS.

Discount Rate

Discounting requires the division of an annual discount rate into future benefits and costs. The annual discount rate (also known as the marginal rate of return of capital) represents the prevailing level of capital productivity that can be achieved at any particular time by investing resources, i.e., the opportunity cost. The real discount rate relevant to all airport projects to be funded with Federal grant funds is 7%. Additionally, sensitivity analysis have been carried out at 3% and 5% discount rates.

Opportunity Cost

Opportunity cost is the value of the benefits foregone when resources are shifted from satisfying one objective to satisfying another. An all-inclusive measure, it represents what society as a whole—government and all private groups—must give up to obtain the desired objective. It is the theoretically correct measure of cost for use in economic analyses of projects funded with government funds. Opportunity costs in the event that HPS are not installed were not considered as they would be complex to estimate due to the possibility of various projects using the same funds and it would require forecasting from each airport's point of view.

Indirect Costs

Indirect costs are costs that are not directly accountable to a cost object (such as a particular project, facility, function or product). Indirect costs may be either fixed or variable. In this study, the indirect benefit of installing HPS is the enhanced safety of ground personnel, reduced passenger waiting times, reduced fuel wastages. Other costs like increase in the number of operations of airports leading to higher revenues are also indirect costs but have not been quantified in this study.

Incremental Cost

A BCA is concerned with the differences between options (the base case and its alternatives). All cost elements which differ between options are defined as incremental costs, and must be reflected in the comparison of options. Costs which are common to all options are not relevant to the investment decision and should be netted out when calculating differences among options.

Sunk Cost

Sunk costs are costs of resources which have already been consumed and cannot be recovered at the time the BCA is being conducted. As a consequence, they are not relevant for current decision making and should not be included in the BCA. Occasionally, projects can be implemented for very little additional or incremental cost because they make use of existing fixed assets. If these assets have no opportunity cost (i.e., no alternative uses), they are free to the project under consideration.

Depreciation

Frequently, large costs must be incurred in the beginning of a project in order to obtain benefits (or revenues) in later years. It is often useful to know by how much annual benefits (or revenues) exceed annual costs, or the net benefit (or income) of the project. In order for this value to be reasonable, it is necessary to allocate the large initial costs to later years when benefits occur.

Inflation

The dollar is the measure into which all costs and benefits must be converted in order to be compared. However, due to the process of inflation, the amount of physical resources that may be purchased by a dollar will decrease over time. Consequently, it is necessary to cost all resources in the form of dollars of a given year, known as constant dollars, to facilitate year-to-year comparisons. The year 2014 was taken as the base year and all monetary values are in terms of 2014 dollar values.

Economic Analysis Techniques

The following section present the techniques utilized to conduct an economic analysis in order to compare the net benefits and costs of installing HPS and their relative costs/benefits to conventional methods.

Net Present Value (NPV)

NPV is a method of calculating return on investment (ROI) for a project. The sum of the present value of cash flows (both positive and negative) is calculated for each year associated with the investment and discounted so that it expresses value in terms of the base year's dollars. If NPV is greater or equal to zero the project is acceptable (Park et al 2007). Equation 3 can be used to calculate the NPV.

$$NPV = C_0 + \sum_{i=1}^{T} \frac{Ci}{(1+r)i} \tag{3}$$

Benefit Cost Ratio (BCR)

Benefit-cost analysis (BCA) is a widely used economic analysis technique for evaluating a project or investment by comparing the economic benefits with the economic costs of the activity to help policymakers identify the best option to pursue. Specifically, the BCR is a ratio of the net benefits to the net costs involved in a project. If the ratio of the sum of the present value of benefits of the project or policy to the costs exceeds one, then there is a general economic argument supporting the action to make the investment or implement the policy in a project. This can be seen in Equation 4.

$$\boldsymbol{BCR = \frac{Present\ value\ of\ benefits}{Present\ value\ of\ costs}} \tag{4}$$

The methods used in BCA require an examination of all benefits resulting from the production and consumption of the output, regardless of who realizes the benefits (FAA 1999). The first step in performing a BCA is to establish the base case conditions from which any proposed alternatives can be differentiated and analyzed. This is crucial, since BCA focuses on monetizing only those effects that differ significantly between the base case and alternative cases. In general, the base case represents the best course of action that would be pursued in the absence of a major alternative to obtain the specified objectives. As such, the base case represents the reference point against which the incremental benefits and costs of various possible investment alternatives will be measured. The base case should be modeled for the analysis period with as much information as possible about changing conditions that are expected to occur, regardless of the final decision regarding construction of an alternative system.

In the current study, the use of conventional methods, i.e., SRE and deicing chemicals to clear snow/ice is taken as the base case. In order to examine the net costs and benefits of HPS and conventional methods, incremental BCR was also calculated. Incremental BCR analysis is used to select the best alternative from a set of mutually exclusive alternatives. The differences in benefits and costs between HPS powered by natural gas (alternative) and conventional methods (base case) are calculated and then the ratio of the equivalent worth of incremental benefits to that of incremental costs is calculated by using Equation 5 shown below (Park et al 2007).

$$\textit{Incremental BCR} = \frac{\textit{Present Value of benefits}(\textit{Alternative } 1 - \textit{Alternative } 2 \textit{ or base case})}{\textit{Present value of costs } (\textit{Alternative } 1 - \textit{Alternative } 2 \textit{ or base case})} \qquad (5)$$

Estimation of Costs and Benefits

This section describes the relative costs and benefits related to removal of snow using conventional strategies and HPS. Once the costs and benefits are identified they are quantified in monetary terms. The effect of lost time and reduced efficiency in preparing an aircraft for arrival and departure during snowy conditions were studied and estimated in terms of monetary values. This preparation includes passenger movement, aircraft refueling, and luggage allocation, change of crew, cleaning the aircraft, navigating and hauling the aircraft and most importantly clearing the areas off snow. The potential cost and benefits studied in the analysis have been listed in Table 2.

Table 2. Description of the cost and benefit items considered in the analysis.

Cost/Benefit category	Conventional	Heated pavement
Initial cost	Snow removal equipment purchase	Heating system installation
Operation cost	Labor, fuel, and deicing agents	Energy source cost (geo-thermal energy, fuel, natural gas, and etc.)
Maintenance cost	Maintenance for system	Maintenance for system
Benefit	-	Aircraft and passenger delay costs are minimized, Enhanced safety and better working conditions

Estimation of Costs for Conventional Methods

Machinery, deicing salts/chemicals and labor are the units required for deicing pavements. The ramp and apron areas of the airports have been considered for analysis, and the cost of equipment required to deice this area was estimated. The various types of snow removal equipment and the associated purchase cost were identified for airports after carrying out discussions with airport management at each airport (as seen in Table 3 for the conventional strategies). That would serve as the initial cost (cost at year 0; 2014 in this analysis) for the conventional strategies. A fraction of these costs corresponds to the aprons and ramp areas. In this study it is assumed that this cost can be approximated by using a ratio between the apron area and total paved area. Figure 10 depicts the various cost factors considered in the cost estimation of conventional methods which can be calculated using Equation 6 and 7.

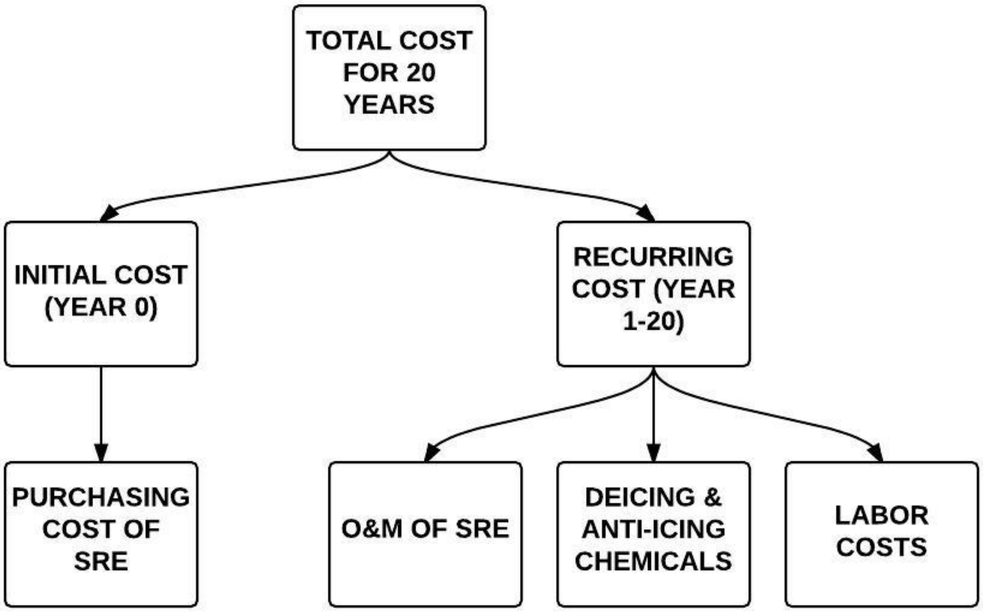

Figure 10. Cost factors in the base case (conventional methods)

The initial (capital) cost can be estimated using the following equation:

Capital cost =Purchasing cost of entire SRE fleet × (Area of pavement under consideration/Total pavement area) ***(6)***

Table 3 presents the cost of the snow removal equipment by equipment type considered for this analysis.

Table 3. Purchasing cost of snow removal equipment identified from airport site visits and survey (identified from survey and field visits).

Item	Unit price
Displacement plows	$485,000
Rotary brooms	$650,000
Blowers	$875,000
Loaders	$250,000
Sprayer truck and spreader	$34560
Deicer truck	$44,000
Multifunctional Vehicle	$910,000

The recurring costs associated with snow removal using conventional strategies consist of the fuel consumed by the equipment, labor, deicing agents, and maintenance of the equipment. The type, amount, and costs of the deicing agents were obtained from a survey carried out at the airports under study. Follow-up discussions with the airport managers through airport site visits and survey revealed that they limit the use of deicing and anti-icing agents where ever possible as they are expensive, and rather only rely on the SRE to clear snow.

The labor costs involved in snow removal operations at commercial airports may range from $14/h to $50/h. The higher values indicate work during late nights or overtime. For simplicity a value of $27 per hour per person was adopted for calculations (values were provided by the airport managers through airport site visits and survey). The duties of the personnel responsible are limited to operating machines to clear out snow and dumping it in designated areas. The number of personnel, amount of deicing agents, and fuel required for the operation of equipment will increase as the storm intensity increases. Average annual values were then taken for different snowfall intensities. These may be calculated using Equation 7.

Annual recurring cost=Total cost of (labor + fuel + deicing agents + O&M costs of SRE) × (Area of pavement under consideration/Total pavement area) **(7)**

Estimation of Costs for Hydronic Heated Pavement System

The total cost of heated systems can be divided into initial construction costs and maintenance and operation costs as illustrated in Figure 11. The initial cost of the hydronic heated pavement consists of installing the hydronic pipes in or below the pavement along with the heating system facility including control systems. It is not advisable to use asphalt in hydronic pavements, as the high temperature of asphalt during laying may damage the PEX pipes. As the installation costs of hydronic hated pavement systems would play a crucial role in estimating their economic usefulness it was decided to analyze various cost scenarios. These costs include the entire installation and startup costs.

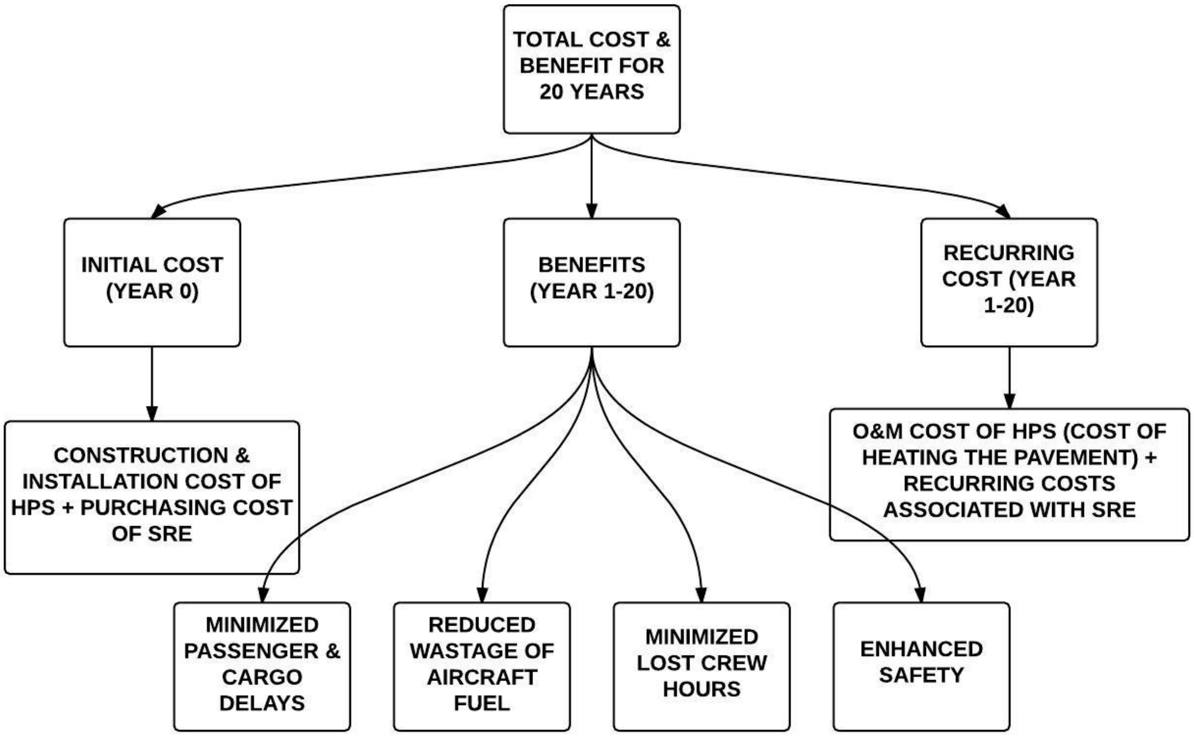

Figure 11. Cost factors for the hydronic heated pavement (HPS) system

It was assumed that the hydronic system would be operated by means of automated valves and switching equipment and hence, would involve no labor cost. It is expected that the heated pavement system will be sufficient to clear the snow, and thus assumed that no deicing agents or snow removal equipment would be required for the ramp and apron area.

Operation costs consist of the cost of natural gas needed to heat anti-freeze circulating in the pipes and electricity needed to power the control system. To quantify the amount of natural gas needed, the energy required to melt snow or the design heat load was first calculated. The design of the heated pavement systems should be able to meet both design load requirements and heating needs of the system (FAA 2011). The required system performance includes maintaining a surface condition of “no worse than wet”, by maintaining a surface temperature above freezing. The required heat design load can be determined by considering the expected rate of snowfall, air temperature, humidity, wind speed, dimensions and material characteristics of the pavement. These design requirements impact the cost of heated pavement system.

Estimation of Benefits for Hydronic Heated Pavement System

The analysis has been conducted in comparison to the base case scenario (conventional methods). The anticipated benefits after the installation of hydronic heated system considered in this analysis include lesser passenger delays, minimized aircraft fuel wastage, loss of crew working hours and enhanced safety.

Value of Lost Passenger Time

When defining delays, FAA's Air Traffic Organization considers flights delayed 15 minutes or more as delays. The Bureau of Transportation Statistics provides publically accessible data on several aviation operation components including delay and delay causes for each airport on a monthly basis. Another important factor to account for is the value of time of the passengers that suffer a delay. Specifically, passenger delay costs herein consist of the opportunity costs of time lost due to weather-related delays at the airports. These represent indirect costs as, in general, aircraft operators do not offer any form of compensation including discounts on meals or hotels due to weather related delays.

Passenger costs associated with flight delays were based on air traffic demand. Specifically, the total aircraft seats available and an estimation of the load factor were used to estimate the demand. Load factor is a measure of the use of aircraft capacity that compares revenue passenger-miles (RPMs) as a proportion of available seat-miles (ASMs) (BTS 2014). The average total load factor for domestic flights in U.S. for 2014 was 83.38 %. (BTS 2015). In addition, the air traffic does not remain constant but is expected to increase, on average, every year. Thus, we considered the average traffic growth forecast of 2.8% for the next 20 years based on the FAA recommendation (FAA 2014).

The extra time that the passengers spend waiting at the airport (or in the air) due to snow clearing operations using conventional strategies needs to be accounted for in monetary terms. The elimination or reduction of this cost will constitute a benefit for the hydronic heated pavement systems. According to a report generated by NEXTOR, passenger travel is highly disrupted by weather delays; an annual cost of $16.7 billion (2010 value) was estimated to account for passenger delay out of a total cost of $31.2 billion to the U.S. economy (Airlines for America, 2010).

To estimate this cost, passengers were grouped into two categories, those traveling for business and those for personal purpose or leisure (Ardent et al. 2015). There are different values available for passengers depending on trip purpose as seen in Table 4. Based on the load factor and type of aircraft considered, an average load of 74.5 passengers traveling for leisure and 50.5 passengers traveling for business was calculated (Belenky 2011). The passenger delay costs can be calculated using Equation 8 and 9.

Total delay hours in a season = No. of operations* × *Percentage of snow related delays* × *Passenger growth rate* × *Average duration of one delay (hours) ***(8)***

Annual monetary value of lost passenger time = (A* × *B* × *Total delay hours in a season)* × *(C* × *D) ***(9)***

Where,

A = Total no. of seats in an aircraft

B = Load factor

C = Percentage of passengers based on trip purpose (leisure or business)

D = Value of time (VOT) based on trip purpose

Table 4. Opportunity cost of time for passengers on a delayed flight (Ardent et al. 2015).

Value of time (per hour)	**Cost per hour 2014 ($)**	**Percentage distribution (%) (Belenky 2011)**	**Number of passengers in a flight**
Personal	35.10	59.6	74.5
Business	63.00	40.4	50.5

Cargo

Cargo handling operations at airports involve the preparation of cargo shipments, the loading and unloading of the aircraft, and the transfer of cargo between the storage facilities and land transport. For outbound cargo, the preparation includes consolidation of cargo, building up of the air cargo pallets and containers, inspection, and documentation. For inbound cargo, the preparation includes customs and other regulatory procedures, as well as deconsolidation. For transshipment cargo, the operation is generally limited to unloading, reconsolidating, and reloading the cargo but can be as simple as a direct transfer between aircrafts (The World Bank 2009). This study does not utilize costs due to delays in cargo because it was not found to be a significant factor in the airports considered. Nevertheless, each airport has different policies dealing with cargo and the frequency of cargo movement also varies with each airport. It is arduous to collect information on cargo delays. Airports usually do not have such information and only the cargo carriers would have such information.

Fuel and Crew Costs

As discussed previously, the costs associated with flight delays consist of: cost of fuel, crew costs, and passenger delay impacts (Ferguson et al. 2013). Aircrafts burn about 29.06 gallons of fuel in hotel or ground idle mode (ATR 2011). The installation of hydronic pavement aims to reduce–if not eliminate–the above costs which make a large part of the annual delay costs. Short haul airlines typically get lower fuel efficiency because take-offs and landings consume high amounts of jet fuel. Cost of fuel can be calculated using Equation 10, as provided in (Ferguson et al. 2013):

$$\boldsymbol{cfuel \times fuel\,burn\,rate \times fuel\,price} \qquad \textbf{\textit{(10)}}$$

Where:

$cfuel$ = the Fuel burn coefficient

Fuel burn rate was taken as the fuel consumption rate of a Boeing 737-800, which is $4.88 US gallons per seat per hour. Fuel price is the price of aviation fuel ($3.05/gallon). The estimated equation assumes that for each minute of delay 100% of the fuel burnt contributes to the delay cost; the coefficient of fuel is set as 1 for both taxi and airborne delay cost (Ferguson et al. 2013).

For ease in calculation in the crew cost calculation, we assumed a Boeing 737-800 with 160 passenger seats in total. A Boeing 737-800 typically needs five cabin crew and two flight crew. For the flight crew, the salary is a function of the maximum take-off weight of the aircraft.

There may be cases when working hours of the flight crew increase due to delays; the airlines will incur additional costs in such situations. The total variable cost per block hour was taken as $4,102 (2014 value) (Ardent et al 2015), where block hour is the time from the moment the aircraft door closes at departure of a revenue flight until the moment the aircraft door opens at the arrival gate following its landing (The Boeing Company). The fuel and crew costs are calculated using Equation 11.

***Annual additional aircraft operating cost due to delays = Total delay hours in a season* × *Operating cost of aircrafts (mid, ground and gate delays)* (11)**

Enhanced Safety

The aprons incur tremendous activity in the form of baggage handlers and oil refueling operations. The working conditions in the winter are rough and there are possibilities that the workers may slip and fall during loading and unloading operations. These workers are eithers employed by the airport or the airlines depending upon their policies. Potential accidents may cause additional monetary burden to the airport or airlines. With the use of HPS, the working conditions may improve and the risks of an injury may reduce considerably.

The benefit of preventing a fatality is measured by the Value of Statistical Life (VSL). It is defined as the additional costs that the individuals are willing to bear for improvements in safety. According to the U.S. DOT, the VSL is set as 9.2 million USD (2014 value) (Trottenberg, and Rivkin 2013). Relative Disutility factors by Injury Severity Levels (AIS) can been seen in Table 5. Data for categorizing injuries for this level of detail is not available at the Bureau of Labor Statistics (BLS 2014). The available data as per the BLS report on occupational injuries was collected and certain assumptions were made to quantify cost due to injuries. The ground staff may be employed by the airport or the airlines who will be financially responsible for any injuries. These costs can be calculated using Equation 12.

Table 5. Relative disutility factors by injury severity levels (AIS) (Trottenberg, and Rivkin 2013)

AIS Level	Severity	Fraction of VSL
AIS 1	Minor	0.003
AIS 2	Moderate	0.047
AIS 3	Serious	0.105
AIS 4	Severe	0.266
AIS 5	Critical	0.593
AIS 6	Un-survivable	1.000

Annual cost due to injuries = Percentage of a type of injury (minor, moderate, serious) × VSL ×Fraction of VSL for injury type ×Incidence rate ×No. of full time employees ***(12)***

Sensitivity Analysis

The outcome of a BCA depends on numerous estimates, forecasts, assumptions, and approximations of reality. Each of these factors has the potential to introduce error into the results. The importance of such errors in affecting the outcome of the BCA must be known to the decision-maker if informed decisions are to be made and confidence placed in such decisions.

Moreover, the degree of uncertainty associated with each alternative is itself a factor to be considered in selecting between competing alternatives.

In order to eliminate such concerns sensitivity analysis was carried out. Specifically, the sensitivity analysis was used to determine how different values of certain variables impact the benefit cost ratio under a given set of assumptions. It helps to predict the outcome of a decision under different scenarios. Sensitivity analysis can be a valuable tool for evaluating the impacts of uncertainty on proposed investment projects. The basic approach is to vary key assumptions, estimates, and forecasts systematically over appropriate ranges and observe the impact on the results. For certain items, the impact may be insignificant while for others it may be quite large. In some cases the relative desirability of competing alternatives might be altered while in others might not.

There are several ways by which a sensitivity analysis can be accomplished; each depends on how the key assumptions, estimates, and forecasts are varied. One procedure is to vary only one parameter at a time, holding the others constant so as to determine the independent, or partial effect of this parameter. This procedure is known as a one variable uncertainty test. It is also known as one-at-a-time (OAT) sensitivity analysis. A second procedure is to vary two parameters simultaneously and is known as a two variable uncertainty test. In this study both methods have been adopted to forecast independent and combined effects of critical factors. This procedure has been applied to the major cost and benefit components of each alternative.

The results of this analysis can be used to identify components to which the BCR is sensitive. This can led additional effort be devoted to improving the reliability of the estimates for those components. In addition where reliability cannot be improved, it puts the decision-maker on notice as to potential weaknesses of the BCA. The chapters 4 through 7 present case studies on commercial and general aviation airport. Each airport's characteristics have been discussed in detail. The calculations for carrying out an economic analysis has been shown in depth in accordance with the methodology described here. Each case study is concluded with detailed results, discussions and comparisons with other airports. In addition to the case studies, a different airport could also be analyzed by means of an economic analysis tool developed specifically for evaluating heated pavements. Appendix G depicts the user manual for employing this tool.

CHAPTER 4

CASE STUDY OF COMMERCIAL AIRPORT, MINNEAPOLIS –ST. PAUL INTERNATIONAL AIRPORT (MSP)

Description of the Airport

The Minneapolis-St. Paul International Airport (MSP) is a commercial airport surrounded by Minneapolis and several other suburban cities. MSP, which is a large hub (1% of total U.S. enplanements) (FAA 2014), was selected as one of the case studies. MSP has an annual snowfall of at least 35 inches and icy conditions prevailing for the most part of the winter which makes it a good candidate for the installation of heated pavement systems. MSP has one airfield with four runways and two terminal buildings (See Figure 12 (a)), and was the 17th busiest airport in 2013 based on air traffic volume. There are 125 gates in total at the airport (MSP 2014).

The average annual snowfall hours in MSP are 199 (ASHRAE Handbook 2003). The gate areas are congested and there is not enough space to maneuver large SRE or to pile snow as seen in Figure 12 (b). Most of the injuries (slip and fall) to ground handling staff occur in this area and heated pavements may offer a solution for this. Thus, the energy and economic analyses that are presented next focus on an area of 5 million ft^2 comprising of the ramp and apron areas.


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(b)

Figure 12. (a) Aerial view of the Lindbergh Terminal at the Minneapolis-St. Paul International airport; (b) A combination of snow plow and broom equipment.

MSP has around 100 pieces of snow removal equipment and more than 110 snow removal personnel including on-call workers. As MSP receives a large amount of snow every winter, there are designated accommodation for the workers because they are frequently required to stay at the airport. Some general facts about MSP operations gathered from site visit and survey are summarized in Table 6.

Table 6. General facts about the Minneapolis-St. Paul International Airport (Identified from Survey and Field Visits)

Runways	Open during general operations	4
	Open during winter operations	2 or 3
Time taken to clear snow	Primary taxiway and ramp area	10-35 minutes
Snow removal equipment (SRE) and personnel	Number of equipment	more than 100
	Annual maintenance cost of SRE ($)	600,000
	Personal required to aid in snow removal	110
	Labor rate ($/hour)	25.60
	Average life of SRE (years)	Approximately 20
Anti-icing and de-icing	Types of anti-icer and deicers	Potassium acetate and sodium acetate
Average pavement heat output to melt snow from considered area	Area- 5 million ft^2	1.7 billion Btu/h

Benefit/Cost Calculations

Conventional Method Cost Calculation

Total costs are divided into initial and recurring. Initial cost is a one-time cost and includes the cost for purchasing the entire fleet of SRE. The analysis period is 20 years and was assumed that the airport will not have any more purchases during these 20 years. The number of snow removal equipment and their costs were directly obtained from the airport. The costs were assumed to be a function of the pavement area. In MSP the entire pavement area is 28 million square feet and the apron area is 5 million square feet. The costs were taken only for the apron area. This was calculated by a ratio of the area of apron to the area of the total pavement using Equation 6. The recurring costs are annual costs and include maintenance, operation and labor costs and can be calculated using Equation 7. The recurring costs were obtained from the airports and were also a function of the area. The net present value of the costs involved in the conventional methods was calculated to be $17,053,768.

HPS Capital Cost Calculations

The capital cost consist of installation of HPS. The costs per unit feet are multiplied by the total area to be heated to get the capital cost. Based on the literature (Minsk, 1999) and consulting with companies dealing with heated pavements, a base value of $25/ft^2 was adopted. To make the analysis more complete, a sensitivity analysis was carried out for different unit cost values such as $15/ft^2, $35/ft^2 and $45/ft^2.

HPS Annual Cost Calculations

Annual or recurring cost comprise of the operation and maintenance costs to run the HPS. Operation costs consist of the cost of natural gas needed to heat anti-freeze circulating in the pipes and electricity needed to power the control system. The amount of natural gas required was calculated based upon the annual heat energy required to melt snow or the design heat load of the system. The heat load was calculated using Equation 1. The cost of commercial natural gas in Minnesota was $9.33 per 1,000 cubic feet (April 2014, monthly average) (U.S. Energy Information Administration 2014). The cost for natural gas was calculated to be $5,610,656 for a season. Maintenance cost was taken as 1% of the capital cost based on surveys from contractors and the total O&M costs were calculated to be approximately 6.8 million USD (2014).

HPS Annual Benefit Calculations

As discussed previously, the potential benefits of installing HPS considered are: reduced lost passenger time, airline staff time cost savings, reduced fuel wastage, and safety of ground staff. In this analysis we also considered including benefits related to reduced cargo delays. In the MSP, UPS and FedEx are the two major cargo airlines. They operate a total of 16 aircrafts every night. The cargo planes fly three times a week to the airport and adjust their operations in accordance to the expected snowfall forecast and patterns. Cargo airlines operate under much worse weather conditions than commercial airlines. The discussions with the airport managers and the available data (MSP 2014) revealed that the effect of snow storms on cargo operations is not as significant as the one on passenger operations, and might not involve loss of revenue and resources as they usually adjust their operations according to the weather forecast. Thus, cargo related benefits have been ignored in this analysis.

Value of Lost Passenger Time

The reduced lost passenger time is calculated by first determining the seasonal percentage of delays. As discussed in Chapter 3, a value of 2% of total number of operations is adopted as the percentage of weather related delays. The costs can be estimated using Equation 8 and 9. Four months (Nov-Feb) are considered as peak winter months and delays were calculated for this time period. By multiplying the daily number of operations by 30, monthly operations was calculated. Then this value was multiplied by 4 in order to get the number of operations in 4 months. For example, in 2015, the total operations over the four months considered were 144,000. Two percent of this (i.e., 2,880) were assumed to be the number of delays caused by snow during the 4 winter months for the year 2015. Each of these delay events were assumed to last 1 hour.

As per Table 4, the values assigned to passengers travelling for business is $63/h and for passengers travelling on leisure is $35/h; it was assumed that 40.40% of the total passengers fly for business purposes and 59.60% are leisure travelers. The total number of seats in a mid-sized aircraft is about 150. The average overall load factor for domestic flights in U.S. for 2014 was 83.38%. This translates to 83.38% of 150 seats being occupied that gives a value of 125.07 seats. By multiplying the total number of passengers (each case) by the value of time and the number of delays in four months, the value of lost time can be found. The combined value of lost time for the two categories of travelers was found to be approximately 16.7 million USD for year 2015. As the number of passengers is expected to grow every year, a value of 2.8% annual passenger growth rate (FAA 2011) is considered in the value of time calculation for subsequent years, and thus, the total value of lost passenger time increases over time.

Value of Airline Crew Time and Airplane Fuel Consumption

The number of delayed flights were calculated in the same way as were for the lost passenger time. Aircrafts can incur delays in three possible ways, midair, gate and ground delays. The mid-air delays will result in the most amount of fuel wastage while the others will be related to only idling fuel wastages. According to the ACRP report 123, mid-air delays are assigned a value of $4,960/h, ground delays as $2,148/h and gate delays as $1,442/h. It is undeniable that each category of delay would contribute in different percentages to the total delays and hence incur different costs. However, for ease in computations, it was assumed that all the delays would occur in an equal proportion as seen in Equation 11. This gave an average value of $2,850/h suffered by airlines in weather delays. The annual (four concerned months) cost to airlines due to weather related delays can then be computed by multiplying this value by the total number of operations in four months. This value comes out to be $8,208,576 for the year 2015. Annual growth rate of operations is also accounted for in this case for subsequent years.

Enhanced Safety of Ground Staff

It has been established in the report that the apron has tremendous human and mechanical activity. It is imperative to ensure safety of the ground staff in harsh winter conditions. There are chances of slip and fall injuries due to icy pavement conditions. Data for categorizing injuries for this level of detail is not available at the BLS. The available data as per the BLS report on occupational injuries has been made use of and certain assumptions have been established to quantify cost due to injuries. The ground staff may be employed by the airport or the airlines and they will be financially responsible for any injuries. The categories of injuries and their ratio to VSL have been discussed in Table 5.

It was assumed that slips and falls do not result in critical and un-survivable injuries as per discussions with airport managers. Consequently, in this analysis only three classes of injuries were considered: minor, moderate and serious. Bruises and strains were classified as minor, fractures as moderate, and multiple traumatic injuries as serious. Minor injuries occurring most frequently were assumed to constitute 60% of total injuries. Moderate were assumed as 25% and serious as 15%.

Incident rates are an indication measure that captures how many incidents of injuries have occurred, and/or how severe they were. The information for incidence rates was not accessible by the airport authority as such information is generally confidential. The Bureau of Labor Statistics (BLS) maintains occupational incidence rates for workplace injuries. However, the data published by BLS is composed of broad categories of values of type of workplace and injuries, resulting in very high incidence rate values to the order of 21 incidents per 10,000 full-time workers (BLS 2014). The information reported does not relate explicitly to slips and falls due to snowy conditions at aprons and ramps. Thus the reported values may overestimate the cost due to such injuries. In order to avoid such misleading estimations, a value of 5 incidents per 10,000 full-time workers was adopted. In MSP there are approximately 19,206 full-time workers (MSP 2014). Thus, the estimated number of incidents was 9.603 per year. Based on the above data, the injury cost were calculated by multiplying the percentage of each injury by its contributing fraction of the VSL as seen in Equation 12. The summed value of all the injury cases for MSP for the concerned four months was calculated as $2,588,584 per year.

Comparing the Benefits and Costs

Net Present Value

Net Present Value is the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time. All the costs (cash outflow) and benefits (cash inflow) as calculated above are discounted at 7% discount rate over an analysis period of 20 years and summed to get the net present value of the cost as seen in Table 7. Incoming and outgoing cash flows can also be described as benefit and cost cash flows, respectively.

Table 7. Net Present Value of cost and benefits for HPS over a 20-year analysis period and discounted at 7%

Cost Category	**Annual Dollar Value**	**PV of Costs**
Capital cost	$125,000,000	$197,681,885
Annual recurring cost	$6,860,656	
Benefit Category	**Annual Dollar Value ($) in year 1 (2015)**	**PV of Benefits**
Value of lost passenger time	$16,681,656	$353,996,163
Airline crew time and fuel wastage	$8,208,576	
Safety of ground staff	$2,588,584	

The present value of benefits is $353,996,163 (cash inflow is positive) and of cost is $197,681,885 (cash outflow is negative). The NPV is the sum of the cash inflow and outflow. Thus, the NPV is calculated as $156,314,278 (positive). A positive value of NPV indicates that the project is economically feasible.

Figure 13 represents the cash flow of the likely benefits and costs related to HPS. The benefits are due to reduction in lost passenger time, lost crew hours and aviation fuel. The costs include the installation, operation, and maintenance costs. The benefits of hydronic pavement far exceed their cost of installation, operation and maintenance. The difference minimizes as the years progress due to discounting. Figure 13 also depicts a distinction between the cost of conventional strategies of snow removal and the net cost/benefits due to HPS. The results indicate that the cost of clearing snow using conventional methods is consistently significantly higher for HPS. This may be an argument against the installation of such pavements. However, the use of conventional strategies does no entail significant benefits and without the HPS the snow will continue to disrupt smooth airline operations.

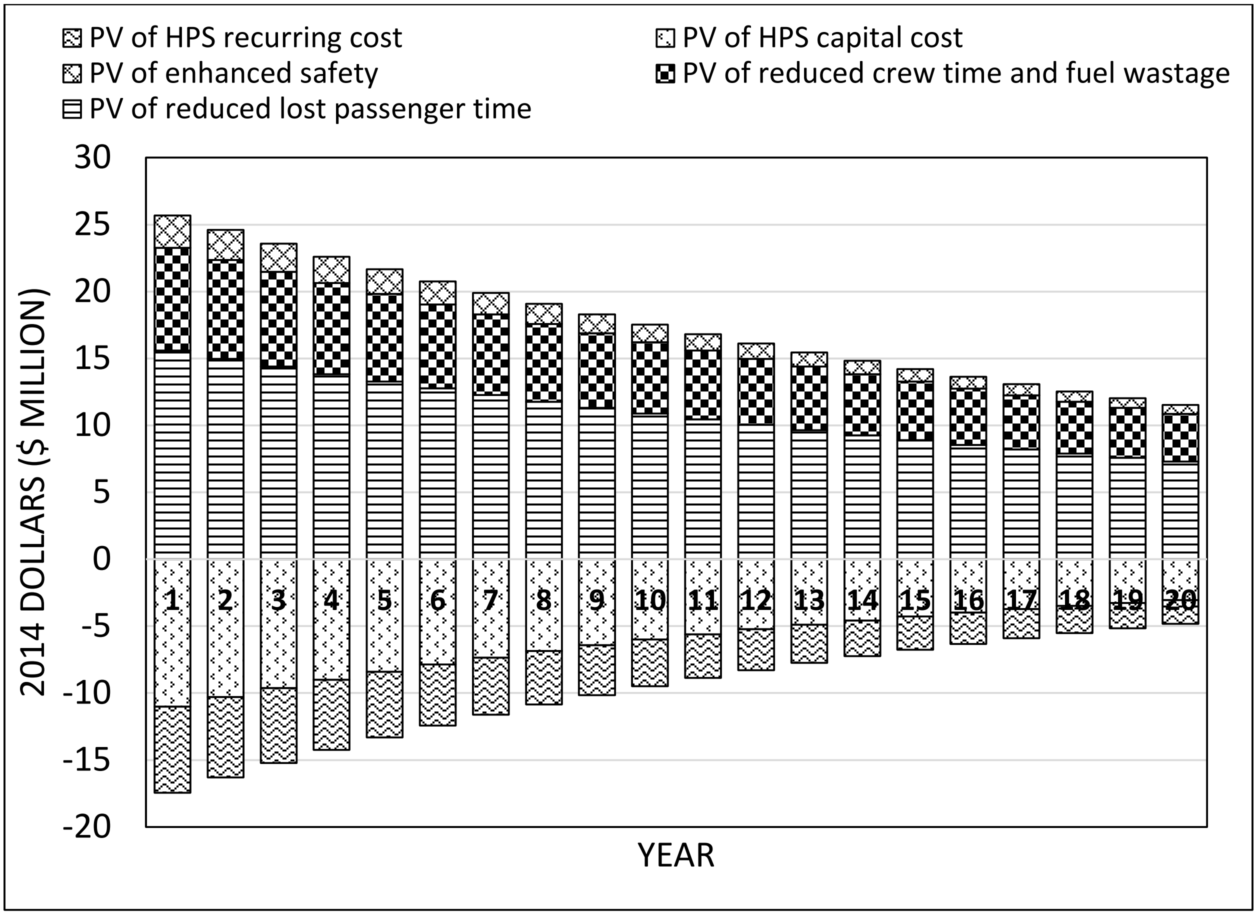

Figure 13. Cash flow for hydronic pavements showing the distributions of costs and benefits

Benefit Cost Ratio

In this analysis, only the apron and gate areas is considered for all comparisons. All costs corresponding to base case in use of conventional methods are taken as a ratio of the area of apron and gates to the total area of the airports. Total cost for base case in use of conventional methods is a fraction of the purchasing cost of entire snow removal equipment (SRE) and operation and maintenance (O&M) cost. Total costs for the alternative case in use of heated pavements systems (HPS) are the installation and O&M costs of HPS at the apron and gate areas. After the NPV is calculated, the BCR is calculated by dividing the net benefits by cost for 20 years. In view of the above, the BCR was found to be 1.79. Following is a sensitivity analysis that presents changes in the BCR based on a set of different conditions that the ones described in Chapter 4 so far to determine the effect of the various factors considered.

Sensitivity Analysis

The initial construction cost is a key factor in influencing the benefit cost ratios. It is anticipated that as the initial cost of construction increases the benefit cost ratio should decrease. It is also evident (refer to Figure 14) that the increase in discount rate has a negative effect on the BCR, as expected. In every case, the BC ratios estimated under the discussed assumptions suggest that the heated pavement systems is a viable alternative to conventional strategies.

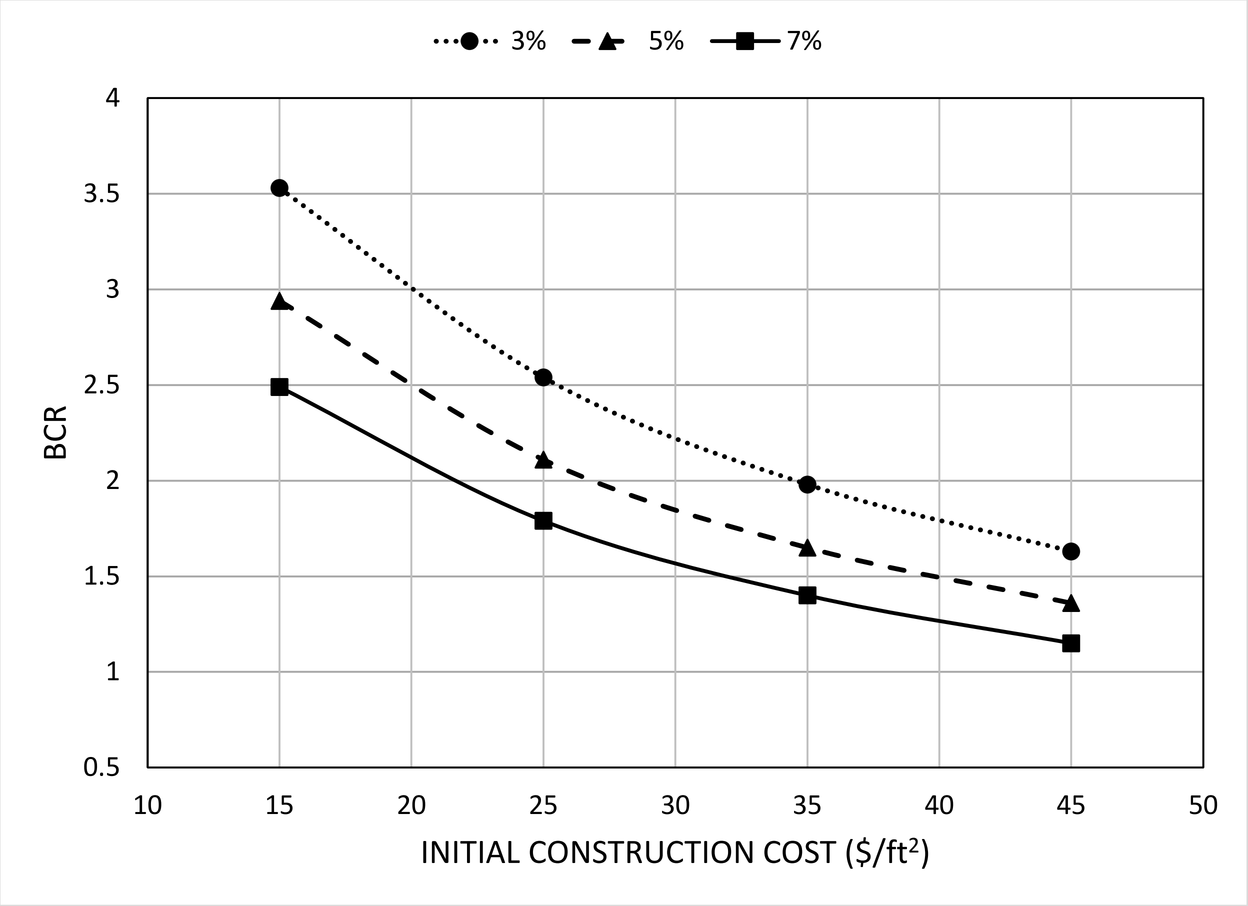

Figure 14. Plot of the BC Ratio versus the initial cost for different discount rates and 1in/h snowfall intensity for MSP

The construction cost of HPS depends upon the area under consideration. The area of aprons in MSP is around 5 million square feet. Site investigations may show that HPS do not need to cover the entire aprons to be effective, and strategic placement of HPS may provide the same benefits but reduce the capital cost considerably. For example, as seen in Figure 15, if the area to be heated reduces by one-fifth, the BCR ascents to 2.5 times. In the analysis the area under HPS has been varied from 100% of apron to 20% of apron in 20% decrements.

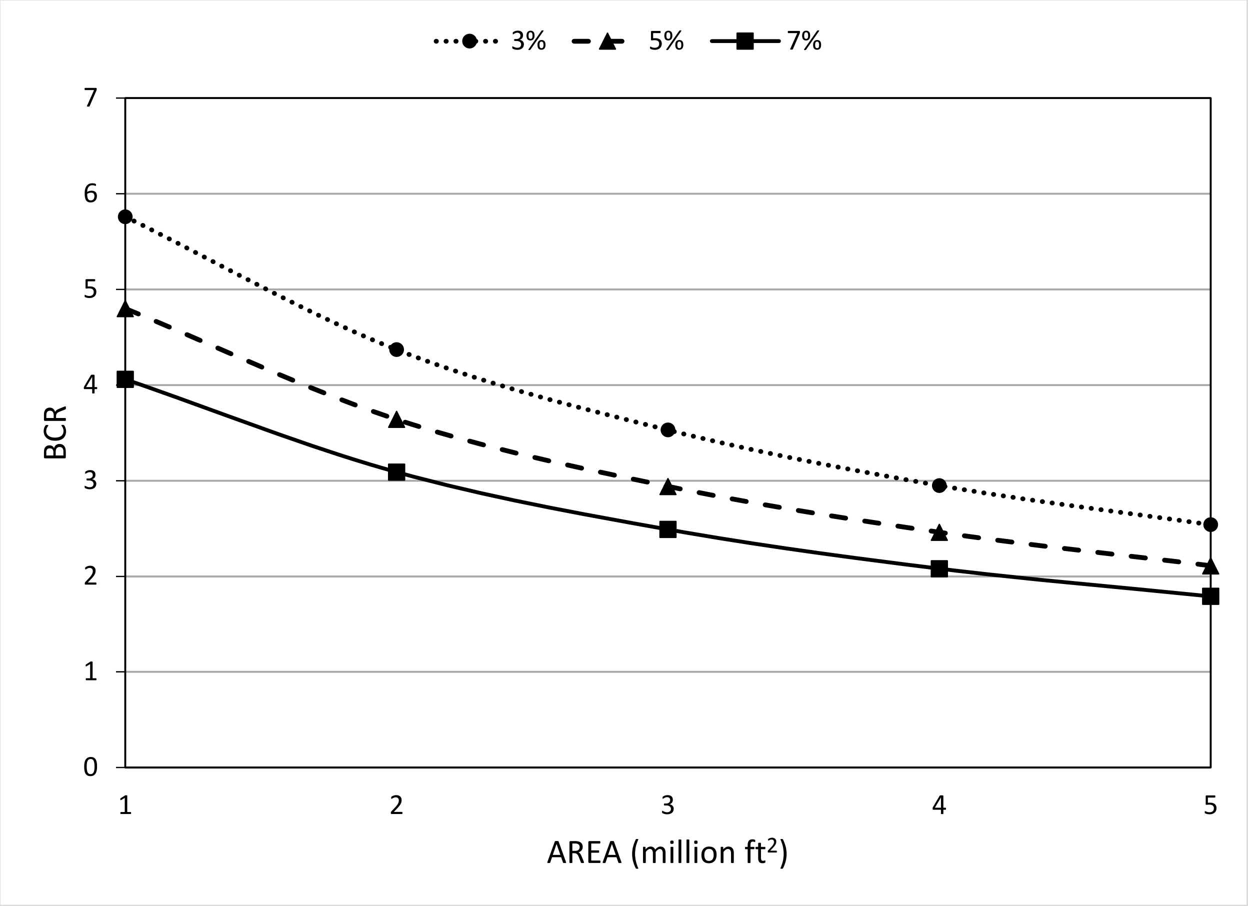

Figure 15. Plot of the BC Ratio versus proportion of the area of aprons under heated pavements

Furthermore, sensitivity analysis studies were carried out by varying two factors at the same time. First factor was the area under heating and the second was the initial construction cost. In the worst case, when the area was 5 million square feet and the initial construction cost was \$45/ft^2 the BCR was 1.15 (see Figure 16). When the lower extremes were chosen (i.e., initial construction cost was \$15/ft^2 and the area under heating was 1 million square feet), the BCR was 4.66. Both these cases showed that the BCR are dictated by the area and capital cost which themselves are related.

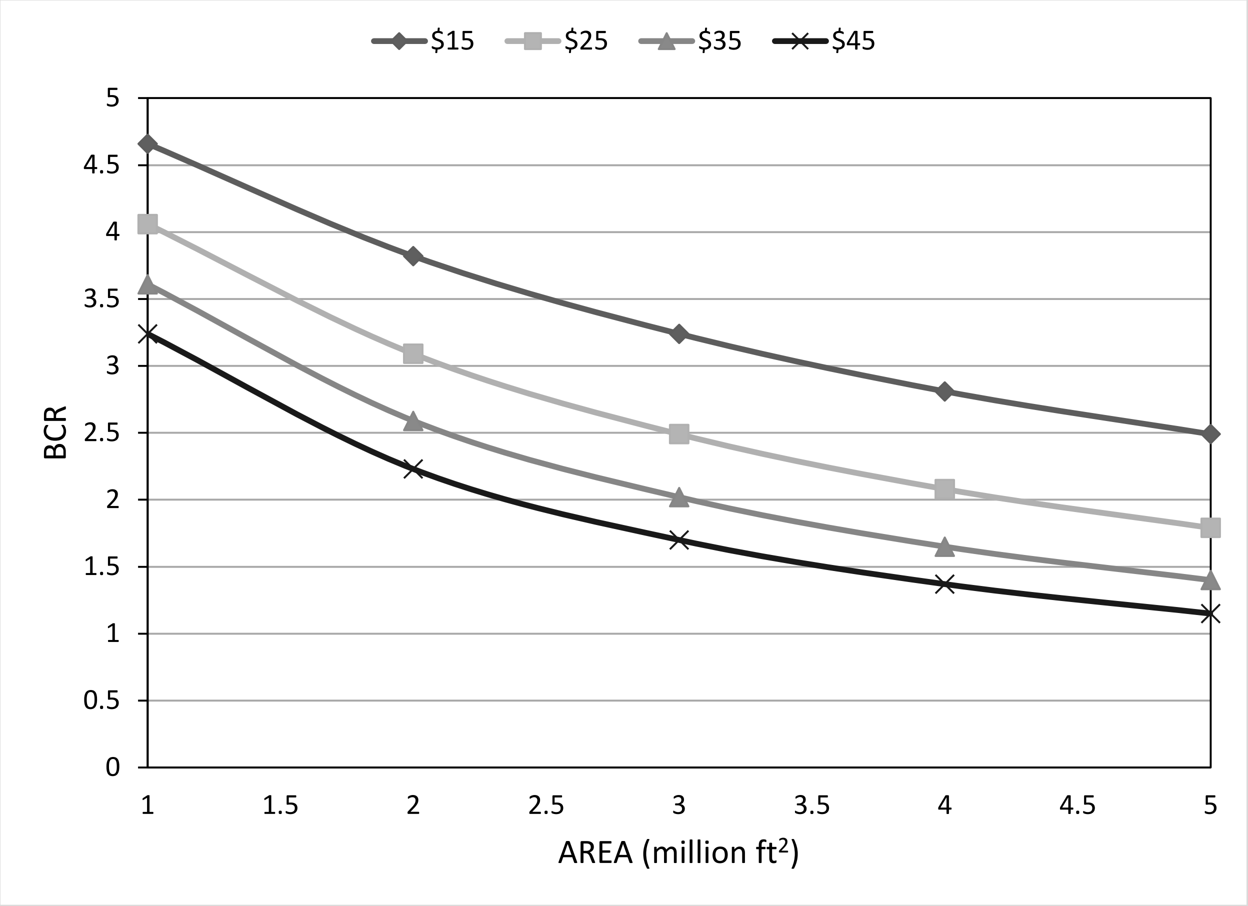

Figure 16. Plot of the BC Ratio versus proportion of the area of aprons under heated pavements at a discount rate of 7% by varying the initial cost

Delays are very unpredictable in nature as they depend on various other factors such as weather, preparedness of airports and airlines. They may change drastically every year and hence, a sensitivity analysis is warranted to see its influence on the BCR. As seen in Figures 17 and 18, BCR is very sensitive to the duration of delays and percentage of delays reinforcing the motivation of this study. As the percentage and number of delays increase, the BCR increases rampantly to the order of 12 portraying that during strong winter storms HPS will be able to cover for their cost to a greater extent. On the other hand, it is interesting to note that even when the duration and percentage of delays is very low, the BCR does not drop below one indicating a financially viable investment.

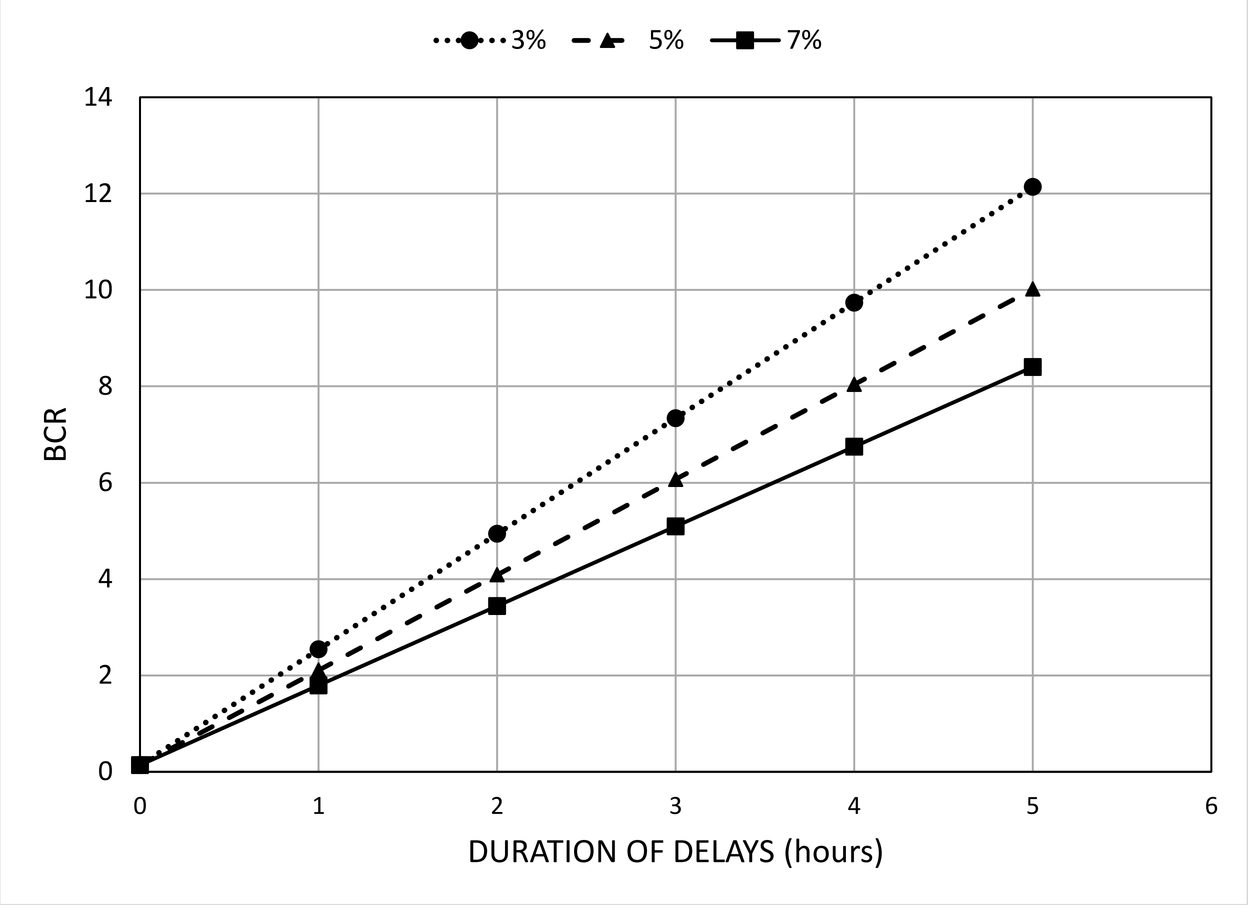

Figure 17. Plot of the BC Ratio versus duration of delays

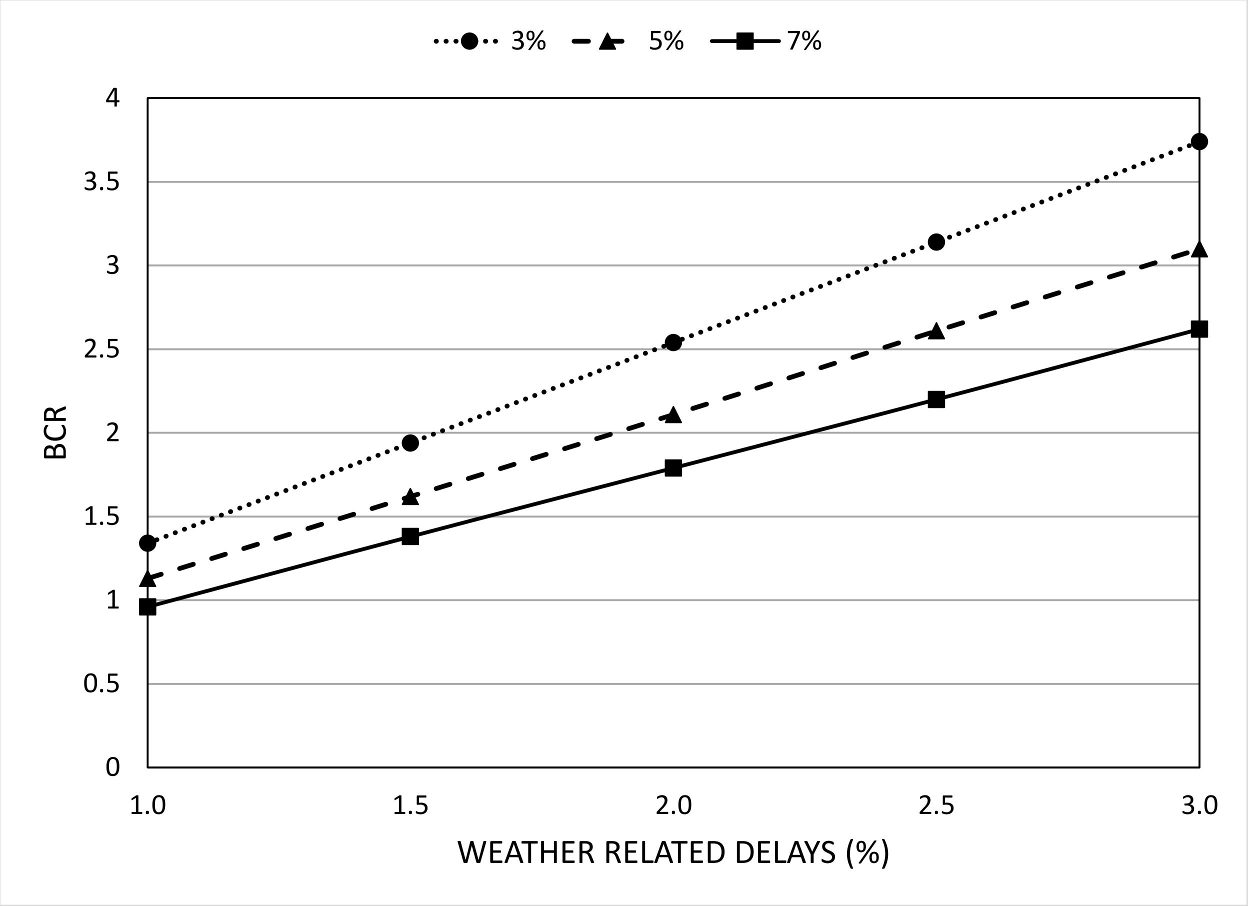

Figure 18. Plot of the BC Ratio versus percentage of weather related delays

<u>Overall cost of Snow Removal for the Airport</u>

This section attempts to explore the overall costs and benefits of snow removal operations in an airport, as incurred by installing HPS in the aprons, in order to put the effects of such an investment into perspective. It is assumed that HPS is used at aprons and conventional methods are used at the remaining areas to clear snow.

The total costs of clearing snow is the sum of the installation and O&M costs of installing HPS at aprons and the purchasing costs of SRE, its O&M costs, labor costs and cost of deicing agents to clear the remaining areas.

As discussed previously, strategic placement of HPS will reduce the installation costs greatly but will not sacrifice on the benefits. The area of apron at MSP is 5 million square feet and it is possible that only a part of it requires heating. The results of the comparisons between different cases of apron areas with HPS are presented in Figure 19.

Specifically, Figure 19 shows the net benefits and costs over a 20-year period for clearing snow from an airport which has HPS at aprons. Even though aprons comprise of a significantly small area as compared to the remaining airports, the total cost over the 20-year period of study of clearing snow from them that involves the installation and operation of heated pavement systems is higher than clearing snow from the remaining areas using conventional methods. However, HPS have several benefits that offset these high costs. Figure 19 also illustrates that even when the entire apron is heated, the overall BCR is above 1. When the area to be heated is only 1 million square feet, the BCR is a little above 2 depicting a strong investment and a more realistic scenario. According to these results, HPS is a financially viable option to heat aprons when used with conventional snow removal methods to reduce winter weather related delays.

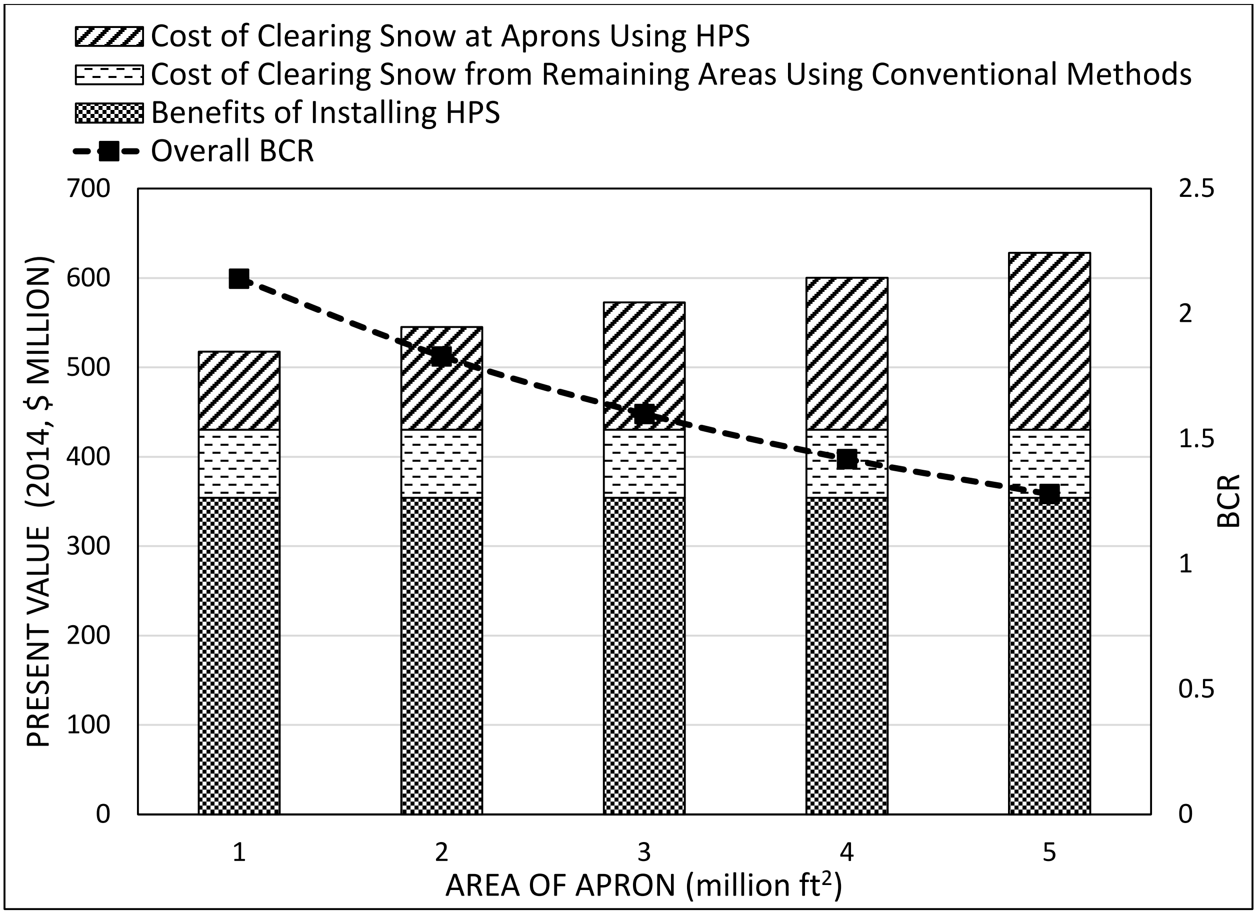

Figure 19. Plot for the costs, benefits and benefit cost ratio of using HPS at aprons and conventional methods at the remaining areas

CHAPTER 5

CASE STUDY OF COMMERCIAL AIRPORT, PORT COLUMBUS INTERNATIONAL AIRPORT, OH (CMH)

Description of the Airport

Port Columbus International Airport (CMH) is a commercial service international airport located in Columbus, Ohio. The area receives around 27 inches of snow annually. Based on the email survey, information pertaining to the current snow removal methods was collected which was used for the economic analysis. The CMH handled more than 3 million enplanements in the year 2013. It has two parallel runways and both are operational during winter storms. The area of aprons and ramps is around 2.2 million square feet. The CMH has 17 pieces of SRE, 20 snow removal personnel, three airport concourses and around 40 gates. The aerial view of the CMH airport can be seen in Figure 20.

The airport manager at CMH pointed out that the high cost of chemicals, aging equipment, insufficient labor and large apron clearance times during high snowfall events contribute greatly to delays.

According to the data provided by CMH, the labor cost ranges between $14/h to $50/h depending on the time and day of the snow storm. They usually employ a liquid deicer (Potassium Acetate) for runways and a solid deicer (Sodium Formate) for taxiways, taxi lanes and aprons.

Figure 20. Aerial view of the CMH airport

Benefit/Cost Calculations

Conventional Method Cost Calculation

The number of snow removal equipment and their costs were directly obtained from the airport. The costs were assumed to be a function of the pavement area. The costs were taken only for the apron area using equation 6. The recurring costs were obtained from the airports and were calculated using equation 7.

HPS Capital Cost Calculations

The capital cost consist of installation of HPS. The costs per unit feet are multiplied by the total area to be heated to get the capital cost. Based on the literature (Minsk, 1999) and consultation with companies dealing with heated pavements, a base value of $25/ft^2 was adopted.

To make the analysis more complete, a sensitivity analysis was carried out for different unit cost values such as \$15/ft^2, \$35/ft^2 and \$45/ft^2.

HPS Annual Cost Calculations

The amount of natural gas required was calculated based upon the annual heat energy required to melt snow or the design heat load of the system. The heat load was calculated using Equation 1. The amount of the cost of commercial natural gas in Ohio was $10.13 per 1,000 cubic feet (April 2014, monthly average). The cost for natural gas was calculated to be $1,801,475 for a season. Maintenance cost was taken as 1% of the capital cost based on surveys from contractors and the total O&M costs were calculated to be approximately 2.3 million USD (2014).

HPS Annual Benefit Calculations

As discussed previously, the potential quantified benefits of installing HPS will be reduced lost passenger time, airline staff time cost savings, reduced fuel wastage and safety of ground staff.

Value of Lost Passenger Time

As per Table 4, the values assigned to passengers travelling for business is $63/h and for passengers travelling on leisure is $35/h; 40.40% of the total passengers fly for business purposes and 59.60% are leisure travelers. The combined value of lost time for the two categories of travelers was found to be approximately 5 million USD for the year 2015 using

Equation 8 and 9. As in the case of MSP, the annual growth rate of operations is considered, and thus, the total value of lost passenger time increases over time.

Value of Airline Crew Time and Airplane Fuel Consumption

The number of delayed flights were calculated using Equation 11. This value comes out to be approximately 2.5 million USD for the year 2015. Annual growth rate of operations is also accounted for in this case for subsequent years.

Enhanced Safety of Ground Staff

In CMH there are about 2,500 full-time workers Number of cases were determined using this data. The number of cases for an incidence rate of 5 were 9.603. Based on the above data, the injury cost were calculated by multiplying the percentage of each injury by its contributing fraction of the VSL. The summed value of all the injury cases for CMH for the concerned four months was calculated using Equation 12 as $336,950, annually.

Comparing the Benefits and Costs

Net Present Value

All the costs (cash outflow) and benefits (cash inflow) as calculated above are discounted at 7% discount rate over an analysis period of 20 years and summed to get the net present value of the cost as seen in Table 8. Incoming and outgoing cash flows can also be described as benefit and cost cash flows, respectively.

Table 8. Net Present Value of cost and benefits for HPS over a 20-year analysis period and discounted at 7%

Cost Category	Annual Dollar Value ($)	PV of Costs ($)
Capital cost	$55,000,000	$79,911,564
Annual recurring cost	$2,351,475	
Benefit Category	**Annual Dollar Value in year 1 (2015)**	**PV of Benefits**
Value of lost passenger time	$5,004,497	$105,904,995
Airline crew time and fuel wastage	$2,462,573	
Safety of ground staff	$336,950	

The present value of benefits is $105,904,995 of cost is $79,911,564. The NPV is calculated as $25,993,431 (positive). A positive value of NPV indicates that the project is economically feasible.

Figure 21 represents the cash flow of the likely benefits and costs related to HPS. The benefits are due to reduction in lost passenger time, lost crew hours and aviation fuel. The costs include the installation, operation, and maintenance costs. The benefits of hydronic pavement far exceed their cost of installation, operation and maintenance. The difference minimizes as the years progress due to discounting.

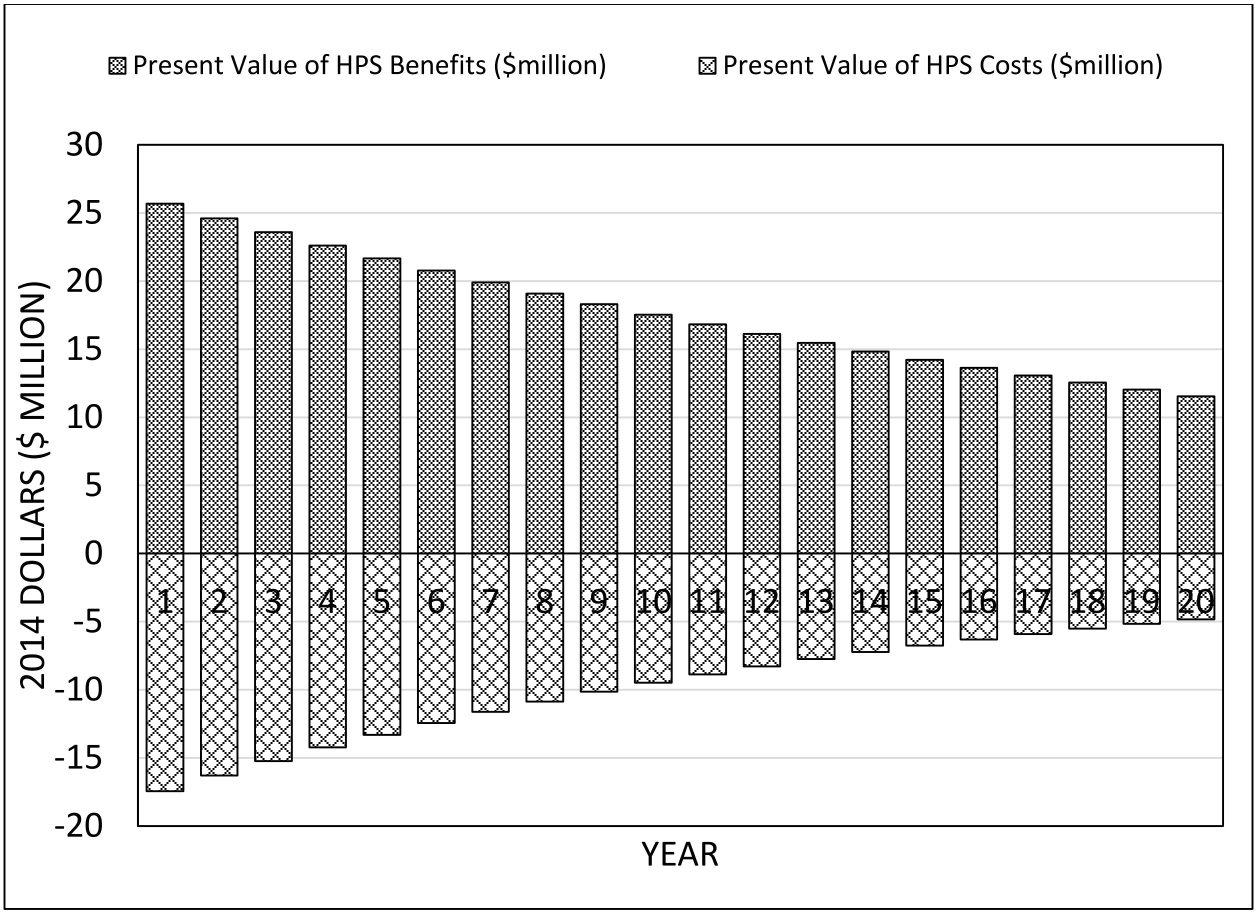

Figure 21. Cash flow for hydronic pavements

<u>Benefit Cost Ratio</u>

As only the apron and gate areas is considered for all comparisons, the entire airport is not considered. All costs corresponding to base case in use of conventional methods are taken as a ratio of the area of apron and gates to the total area of the airports. Total cost for base case in use of conventional methods is a fraction of the purchasing cost of entire snow removal equipment (SRE) and operation and maintenance (O&M) cost. Total costs for alternative case in use of heated pavements systems (HPS) at aprons/gates are the installation and O&M costs of HPS. After the NPV is calculated, the BCR is calculated by dividing the net benefits by cost for

20 years. Then, the benefit cost ratio is calculated as 1.33 for the base case values. In comparison, in MSP the BCR was found to be higher (1.79).

Sensitivity Analysis

The initial construction cost is a key factor in influencing the benefit cost ratios. It is anticipated that as the initial cost of construction increases the benefit cost ratio should decrease. It is also evident (refer to Figure 22) that the increase in discount rate has a negative effect on the BCR, as expected. The BC ratios estimated under the discussed assumptions suggest that the heated pavement systems is a viable alternative to conventional strategies. It is seen that when these results are compared with MSP (case study 1) the BCR values are moderately lower. This may imply that the BCR is dependent on the size of the airport in terms of the number of operations and areas of the pavement. For CMH, for a discount rate of 7% the values range between 1.91 and 0.82. The investment becomes no longer feasible if the initial construction cost is \$45/ft^2. In MSP, under the installation of HPS was found to be feasible between different values of initial construction cost.

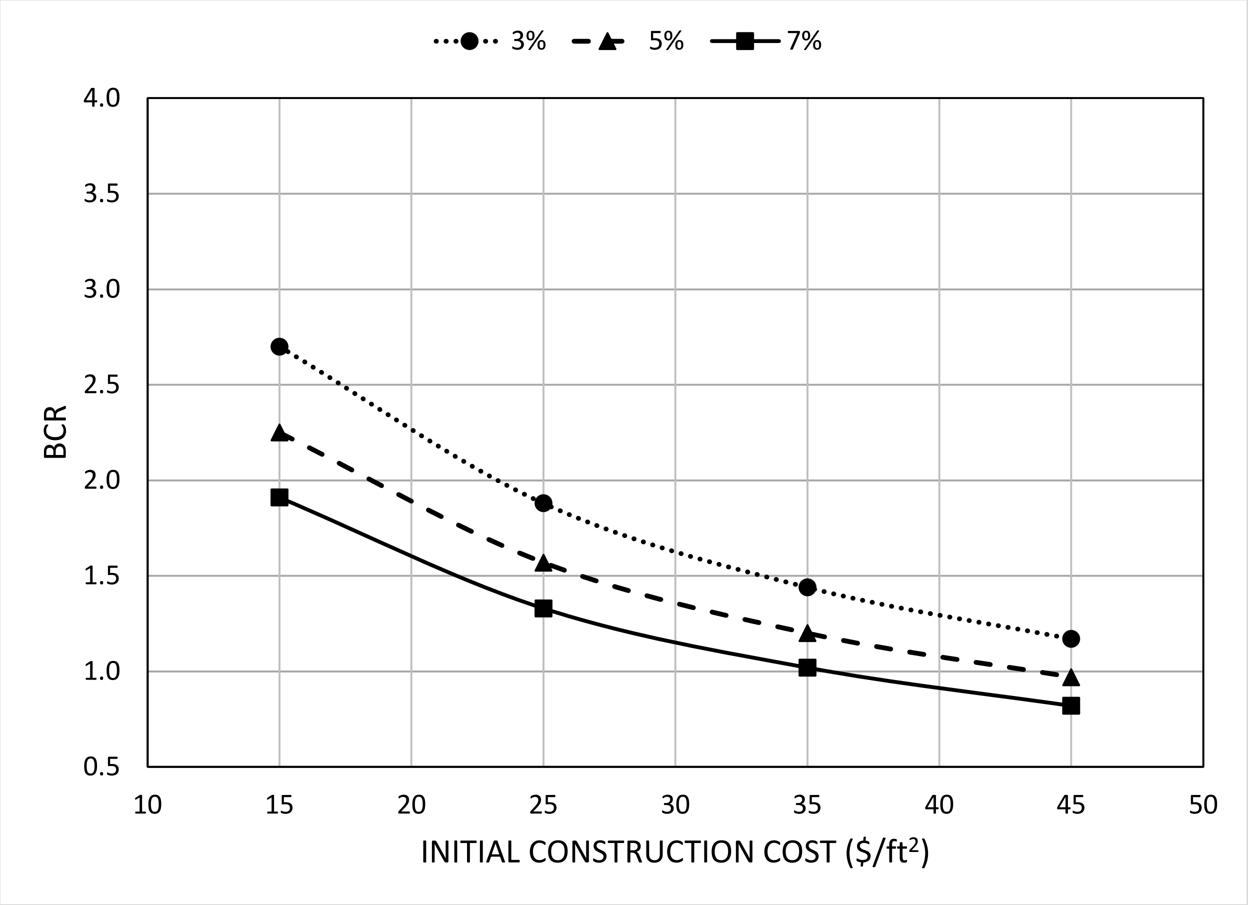

Figure 22. Plot of the BC Ratio versus the Initial Cost for Different Discount Rates and 1in/h Snowfall Intensity for CMH

The construction cost of HPS depends upon the area under consideration. The area of aprons in CMH is around 2.2 million square feet. Site investigations may show that HPS do not need to cover the entire aprons and strategic placement may provide the same benefits but reduce the capital cost considerably. The variation of BCR with the area has been shown in the Figure 23 below. In the figure the area under HPS has been varied from 100% of apron to 20% of apron in 20% decrements. When the results of this analysis are compared to the MSP results it can be seen that a similar trend is followed among the BCR values; however, the ratios for CMH are a little lower. Even though, the area is lesser in CMH than MSP the BCR values for CMH are lower. This may be explained by the higher potential benefits incurred at MSP due to larger number of aircraft operations.

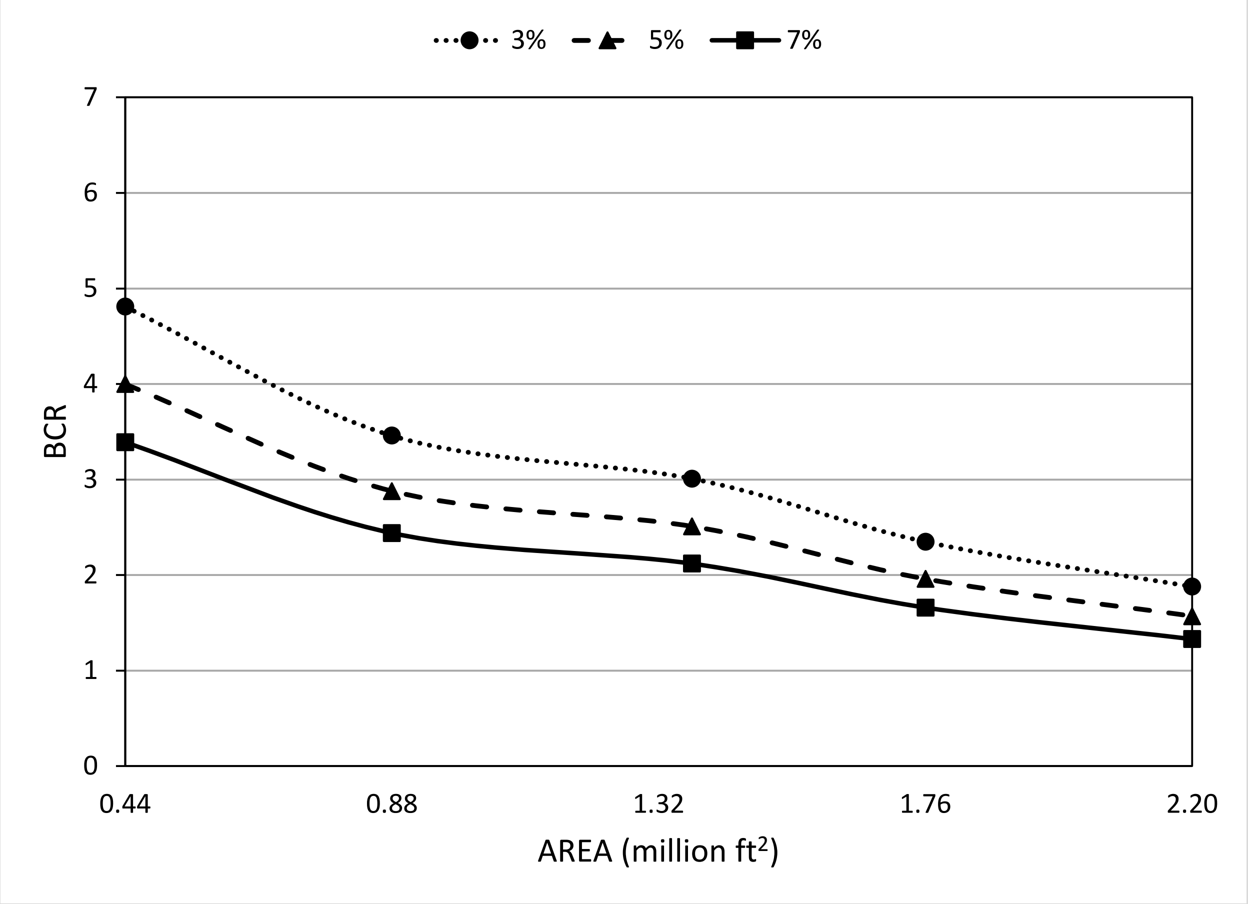

Figure 23. Plot of the BC Ratio versus proportion of the area of aprons under heated pavements

Furthermore, sensitivity analysis studies were carried out by varying two factors at the same time. The first factor was the area under heating and the second was the initial construction cost. In the worst case, when the area was 2.2 million square feet and the initial construction cost was \$45/ft^2, the BCR was 0.82 (see figure 24). When the lower extremes were chosen (i.e., initial construction cost was \$15/ft^2 and the area under heating was 0.44 million square feet), the BCR was 4.01. In MSP, the values ranged between 1.15 and 4.66.

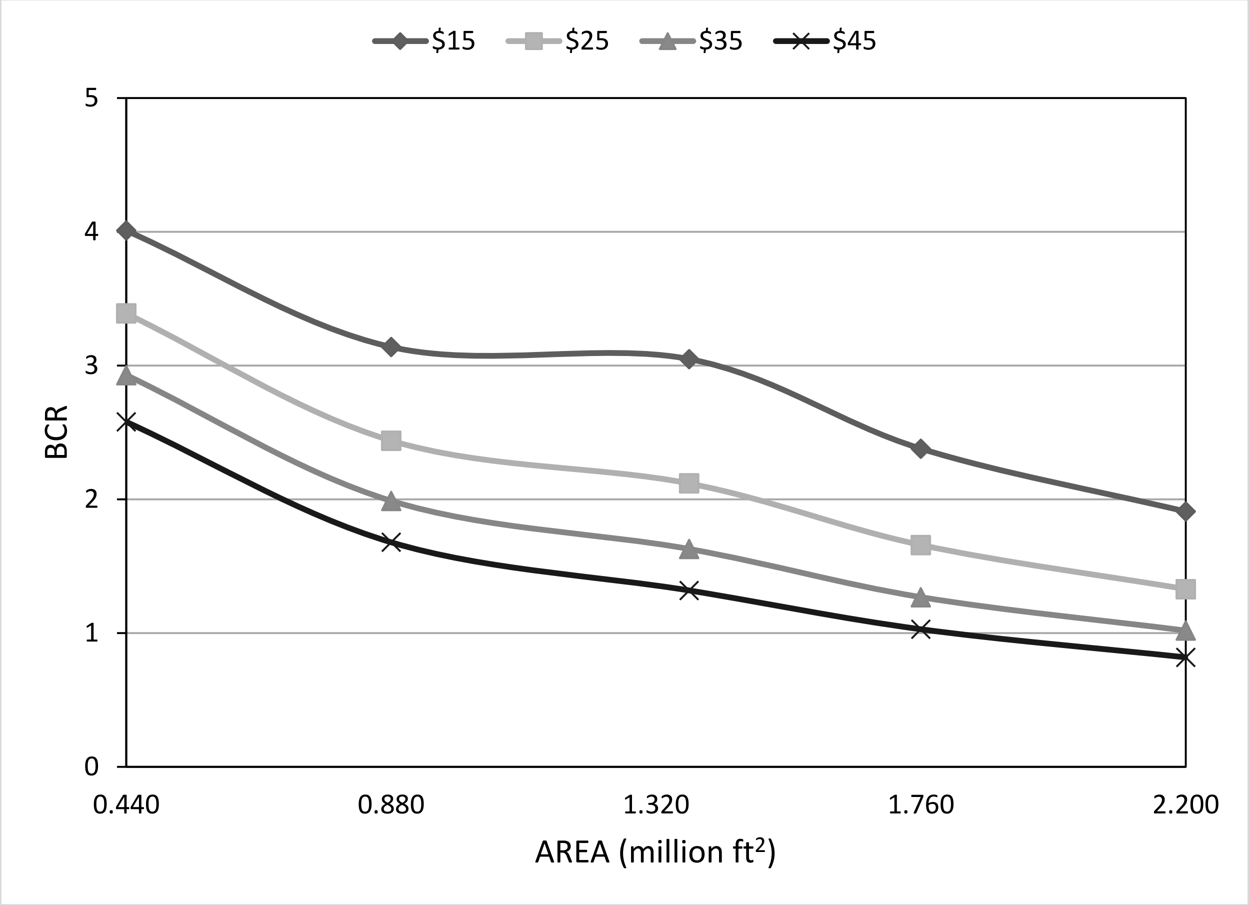

Figure 24. Plot of the BC Ratio versus Proportion of the Area of Aprons under Heated Pavements at a Discount Rate of 7% by Varying the Initial Cost

Delays are very unpredictable in nature as they depend on various other factors such as weather, preparedness of airports and airlines. They may change drastically every year and hence, a sensitivity analysis is warranted to see its influence on the BCR. As seen in Figures 25 and 26, BCR is very sensitive to the duration of delays and percentage of delays reinforcing the motivation of this study.

As the duration of delays increase, the BCR increases rampantly to the order of 9.0 for a discount rate of 3% portraying that during strong winter storms HPS will be able to cover for their cost to a greater extent. On the other hand, it is interesting to note that even when the duration and percentage of delays is very low, the BCR does not drop below 1 indicating a financially viable investment. In MSP the values range between 1.79 and 8.4 for a 7% discount rate when the duration of delays vary from 1 hour to 5 hours. For the same band, the values range between 1.33 and 6.23 for CMH. In relation to these figures, similar trends are followed for MSP and CMH but the values of latter are lower.

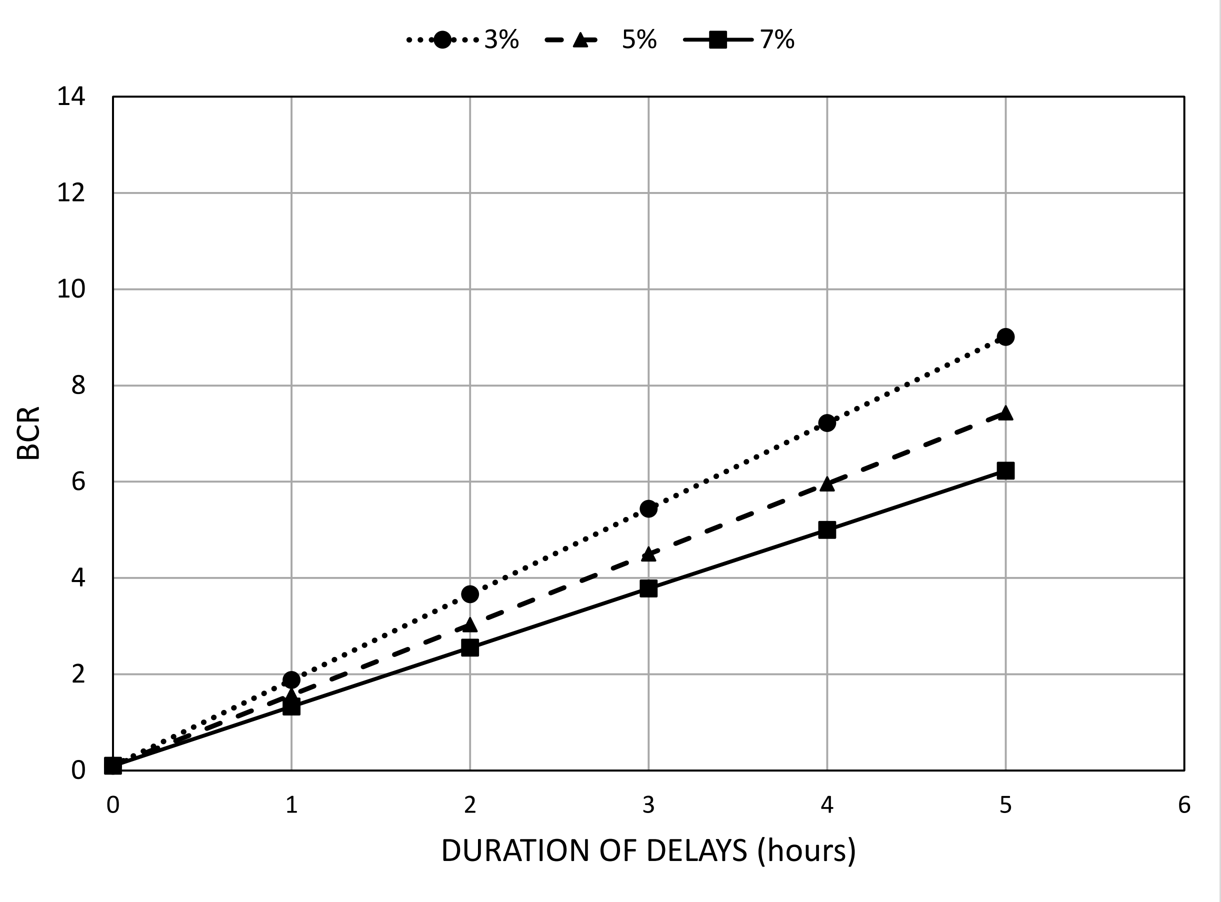

Figure 25. Plot of the BC Ratio versus duration of delays

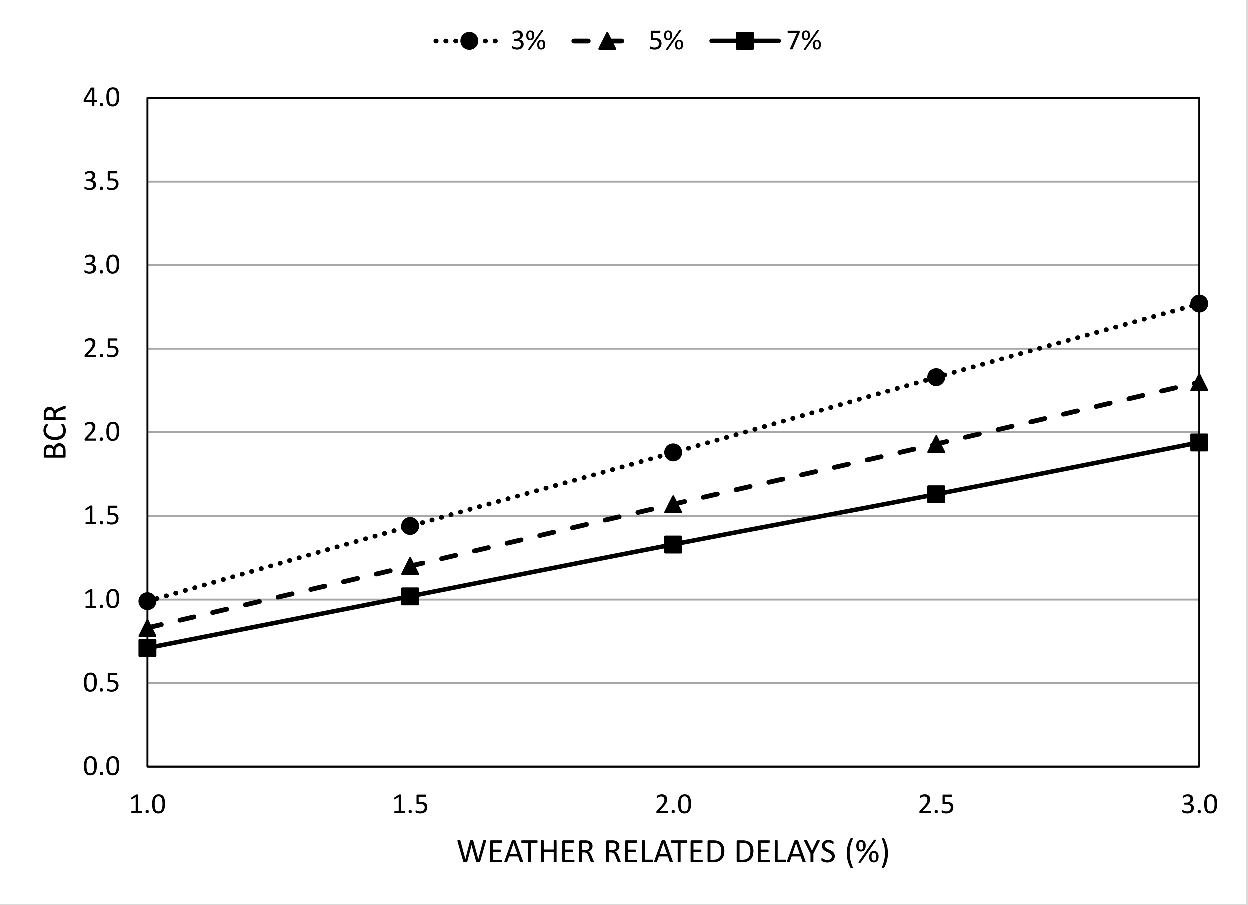

Figure 26. Plot of the BC Ratio versus percentage of weather related delays

CHAPTER 6

CASE STUDY OF COMMERCIAL AIRPORT, DES MOINES INTERNATIONAL AIRPORT, IA (DSM)

Description of the Airport

The Des Moines International Airport (DSM) is a commercial service airport located in the capital city of Iowa. Based on the email survey information pertaining to the current snow removal methods was collected which was used for the economic analysis. DSM handled more than 3 million enplanements in the year 2013. It has daily operations of around 220 aircrafts. It has two operational runways and can handle around 140 million pounds of cargo annually. On an average, it receives around 35 inches of snow annually. They have two runways and both are operational during winter storms. The area of aprons and ramps is around 1.5 million square feet. They have 22 pieces of SRE and 28 snow removal personnel.

DSM uses the FAA specified deicing and anti-icing agents that do not cause any known harm to the environment. The contaminated snow is drained into storm water drains, which go to the city waste water treatment plant. There are separate tanks to collect water with high concentrations of aircraft deicing fluid (ADF).

Benefit/Cost Calculations

HPS Capital Cost Calculations

The capital cost consist of installation of HPS. The costs per unit feet are multiplied by the total area to be heated to get the capital cost. Based on the literature (Minsk, 1999) and consultation with companies dealing with heated pavements, a base value of $25/ft^2 was adopted.

To make the analysis more complete, a sensitivity analysis was carried out for different unit cost values such as \$15/ft^2, \$35/ft^2 and \$45/ft^2.

HPS Annual Cost Calculations

The heat load was calculated using Equation 1. The amount of the cost of commercial natural gas in Iowa was \$7.44 per 1,000 cubic feet (April 2014, monthly average). The cost for natural gas was calculated to be 1.6 million USD for a season. Maintenance cost was taken as 1% of the capital cost based on surveys from contractors and the total O&M costs were calculated to be approximately 1.8 million USD (2014).

HPS Annual Benefit Calculations

As discussed previously, the potential quantified benefits of installing HPS will be reduced lost passenger time, airline staff time cost savings, reduced fuel wastage and safety of ground staff.

Value of Lost Passenger Time

As per Table 4, the values assigned to passengers travelling for business is \$63/h and for passengers travelling on leisure is \$35/h; 40.40% of the total passengers fly for business purposes and 59.60% are leisure travelers. The combined value of lost time for the two categories of travelers was found to be approximately 3 million USD in year 2015 using Equation 8 and 9. As in the previous cases, the annual growth rate of operations is considered, and thus, the total value of lost passenger time increases over time.

Value of Airline Crew Time and Airplane Fuel Consumption

This value of loss due to extra airline crew time and fuel wastage comes out to be approximately 1.5 million USD for the year 2015 using Equation 11. Annual growth rate of operations is also accounted for in this case for subsequent years.

Enhanced Safety of Ground Staff

In DSM there are about 2000 full-time workers. Number of cases were determined using this data. The number of cases for an incidence rate of 5 were 9.603. Based on the above data, the injury cost were calculated by using Equation 12. The summed value of all the injury cases for DSM for the concerned four months was calculated as $269,560.

Comparing the Benefits and Costs

Net Present Value

Net Present Value is the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time. All the costs (cash outflow) and benefits (cash inflow) as calculated above are discounted at 7% discount rate over an analysis period of 20 years and summed to get the net present value of the cost as seen in Table 9. Incoming and outgoing cash flows can also be described as benefit and cost cash flows, respectively.

Table 9. Net Present Value of costs and benefits for HPS over a 20-year analysis period and discounted at 7%

Cost Category	Annual Dollar Value ($)	PV of Costs ($)
Capital cost	$37,500,000	$59,304,556
Annual recurring cost	$1,758,179	
Benefit Category	**Annual Dollar Value in year 1 (2015)**	**PV of Benefits**
Value of lost passenger time	$3,058,303.69	$62,727,377
Airline crew time and fuel wastage	$1,504,906	
Safety of ground staff	$269,560.00	

The present value of benefits is $62,723,377 (cash inflow is positive) and of cost is $59,304,556 (cash outflow is negative). The NPV is the sum of the cash inflow and outflow. The NPV is calculated as $3,422,821 (positive). A positive value of NPV indicates that the project is feasible.

Figure 27 represents the cash flow of the likely benefits and costs related to HPS. The benefits are due to reduction in lost passenger time, lost crew hours and aviation fuel. The costs include the installation, operation, and maintenance costs. The benefits of hydronic pavement far exceed their cost of installation, operation and maintenance. The difference minimizes as the years progress due to discounting.

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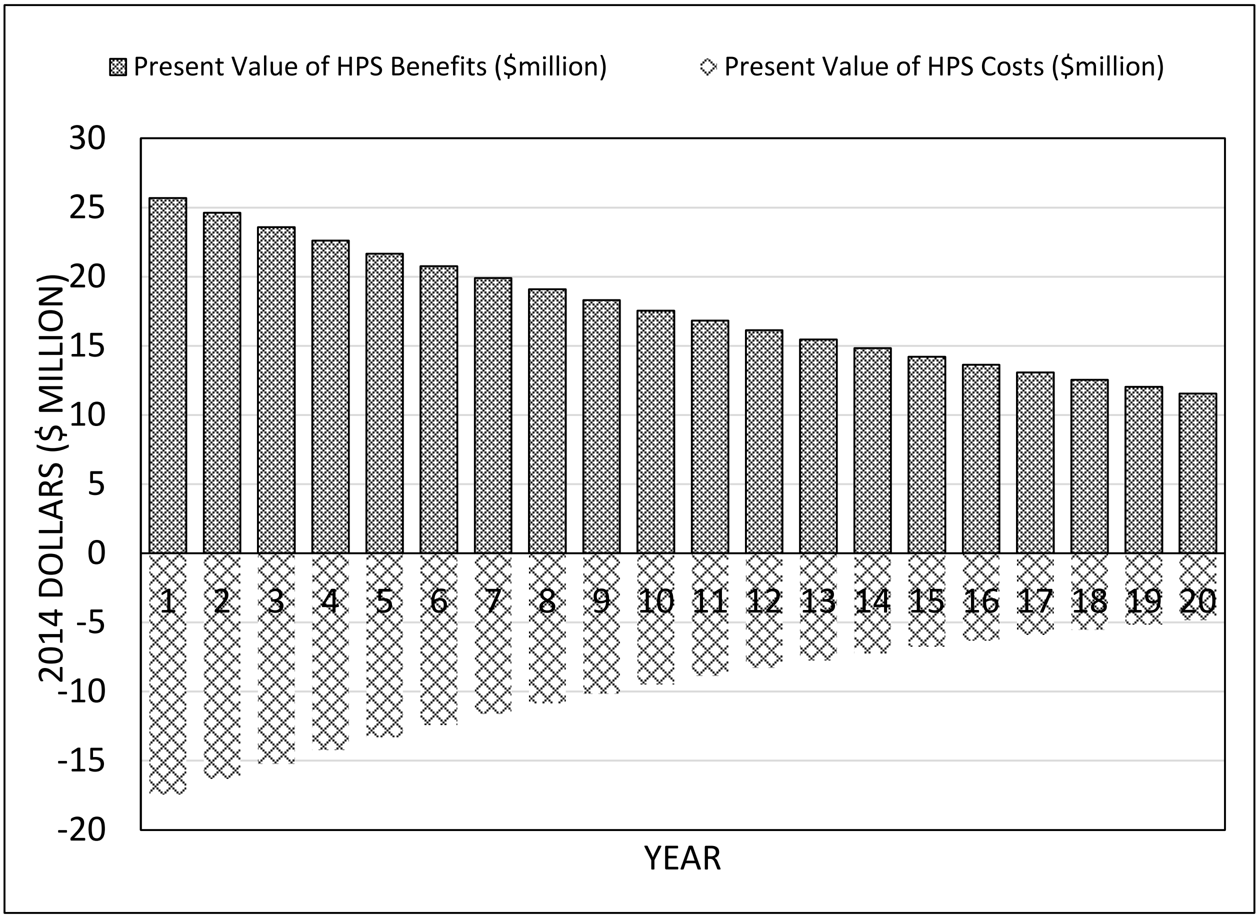

Figure 27. Cash Flow for hydronic heated pavements

Benefit Cost Ratio

The apron and gate areas are considered for all comparisons. The entire airport is not considered. All costs corresponding to base case in use of conventional methods are taken as a ratio of the area of apron and gates to the total area of the airports. Total cost for base case in use of conventional methods is a fraction of the purchasing cost of entire snow removal equipment (SRE) and operation and maintenance (O&M) cost. Total costs for alternative case in use of heated pavements systems (HPS) at aprons/gates are the installation and O&M costs of HPS.

After the NPV is calculated, the BCR is calculated by dividing the net benefits by cost for 20 years. Then, the benefit cost ratio is calculated as 1.06, much lower than MSP and CMH.

Sensitivity Analysis

The initial construction cost is a key factor in influencing the benefit-cost ratios. It is anticipated that as the initial cost of construction increases the BCR should decrease. It is also evident (refer to Figure 28) that the increase in discount rate has a negative effect on the BCR, as expected. The BC ratios estimated under the discussed assumptions suggest that the heated pavement systems is a viable alternative to conventional strategies.

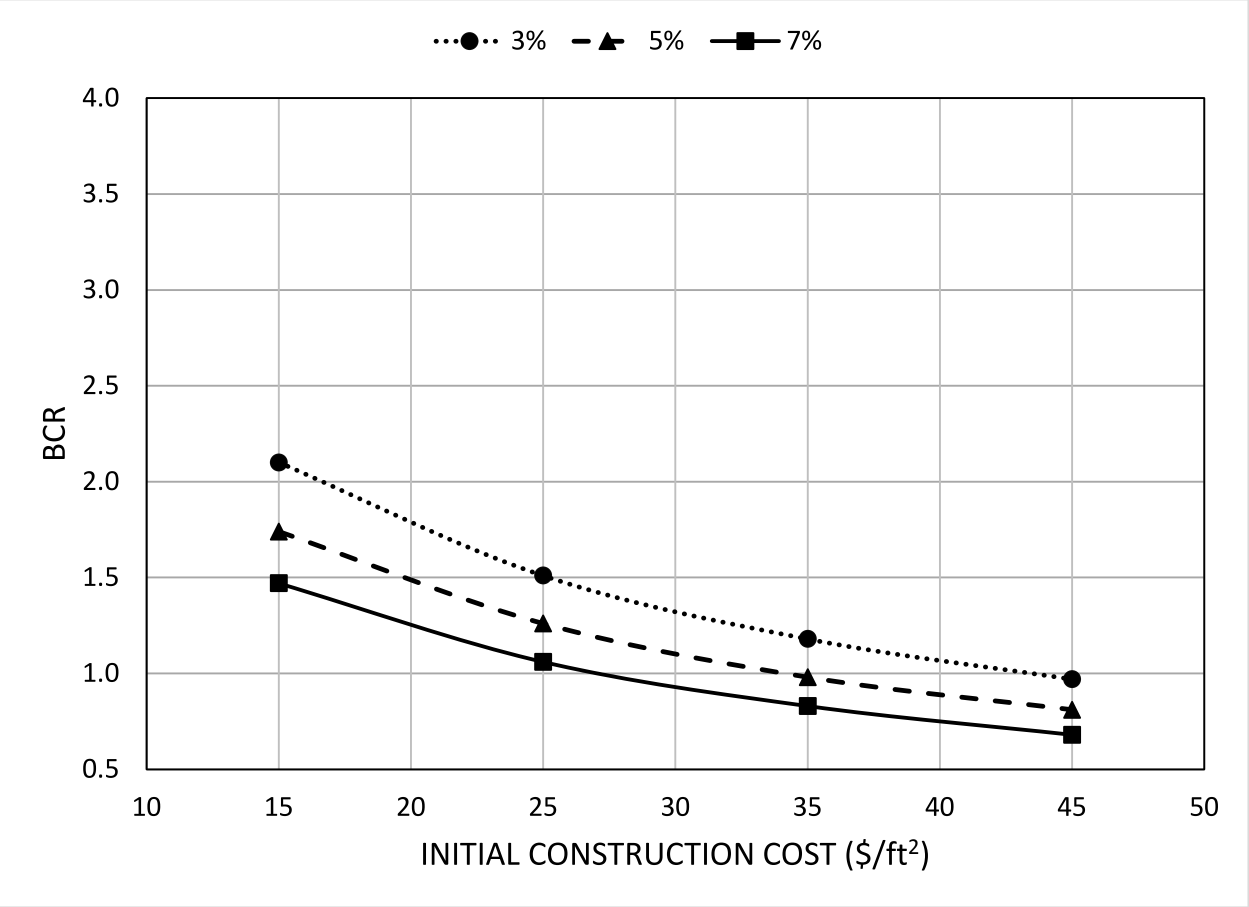

Figure 28. Plot of the BC Ratio versus the initial cost for different discount rates and 1in/h snowfall intensity for DSM

The construction cost of HPS depends upon the area under consideration. This can be seen in Figure 29. The area of aprons in MSP is around 5 million square feet. Site investigations may show that HPS do not need to cover the entire aprons and strategic placement may provide the same benefits but reduce the capital cost considerably. In the figure the area under HPS has been varied from 100% of apron to 20% of apron in 20% decrements.

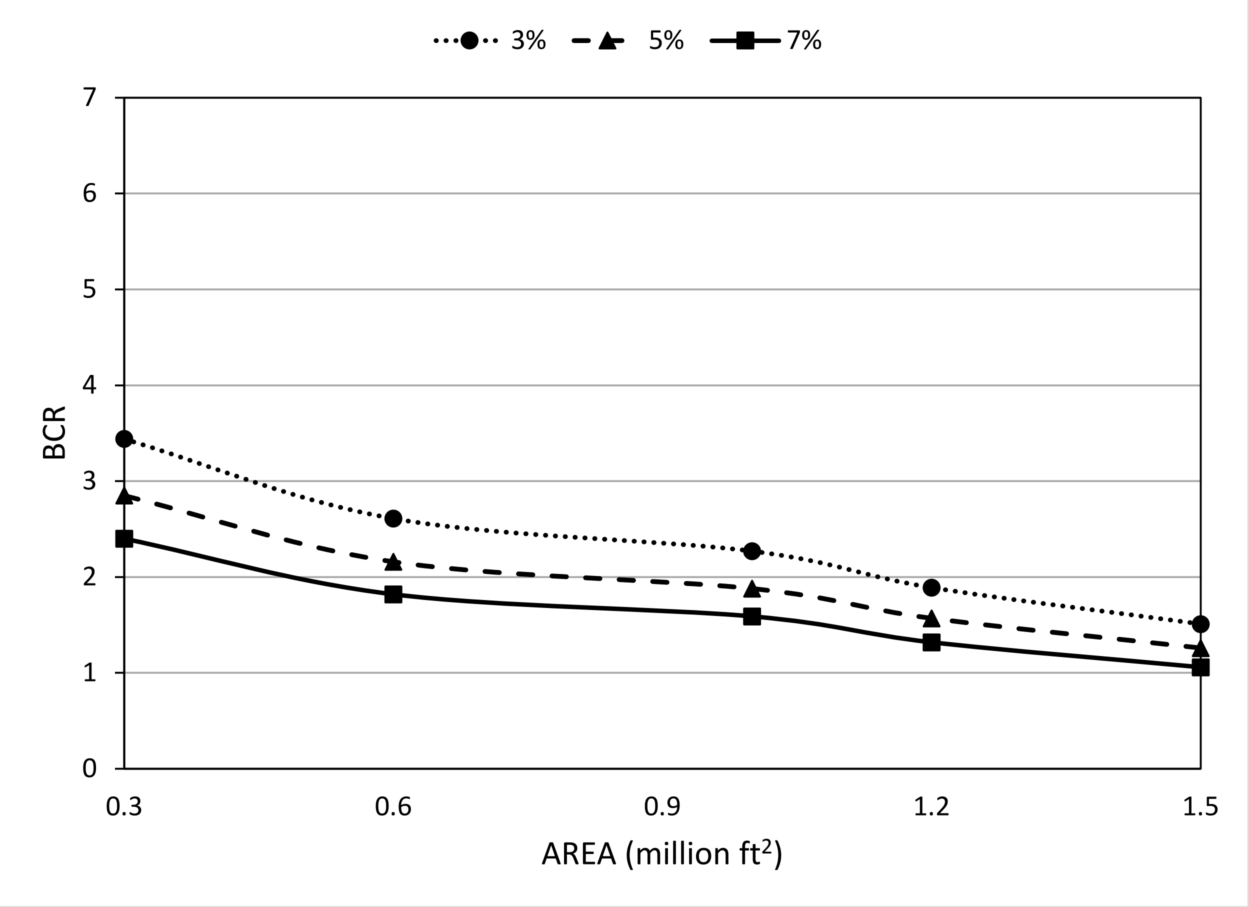

Figure 29. Plot of the BC Ratio versus proportion of the area of aprons under heated pavements

Furthermore, sensitivity analysis studies were carried out by varying two factors at the same time. First factor was the area under heating and the second was the initial construction cost. In the worst case, when the area was 5 million square feet and the initial construction cost was $45/ft^2 the BCR was 1.15 (see Figure 30). When the lower extremes were chosen (i.e., initial construction cost was $15/ft^2 and the area under heating was 1 million square feet), the BCR was 4.66. Both these cases showed that the BCR are dictated by the area and capital cost which themselves are related.

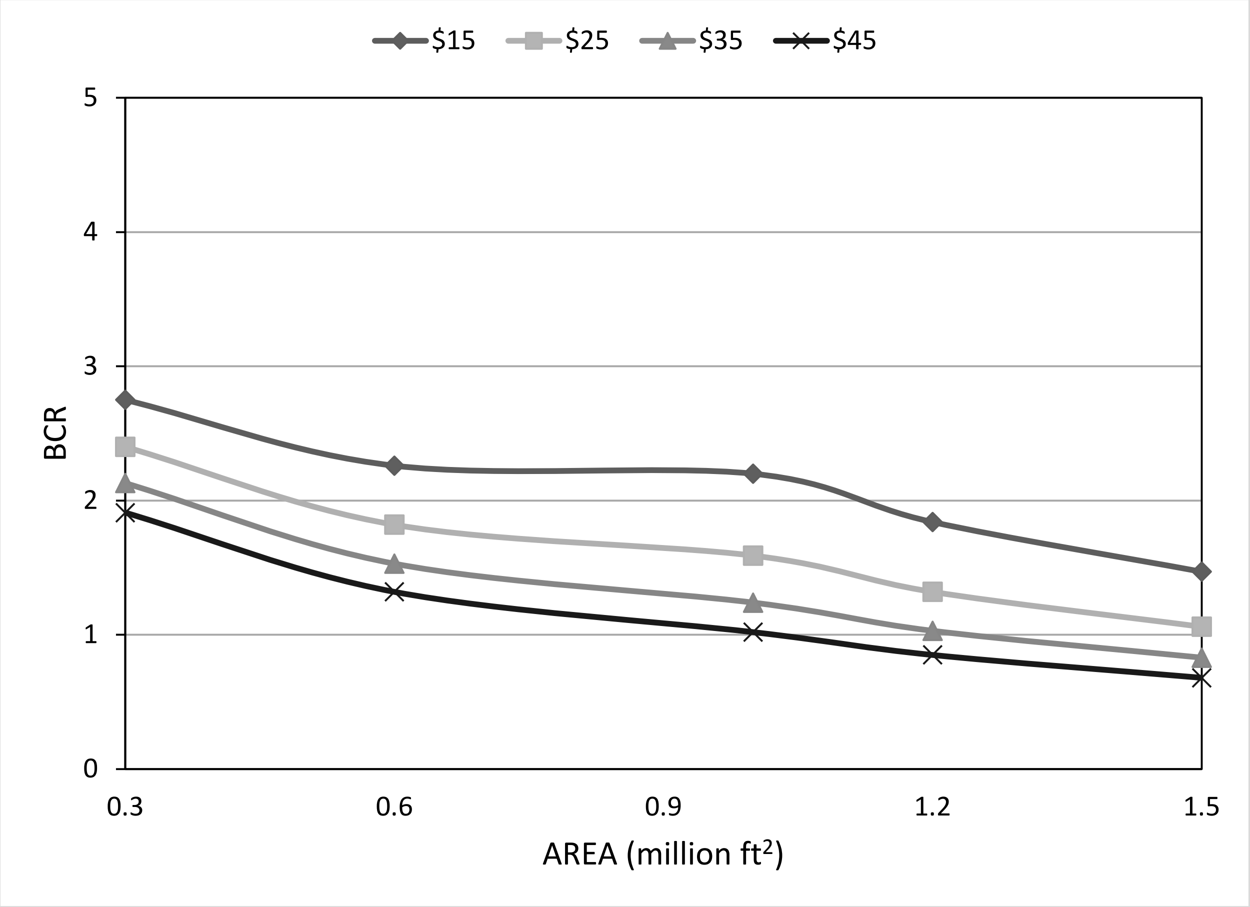

Figure 30. Plot of the BC Ratio versus proportion of the area of aprons under heated Pavements at a Discount Rate of 7% by Varying the Initial Cost

Delays are very unpredictable in nature as they depend on various other factors such as weather, preparedness of airports and airlines. They may change drastically every year and hence, a sensitivity analysis is warranted to see its influence on the BCR. As seen in Figures 31 and 32, BCR is very sensitive to the duration of delays and percentage of delays reinforcing the motivation of this study. As the percentage and number of delays increase, the BCR increases rampantly to the order of 12 portraying that during strong winter storms HPS will be able to cover for their cost to a greater extent. On the other hand, it is interesting to note that even when the duration and percentage of delays is very low, the BCR does not drop below 1 indicating a financially viable investment.

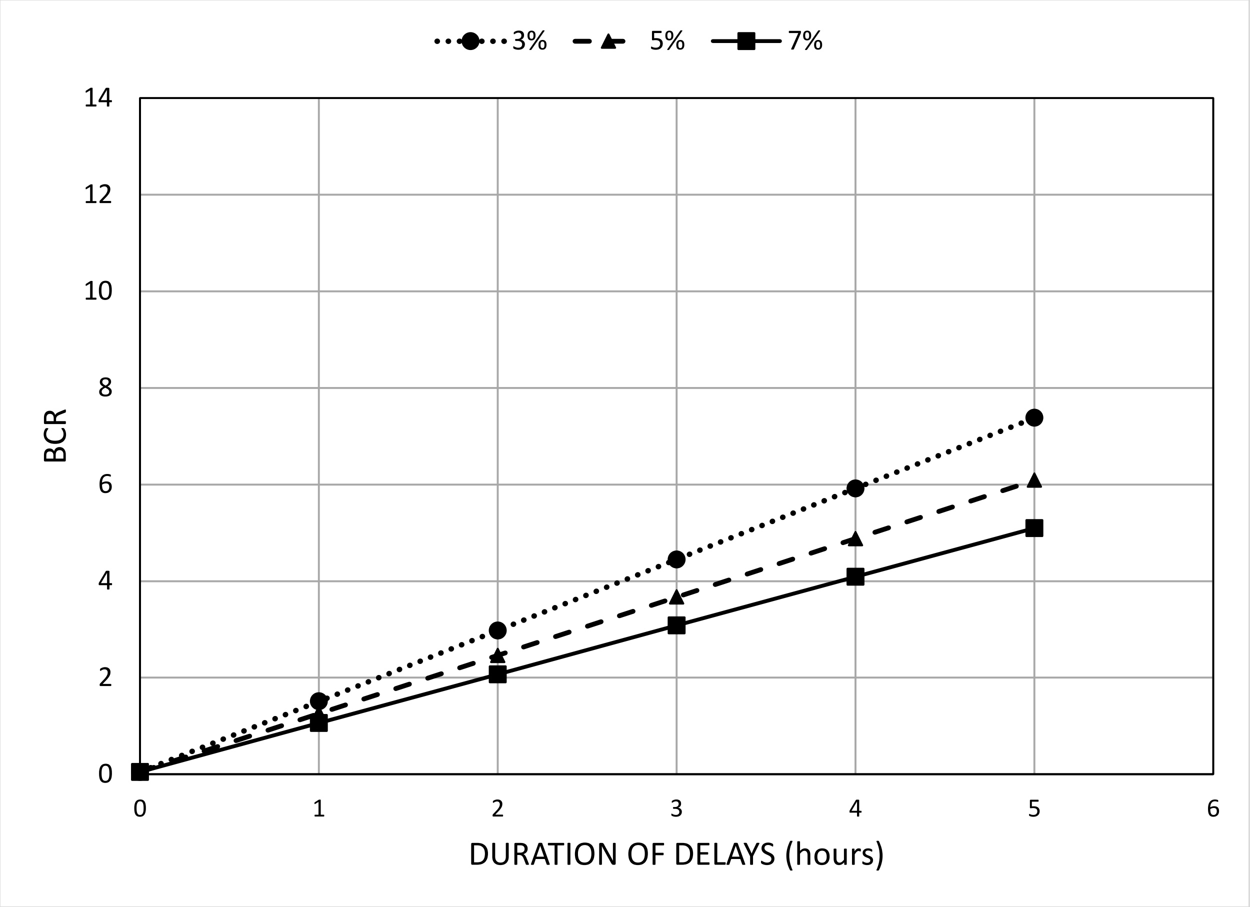

Figure 31. Plot of the BC Ratio versus duration of delays

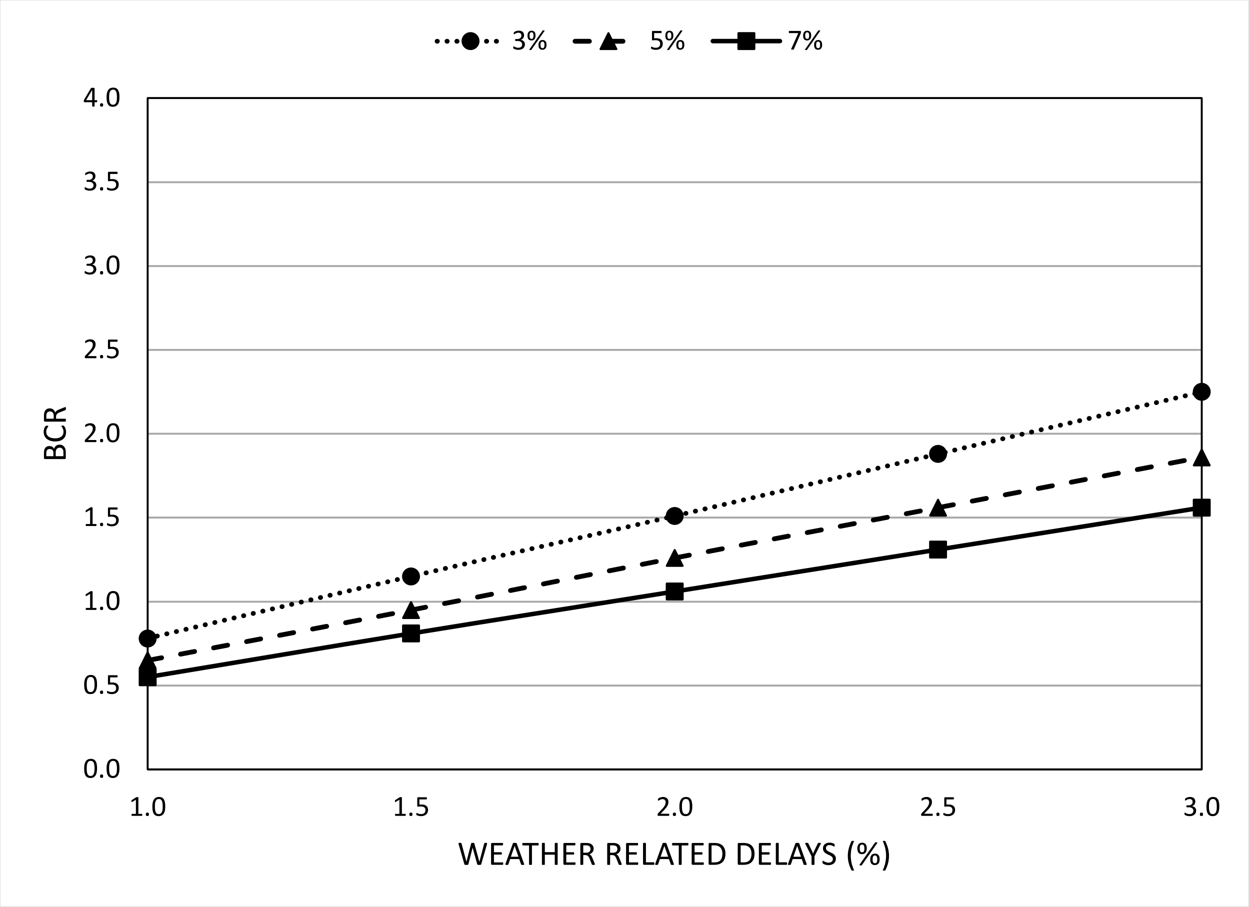

Figure 32. Plot of the BC Ratio versus percentage of weather related delays

CHAPTER 7

CASE STUDIES OF GENERAL AVIATION AIRPORTS

General aviation airports focus mainly on more specialized services that scheduled airline service cannot provide like emergency medical services, aerial firefighting, law enforcement and border control, agricultural functions, flight training, time-sensitive air cargo services, business travel, and scheduled services. Some general aviation airports provide all of these aeronautical functions, while others provide only a few. Some airports are large and have multiple runways and extensive facilities, while others are relatively small and may need only a short, single runway, helipad, or sea lane to serve a critical function.

According to the FAA, general aviation airports are divided in to four categories (FAA 2012):

- *National:* Serve the national and state system by providing communities with access to national and international markets in multiple states and throughout the United States. They have around 200 total based aircrafts and 30 jets.
- *Regional:* Support regional economies by connecting communities to statewide and interstate markets. They have around 90 total based aircrafts with 3 jets.
- *Local:* Serve the local or regional markets with 33 based propeller driven aircrafts and no jets.
- *Basic:* Have low levels of activity with about 10 propeller driven aircrafts and no jets.

There are 2,952 GA airports in the U.S. and about half of these are Local GA airports. Usually, smaller sized GA charge very low or zero landing fees. However, a fixed-base operator (FBO) is someone who chargers additional fees like ramp usage charges. An FBO is a commercial business granted the right by an airport to operate on the airport and provide aeronautical services such as fueling, hangaring, tie-down and parking, aircraft rental, aircraft maintenance, flight instruction, etc. Owning an aircraft does incur regular parking space and utility charges but such costs are not related to the rate of snow removal and hence not considered (FAA 2012).

In GA airports, the airport owner, FBO or other contractors hired by the owner may be responsible for snow removal and maintenance. Charters and private plane owners will usually give their flying schedule to the airports beforehand and they may prepare the pavements accordingly. For GA airports, as the pavements are not as large as the commercial airports they may use the same SRE for the aprons and runways. The data was collected for two GA airports, Mason City Municipal Airport and Kent State University Airport through e-mails. Data collection was particularly challenging for GA airports as the responses were missing or incomplete.

The operational status of GA airports during snow may have many benefits like emergency medical services, aerial firefighting, law enforcement and border control, agricultural functions, time-sensitive air cargo services, etc. These benefits are very case specific and calculating their approximating their frequency may demand more in depth studies. In this report, only the benefits due to delays in scheduled airplane service have been estimated. The results might be biased results and not in favor of installing airports but a tradeoff occurs between high cost and maintaining the airports in winter to deal with any emergency situation.

Case Study of Mason City Municipal Airport, IA (MCW)

The Mason City Municipal Airport (MCW) is a city owned public use regional airport located in Mason City, Iowa. The aerial view of the airport can be seen in Figure 33.

Figure 33. Aerial view of the Mason City Municipal Airport (MCW)

Delta connection (operated by Great Lakes Airlines) previously provided service from MCW to MSP. They pulled out all commercial service in January 2014. But in November 2014, Air Choice One started service from MCW to Chicago O'Hare International Airport and early this year to St. Louis Lambert International Airport. In addition to this, they offer charter services and flight training as well. The exact numbers of these operations were not available after even the survey was carried out.

Since MCW handles a low volume of traffic, they coordinate snow removal operations around them. They do not handle any cargo and have two operational runways.

HPS Capital Cost Calculations

The capital costs were calculated in a similar manner as the commercial airports. They consist of the installation of HPS. The costs per unit feet are multiplied by the total area to be heated in order to estimate the capital cost. Based on the literature (Minsk, 1999) and consulting with companies dealing with heated pavements, a base value of $\$25/ft^2$ was adopted. To make the analysis more complete, a sensitivity analysis was carried out for different unit cost values such as \$15/ft^2, \$35/ft^2 and \$45/ft^2. The total are of MCW pavements is around 3 million square feet and aprons comprise of about 600,000 ft^2.

HPS Annual Cost Calculations

Annual or recurring costs comprise of the operation and maintenance costs to run the HPS. Operation costs consist of the cost of natural gas needed to heat anti-freeze circulating in the pipes and electricity needed to power the control system. The amount of natural gas required was calculated based upon the annual heat energy required to melt snow or the design heat load of the system. The heat load was calculated using Equation 1. The amount of the cost of commercial natural gas in Ohio was \$7.44 per 1,000 cubic feet (April 2014, monthly average). The cost for natural gas was calculated to be \$673,279 for a season. Maintenance cost was taken as 1% of the capital cost based on surveys from contractors and the total O&M costs were calculated to be approximately \$823,279 million USD (2014).

HPS Annual Benefit Calculations

Value of Lost Passenger Time

As per Table 4, the values assigned to passengers travelling for business is \$63/h and for passengers travelling on leisure is \$35/h; 40.40% of the total passengers fly for business purposes and 59.60% are leisure travelers. The combined value of lost time for the two categories of travelers was found to be approximately \$3,000 USD annually using Equation 8 and 9.

Value of Airline Crew Time and Airplane Fuel Consumption

Since MCW is a GA airport there are only 4 flight operations in a day and the aircraft seats 8 passengers. This value is calculated to be $27,362 for the year 2014 using Equation 11. Annual growth rate of operations is also accounted for in this case for subsequent years.

Enhanced Safety of Ground Staff

There are 200 full time workers at MCW and the injury cost is estimated at $26,956 annually using Equation 12.

Table 10 shows the net present values of cost and benefits for HPS for MCW. As is evident from the Table, the NPV is a negative value indicating that the use of HPS at MCW is not feasible under the current assumptions. GA airports are not as frequently used as commercial airports and so do not have indirect or soft benefits that commensurate the high cost of installation of HPS. HPS may be feasible in a GA airport with higher number of aircraft operations. GA airports are used only in times of emergency or crisis and interpreting the use of airports in these situations in monetary terms may be very case-specific and challenging.

Table 10. Net Present Value of cost and benefits for HPS over a 20-year analysis period and discounted at 7%

Present value of cost or benefit	**Dollar values**
Present value of costs of HPS	($23,721,826)
Present value of benefits of HPS	$683,485
Net present value of HPS	($23,038,341)
Present value of cost of conventional methods	($5,377,621)

Case Study of Kent State University Airport, OH (1G3)

Kent State University Airport (1G3) is a public airport in Stow, Ohio owned by Kent State University. The airport is located along State Route 59 (Kent Road) approximately three west of the central business district of Kent. The aerial view of the airport is shown in Figure 34.

Figure 34. Aerial view of the Kent State University Airport (1G3) (Courtesy of Kent State University)

The Kent State University Airport is used by the College of Applied Engineering, Sustainability and Technology for its in-house Aeronautics program which provides flight training and other professional aeronautical training including Air Traffic Control and Airport Management studies to enrolled Kent State University students. The airport also operates a Flight Clinic for the general public who are interested in attaining private pilot instruction.

It does not handle any cargo and has one operational runway. Kent State University's Aeronautics program, has a 30 aircraft fleet that cycles every 90 minutes. They take about 90 minutes to clear the surface of snow. 5 snow removal personnel aid in the clearing of snow. The labor rate is approximately $10/h. They have a total of 5 SRE. They charge a ramp fee of $50 and other services like aircraft storage, wash, pre-heating engines etc. can be availed at extra costs.

HPS Capital Cost Calculations

The capital costs were calculated in a similar manner as the commercial airports. They consist of installation of HPS. The costs per unit feet are multiplied by the total area to be heated to get the capital cost. Based on the literature (Minsk, 1999) and consulting with companies dealing with heated pavements, a base value of $\$25/ft^2$ was adopted. To make the analysis more complete, a sensitivity analysis was carried out for different unit cost values such as $\$15/ft^2$, $\$35/ft^2$ and $\$45/ft^2$.

HPS Annual Cost Calculations

Annual or recurring cost comprise of the operation and maintenance costs to run the HPS. Operation costs consist of the cost of natural gas needed to heat anti-freeze circulating in the pipes and electricity needed to power the control system. The amount of natural gas required was calculated based upon the annual heat energy required to melt snow or the design heat load of the system. The heat load was calculated using Equation 1. The amount of the cost of commercial natural gas in Iowa was $10.13 per 1,000 cubic feet (April 2014, monthly average). The cost for natural gas was calculated to be $168,320 for a season. Maintenance cost was taken as 1% of the capital cost based on surveys from contractors and the total O&M costs were calculated to be approximately $205,820 USD (2014).

HPS Annual Benefit Calculations

As 1G3 is used only as a flight training airport there are no costs to passengers or airplane carriers. Winter weather may disrupt the normal schedule of flight training but that have not been included as a part of the analysis.

Enhanced Safety of Ground Staff

In 1G3 there are about 50 full-time workers. Number of cases were determined using this data. The number of cases for an incidence rate of 5 were 9.603. Based on the above data, the injury cost were calculated by multiplying the percentage of each injury by its contributing fraction of the VSL. The summed value of all the injury cases for 1G3 for the concerned four months was calculated as $6,739 using Equation 12.

Table 11 shows the net present values of cost and benefits for HPS for 1G3. As is evident from the table the NPV is a negative value indicating that the use of HPS at 1G3 is not feasible under the current assumptions. GA airports are not as frequently used as commercial airports and so do not have indirect or soft benefits that commensurate the high cost of installation of HPS. HPS may be feasible in a GA airport with higher number of aircraft operations. GA airports are used only in times of emergency or crisis and interpreting the use of airports in these situations in monetary terms may be very case specific and challenging.

Table 11. Net Present Value of cost and benefits for HPS over a 20-year analysis period and discounted at 7%

Present value of cost or benefit	Dollar values
Present value of costs	($5,930,457)

Present value of benefits	$71,393
Net present value	($5,859,063)
Present value of cost (base case)	($855,118)

Maintaining operational status of GA airports during snow may have many benefits like emergency medical services, aerial firefighting, law enforcement and border control, agricultural functions, time-sensitive air cargo services, etc. During emergency situations there may not be enough time to look for labor and get the airport ready for an incoming aircraft. HPS might be a good solution in this case as there will be no labor requirements and the airport can be ready for the arrival of an aircraft.

CHAPTER 8

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

Conclusions

The potential benefits of heated pavement systems are numerous. The installation of such systems can greatly reduce the dependency on snow removal equipment and deicing chemicals. In addition, heated pavement systems have the capability to provide enhanced safety for ground staff and vehicles, reduce the labor of snow and slush removal, and create better working conditions at the airport. However, a major challenge involved with the installation of heated pavement systems is the high initial costs. In view of the above, the objective of this study was to carry out a benefit cost analysis in order to evaluate the feasibility of this alternative snow removal method.

The basic strategy started with selecting airports that had an annual snowfall of at least 35 inches. Data was then collected from these airports through email surveys and on-site visits. The various costs and benefits of installing HPS were identified and monetized. Economic analysis techniques like NPV and BCR were then used to analyze the viability of installing HPS over an analysis period of 20 years.

Heated pavements are expected to have maximum benefits in the ramps and aprons, where clearing and hauling snow is more time consuming and cumbersome than other airport areas, mainly due to skewed geometric designs and heavy human and machine activity. Correspondingly, this analysis focuses on an assessment of the installation of heated pavement systems in such areas.

The results of this analysis suggest that, among stakeholders, delays affect passengers the most. Specifically, it is anticipated that passengers' lost time would substantially decrease with the installation of heated pavements. In addition, the results of the sensitivity analyses show that the benefit cost ratio is very sensitive to any changes in the duration and time period of delays and a slight increase can cause the BCR to increase considerably. Furthermore, the findings suggest that strategic placement of HPS after critical field investigations is the most desirable option with maximum benefits and least costs.

An Excel Spreadsheet-based toolbox for evaluating the energy and economic viability of heated pavement systems and its user manual have also been developed for use by airport mangers (see Appendix G)

Comparison of Financial Feasibility of HPS across Commercial Airports

The case studies suggest that HPS may be feasible in all types of commercial airport under a given set of assumptions and conditions. It is interesting to compare how the BCR changes for each type of airport. The case study on the Minneapolis-St. Paul International Airport (MSP) in Minnesota, representing a large primary hub in the analysis, indicates very strongly that use of HPS is economically feasible under the given set of assumptions. The findings of the case studies suggest that the larger the airport in terms of both the area of pavements and the number of operations, the more feasible the installation of HPS. As seen in Table 12, the BCR decreases as the size of the airport (number of operations and area) decreases. There is a 25% decrease in the BCR between a large hub (MSP) and medium hub (CMH) airport and approximately 40% decrease between a large hub and a small hub (DSM) airport.

Table 12. Benefit Cost Ratios for the different airports considered in this analysis

Airport	BCR
Minneapolis-St. Paul International Airport (MSP)	1.79
Port Columbus International Airport (CMH)	1.33
Des Moines International Airport (DSM)	1.06

Nevertheless, HPS is still a financially viable snow melting option among small hub airports (0.05% to 0.25% of total U.S. passenger enplanements) like DSM.

Table 13 summarizes the results presented in the case studies. It is seen that the results of the study indicate that the high installation costs may be offset by the large amount of benefits over a 20-year analysis period. In addition, the costs of HPS are area-dependent. Thus, strategic placement of these systems could greatly reduce the capital costs without compromising the benefits. Reducing pavement areas with HPS could greatly reduce the capital costs making them comparable to the cost of the current snow removal methods. If site investigations can prove that heating only about 20% of the total apron area instead of the entire apron can help in reducing delays, then HPS may prove to be very cost beneficial.

Table 13. Variation of Benefit Cost Ratios with the Change in the Percentage of Area under HPS for Different Airports That Are Part of the Study

Percentage of area of apron to be heated	BCR for MSP	BCR for CMH	BCR for DSM
20	4.06	3.39	2.4
40	3.09	2.44	1.82
60	2.49	2.12	1.59
80	2.08	1.66	1.32
100	1.79	1.33	1.06

The results can be transferred to other airports with similar operations and weather conditions. A few large hub airports that would benefit from the study are Denver International

Airport, Chicago O'Hare International Airport, Newark Liberty International Airport, John F. Kennedy International Airport, and LaGuardia Airport because they have similar snowfall characteristics, area, and number of operations.

Summary of the Key Findings of the Case Studies

The key findings of this study are as discussed as below:

- Heated pavement systems (HPS) are expected to have maximum benefits in the ramps and parking apron areas where clearing and hauling snow more time consuming and cumbersome due to different geometric designs and activities involving airport ground crew.
- General aviation airports do not have as many indirect benefits and soft costs as commercial airports. General aviation airports would benefit from HPS in case of emergency situations when it becomes imperative to keep the airport functional.
- HPS application is a viable option from an energy or financial perspective for achieving pavement surfaces free of ice/snow without using mechanical or chemical methods. They may be exclusively beneficial at aprons that have a small area relative to the total paved surfaces of the airport but have the potential to cause winter weather related delays. Snow accumulation in the aprons causes most of the airline delays as pointed out by the airport mangers, so it becomes crucial to keep them clear of snow.
- As the initial costs of installation are very high such systems may be feasible only in commercial airports where the costs may be offset through airport usage and improvement charges or taxes. It may not be financially viable to install HPS for the entire area of airport paved surfaces.

- Strategic placement of HPS can reduce the initial construction costs significantly making a strong argument in favor of installing HPS. The results of the benefit cots analysis are dependent on the size of the airport examined, both in terms of operations and of area.
- HPS have the potential to reduce the dependency on deicing salts, minimize the use of snow removal equipment and reduce labor requirements.
- Passengers/airport users are greatly affected due to the delays. It is anticipated that with the installation of heated pavements the passengers’ lost time would substantially decrease.

Limitations and Future Research Directions

Limitations

The current study focused on studying the effect of delays due to winter storms. Instead of studying the annual effects of winter storm and averaging them for the entire analysis period studying each storm independently and categorizing the effects based on the intensity or number of days it lasted, might provide further insights. In view of the scope of this study, it is challenging to estimate the costs for one winter storm due to unavailability of data as it is case specific. However, airports managers may be able to collect this information and make use of the developed Spreadsheet tool to examine the economic effects for different frequencies of a winter storm and not only the average seasonal effects.

In addition, the estimation of the cost for conventional methods in this study were largely dictated by the area considered. It is challenging to break down the amount of SRE, labor and deicing salts specifically for specific areas. Nonetheless, airport mangers might have this information or they may observe it during snow clearing operations. This information can then be utilized in the developed Spreadsheet tool to discern the exact economic impacts. Along the same lines, the amount of weather related delays were extracted from the Research and Innovative Technology Administration (RITA) website. There might be discrepancies in estimating the exact amount of delays only due to high levels of snowfall leading to the airport not being able to cope with snow clearing. Such statistics may be maintained by the airports making them more explicit and reliable.

In addition, due to limited availability of data, the potential rise in the number of operations after installing HPS (i.e., induced demand) have not been considered in the analysis; these costs may further magnify the expected benefits. Nevertheless, it is believed that heated pavements will be able to reduce delays and improve the efficiency of daily aircraft operations, thereby having a direct effect on the revenue.

Furthermore, this study does not utilize costs due to delays in cargo, as discussed in the case studies, because it was not found to be a significant factor in the airports considered. Nevertheless, each airport has different policies dealing with cargo and the frequency of cargo movement also varies with each airport. It is arduous to collect information on cargo delays. Airports usually do not have such information and only the cargo carriers would have such information. Another factor to consider would be belly cargo which is the cargo transported in the passenger flights. Although the amount of belly cargo is significantly less than the normal cargo it may be considered. At smaller airports where there are no dedicated cargo carriers they may rely on passengers flights to transfer cargo. This data might be collected by contacting the concerned air carriers but they might be apprehensive to publish such data. Usually larger airports handle more amount of cargo which is either transferred to other states/countries or flows to smaller airports in the states. On a case by case situation, and upon discussion with the cargo carriers, it might be beneficial to consider the cost of cargo delays, at least for larger airports like MSP to show the feasibility of installing HPS.

Along the same line, the current report only estimates the economic impact of installing HPS due to domestic flights as certain airports in the study do not cater to international flights. International delays are complicated to estimate due to their routing and knowledge of the source of delay. Such delays may be considered in future studies.

Finally, the justification for the use of heated pavement systems in the aprons has been established in this report. Nevertheless, some airports might benefit from heating portions of the airports apart from the aprons as well. Thus, it is crucial to examine the relative benefits and costs of heating other pavement areas like runways and taxiways as well. In any case though, it is recommended that the installation of heated pavement systems in such areas will be in addition to the aprons. The methodology described in this report can be adapted to explore the financial viability of installing heated pavement systems in the total paved area of an airport.

Future Research Directions

The current study aims to serve as a guidance to the airport managers to investigate the feasibility of installing HPS. The Spreadsheet tool can be used to examine any airport by changing the input values. The study focuses on the use of HPS at aprons as they will have the maximum benefits at the aprons. However, with the advancement in technology HPS may be used cost effectively at other locations as well. MSP has been taken as an example to illustrate the methodology and economic outcomes that can be used to assess the economic viability of heating other areas of an airport as well. Aprons and ramps comprise about 20% of the total airport area (based on data collected by airports).

The total pavement area of MSP is 28 million square feet and benefit cost analysis were carried out by installing HPS at 20%, 40%, 60% 80% and 100% of the total airport area (28 million square feet). Hydronic heated pavement systems are installed in a portion of the airport and the reaming parts are cleared by conventional methods. When HPS is installed at a given percentage, say 20% of the total airport, the remaining 80% is cleared by conventional snow removal strategies. Total costs of heating the concerned areas (say 20% of total area) comprise of the cost of installation and O&M of HPS. The cost for the remaining areas (80% of total area) comprise of the purchasing cost of SRE, its O&M costs and cost of deicing chemicals. Total cost incurred by an airport is the sum of the cost for HPS and conventional methods cover the entire airport. The total benefits incurred by using HPS remain the same if any area is considered in addition to the aprons. It has been established that aprons are the most suitable area for HPS as most delays stem at the aprons. The total benefits are estimated as $353,996,163 for a period of 20 years.

The cost of installing HPS at 20% of the airports and the remaining 80% being cleared by conventional methods together have been estimated as ($274,082,764). If the airport was not using HPS and relied on the use of conventional methods the cost would be approximately ($95,501,100). In this case no benefits were considered as flights will continue to get delayed.

Using the above values, the incremental benefit cost ratio of installing HPS at 20% of the airport area would be 1.98. As the area of installation increases the cost of installing HPS will increase thereby decreasing the incremental benefit cost ratio.

Figure 35 clearly shows that when area of installation increases, the BCR decreases sharply. For MSP, if 30% of the total airport area is heated the BCR value is just above 1 and if the area of installation further increases HPS are no longer a viable option of clearing snow.

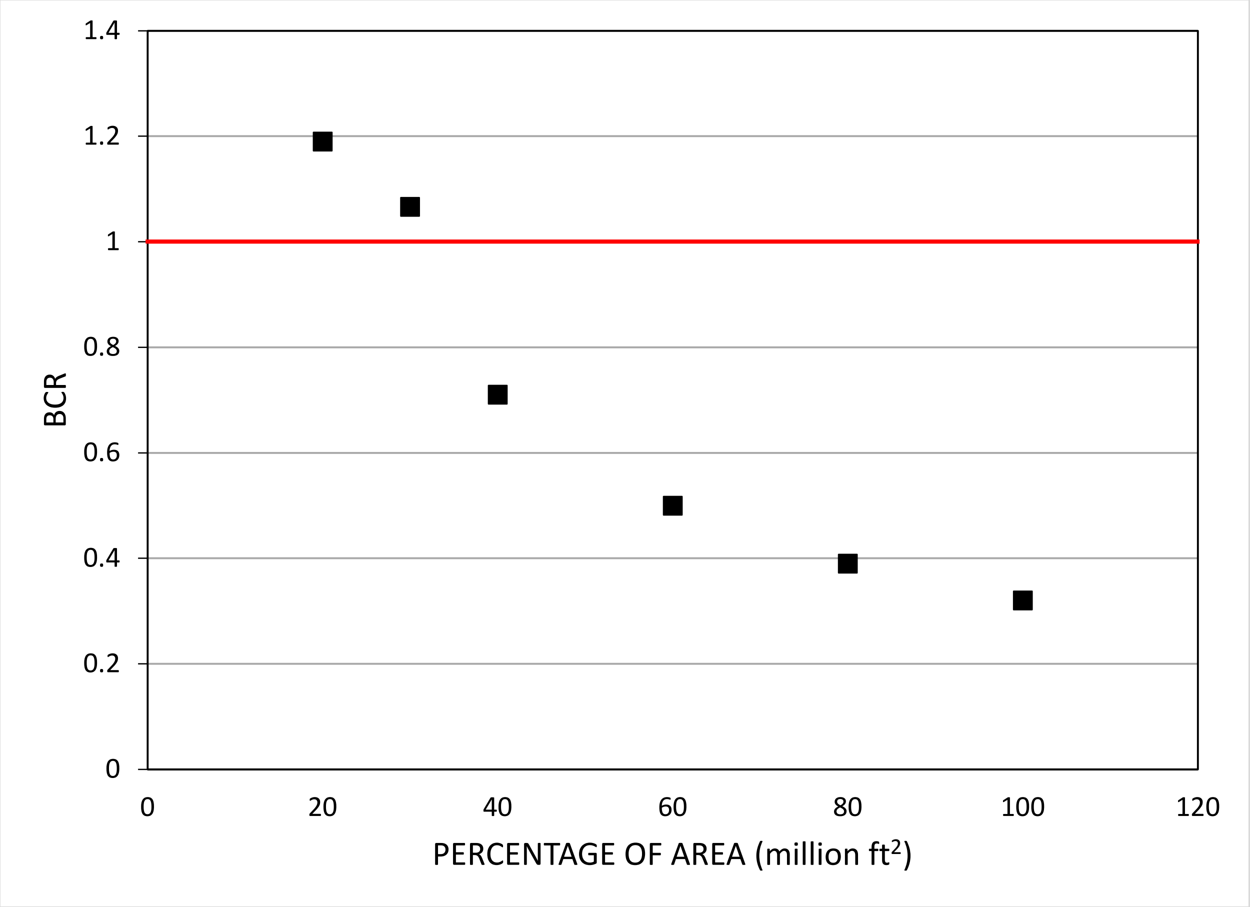

Figure 35. Plot of the BC Ratio versus Proportion of the Area of Aprons under Heated Pavements

As the construction cost of HPS are high it may be viable to heat only the aprons and not the entire airport in order to prevent delays.

Advancements in HPS technology and construction practices may have the potential to significantly reduce the construction costs. This might make the cost of HPS comparable to conventional methods of snow removal. Use of innovative substances like phase change materials (PCM) or conductive concrete alongside HPS may increase the efficiency of HPS and reduce the operational costs.

State-of-The-Art Contributions to Engineering Practices

- Theoretical and experimental results of energy demand for snow melting and pavement idling are utilized in the economic analysis in this research to duplicate the actual behavior of heated pavement system (HPS).
- The current research aims to serve as a decision making tool for airport managers to adopt the alternative technology.
- Energy consumption and cost related to HPS and conventional snow removal systems have been quantified.
- Various direct and indirect costs and benefits related to the installation of HPS have been identified and quantified.
- Different airports can be analyzed with the help of the economic analysis tool.
- This research gave evidences to show that using deicing/anti-icing chemicals for snow removal is not efficient, and HPS as a potential alternative may be able to overcome this problem.
- The methodology developed herein could be extended to examine the financial viability of new HPS technologies such as electrically conductive pavement materials in conjugation with super hydrophobic substances or phase changing materials.
- As this study is the first to compare the economic impacts of conventional methods of snow removal with an alternative winter operations strategy several assumptions have been made and the lack of sufficient data is acknowledged and the gaps for future studies are provided.
- The advancements in HPS technology and construction practices would greatly reduce the installation costs making them comparable to cost of snow removal by conventional methods.

Summary and Recommendations

There has been an attempt to study the energy and economic effects of using an alternative snow removal system for airports. HPS have the capability to provide enhanced safety for ground staff, chemicals and vehicles, reduce the labor of snow and slush removal, and create better working conditions at the airport. However, a major challenge involved with heated pavement systems is to reduce the high installation costs. Realistic assumptions have been made in order to estimate these costs due to the absence of full-scale heated pavements in the U.S. In view of this certain recommendations have been proposed:

- The study quantified soft costs and hard costs of installing heated pavement systems which provides airport authorities with a more informed choice in selecting a snow removal system for their airports.
- Advancements in HPS technology and construction practices are expected to greatly bring down the installation cost making them comparable to cost of snow removal by conventional methods.
- Disruption in the proper functioning of HPS may occur due to problems in the heat generation or distribution system and airports might have to substitute snow removal by SRE. Costs related to this may be accounted for in future studies.
- Operation costs can be reduced by judicious use of HPS and appropriate weather monitoring giving the slab enough time to heat just before the onset of a snow event.
- As all aprons are not used simultaneously, the capacity of the boiler system may be reduced which would lower the initial costs.

- There may be instances of medical emergencies or natural calamities at odd hours and keeping the general aviation airports accessible would be indispensable emphasizing the provision of HPS even at GA airports.
- Indirect costs like increase in the number of daily aircraft operations may also be considered as a benefit in the commercial airports. The actual number of injuries occurring at aprons collected by airports during snow removal operations could provide a more accurate estimation of the indirect benefits of installing HPS.
- The analysis may include opportunity cost of installing such systems to reflect other avenues of airport improvement.

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APPENDIX A - ENERGY REQUIREMENTS FOR HEATED PAVEMENT SYSTEMS

The sensible heat (qs) to bring the snow to 32°F is:

qs = s cp D (32 - ta) / c1

Where:

s = rate of snowfall (inches of water equivalent per hour)

cp = specific heat of snow (0.5 Btu/lb/°F)

D = density of water equivalent of snow (62.4 lbs/ft3)

ta = air temperature (°F)

c1 = conversion factor (12 in/ft)

The heat of fusion (qm) to melt the snow is:

qm = s hf D / c1

where:

hf = heat of fusion for water (143.5 Btu/lb)

The heat of evaporation qe is:

qe = Pdry air hm(Wf-Wa)hfg

where:

Pdry air = density of dry air (lb/ft3)

hm = mass transfer coefficient, concrete slab (ft/h)

Wf = humidity ratio of saturated air at film surface temperature @ 33° (lbvapor/lbair)

Wa = humidity ratio of ambient air @ 20° (lbvapor/lbair)

hfg = heat of evaporation at the film temperature @ 330 (Btu/lb)

The heat transfer qh:

$qh = hc(tf-ta)+\sigma\varepsilon s(T4f -T4MR)$

Where:

hc = convection heat transfer coefficient for turbulent flow (Btu/h·ft^2·°R4)

tf = liquid film temperature, (°F) usually accepted as 33

ta = ambient air temperature coincident with snowfall (°F)

σ = Stephan-Boltzmann constant (Btu/h·ft^2·°F4)

εs = emittance of wet slab

TF = liquid film temperature (°F)

TMR = mean radiant temperature of surroundings (°F)

APPENDIX B - COST CALCULATIONS- APRON

Conventional Methods: Initial Cost Calculations

- Cost of SRE is a function of the area
- Area of the total apron and gate = 5 million ft^2
- Area of the total paved surface = 28 million ft^2
- Ratio of the areas = 5 ÷28 = 0.179
- Fraction of cost for apron and gate = 45,569,920 × 0.179 = $8,137,485

Conventional Methods: Recurring cost calculations

- Deicing agents
- Cost of potassium acetate = $933,750
- Cost of sodium acetate = $675,000
- Labor cost
- No of personnel = 110
- Cost of labor per person per hour = $25.6
- Labor hours = 600
- Total labor cost =110 × 25.6 × 600 = $1,689,600
- Fuel cost for SRE = $814,800
- Maintenance cost for SRE = $600,000
- Total annual recurring cost for entire paved surfaces = $933,750 +$675,000 +$1,689,600 + $814,800 + $600,000 = $4,713,150
- Total annual recurring cost for considered area = $4,713,150 × 0.179= $841,634
- Hydronic heated pavement cost calculations: Initial cost

- Cost of installation of HPS = \$25/ft^2 (Minsk 1999; Lund 2007)
- Area = 5 million ft^2
- Total installation cost = 25 × 5,000,000 = \$125,000,000

Hydronic heated pavement cost calculations: Recurring Cost

- No. of operations in one day = 1,200 (MSP)
- No. of operations in 4 months = 144,000
- 2% of flights are delayed in MSP due to winter weather (RITA, 2013-2014)
- One winter season (year) is assumed to be of 4 months
- Delays in 4 months = 2,880 (2% × 144,000)
- Assuming each delay is 1 hour
- Benefit from prevent delay costs (fuel and crew costs)
- The average total direct operating costs for the applicable aircraft type can be used to quantify the runway closure delay costs to airlines, aircraft owners, and the passengers
- Variable aircraft direct operating costs: (ACRP report # 123)
- Midair = \$4,960/h
- Ground = \$2,148/h
- Gate = \$1,443/h
- Assuming equal no of all 3 delays; combined value = \$2,850/h
- Delays in 4 months = 2,850 × 2,880 = \$8,208,000/yr
- Benefit from prevent delay costs (passenger costs)
- No. of passengers traveling for leisure = 72 (80.6% × 150 × 59.6%)
- No. of passengers traveling for business = 49 (80.6% × 150 × 59.6%)

- Value of lost time for leisure travelers = 72 × $35 × 2,880/yr = $7,257,600/yr
- Value of lost time for business travelers = 49 × $63 × 2,880/yr = $8,890,560/yr

APPENDIX C - COST CALCULATIONS- CONSIDERING ENTIRE AIRPORT

Conventional methods: Initial Cost Calculations

- Cost of SRE is a function of the area
- Area of the total apron and gate = 5 million ft^2
- Area of the total paved surface = 28 million ft^2
- Ratio of the areas = 5 ÷ 28 = 0.179
- Fraction of cost for apron and gate = 45,569,920 × 0.179 = $8,137,485
- Conventional methods: Recurring cost calculations
- Deicing agents
- Cost of potassium acetate = $933,750
- Cost of sodium acetate = $675,000
- Labor cost
- No of personnel = 110
- Cost of labor per person per hour = $25.6
- Labor hours = 600
- Total labor cost =110 × 25.6 × 600 = $1,689,600
- Fuel cost for SRE = $814,800
- Maintenance cost for SRE = $600,000
- Total annual recurring cost for entire paved surfaces = $933,750 +$675,000 +$1,689,600 + $814,800 + $600,000 = $4,713,150
- The initial cost now is $125,000,000 + $45,569,920 (purchasing cost of SRE) = $170,569,920
- Hydronic heated pavement cost calculations: Initial cost calculations

- Cost of installation of HPS = \$25/ft^2 (Minsk 1999; Lund 2007)
- Area = 5 million ft^2
- Total installation cost = 25 × 5,000,000 = \$125,000,000

Hydronic heated pavement cost calculations: Recurring Cost

- No. of operations in one day = 1,200 (MSP)
- No. of operations in 4 months = 144,000
- 2% of flights are delayed in MSP due to winter weather (RITA, 2013-2014)
- One winter season (year) is assumed to be of 4 months
- Delays in 4 months = 2,880 (2% × 144,000)
- Assuming each delay is 1 hour
- Benefit from prevent delay costs (fuel and crew costs)
- The average total direct operating costs for the applicable aircraft type can be used to quantify the runway closure delay costs to airlines, aircraft owners, and the passengers
- Variable aircraft direct operating costs: (ACRP report # 123)
- Midair = \$4,960/h
- Ground = \$2,148/h
- Gate = \$1,443/h
- Assuming equal no of all 3 delays; combined value = \$2,850/h
- Delays in 4 months = 2,850 × 2,880 = \$8,208,000/yr
- Benefit from prevent delay costs (passenger costs)
- No. of passengers traveling for leisure = 72 (80.6% × 150 × 59.6%)
- No. of passengers traveling for business = 49 (80.6% × 150 × 59.6%)

- Value of lost time for leisure travelers = 72 × \$35 × 2,880/yr = \$7,257,600/yr
- Value of lost time for business travelers = 49 × \$63 × 2,880/yr = \$8,890,560/yr

APPENDIX D - AIRPORT SURVEY QUESTIONNAIRE

General Operations

1. What is the number of enplanements in a year?
2. Could you give the number of enplanements for different airlines using your airport? Do any of these airlines avoid using your airport in the winter months?
3. What is the annual cargo handling capacity?
4. How many operational runways does the airport have?
5. How many runways are open during snow storms? How does this effect on-time performance & schedules?
6. In case a flight is delayed or cancelled due to weather related events, would the airport cover any (or all) of the airline (aircraft) expenses related to the delay (such as cost of fuel, cost of crew, compensation to passengers)? If yes, how much and in what form?
7. Do you have any plans to extend, repair or renovate the existing runways in the next few years?

Pavement De-icing

1. What is the time taken to clear a primary taxiway and ramp area?
2. What is the extent of damage on the pavements caused by snow or snow removal operations? How much do you spend on pavement maintenance annually?
3. What types of pavement de-icers do you use?

Pavement area

1. What is the area of the primary taxiway and ramp?
2. What is the total area of the paved surfaces at the airport?
3. What is the total area of the paved surfaces typically de-iced during winter operations?

Equipment required for clearing snow

1. What is the current state of snow and ice removal practice?
2. What are the issues encountered in the current state of practice?
3. Typically what is the number of equipment required to clear a primary taxiway, ramp area and the entire paved surface, respectively, when an average snow fall of 10 inches per day occurs? Could you also please name them?

Initial costs

1. What was the construction cost of the primary taxiway and ramp and in what was the construction year?
2. What was the initial cost incurred on the purchase of the snow removal equipment (and the purchase year)? Could you please specify the cost of each equipment separately?
3. Generally, what is the time period after which you replace the equipment with new ones?

Recurring costs

1. What is the annual maintenance cost of the snow removal equipment? Could you please specify it as a percentage relative to the initial cost of equipment?
2. How much is the fuel cost spent on running the snow removal equipment to clear a primary taxiway and ramp area and in total for the entire airport?

3. How many personnel are required to aid in clearing a primary taxiway and ramp area and in total for the entire airport?
4. What is the labor rate (per hour per person) to run these equipment that aid in snow removal operations?
5. What is the application rate of the de-icers you use?
6. What is the quantity of de-icing agents required to clear the primary taxiway, ramp and the entire paved surface? How much do you spend on these approximately?

Delays

1. What is the average number of delays faced at the airport per year?
2. What percentage of outbound flights out of the total operations are delayed and cancelled during the winter months?
3. Could you categorize and provide an approximate percentage of the number of outbound flights being delayed due to each of the causes like runway closure, heavy winds, low visibility or any other cause?
4. Could you give an approximate value as to how much these delays (closing of runways due to extreme snow) would cost you per annum?
5. How does severe weather affect cargo operations at your airport? Could you give an approximate value as to how much cargo delays (due to extreme snow) would cost you per annum?

Safety issues

1. Any accidents or fatalities caused to the personnel aiding in snow removal and cargo handling by exposure to winter weather conditions and snow removal operations?
2. Are there any known costs related to work related accidents? Who is responsible for it? What is the airport policy to deal with such accidents?
3. Any aircraft accidents reported in the last 20 years due to icy pavements?
4. If yes, how severe was the accident? How much was the cost of repair or compensation and who was responsible for paying for it?

Heating facility

1. Is the airport currently using a geothermal or hydronic heating system to heat pavements, terminal building or parking area to clear ice/snow (could also you provide the name of the construction contractor)?
2. If yes, what are the installation and operation costs?
3. What is the capacity of the system?
4. What is the energy demand per hour?

APPENDIX E - AIRPORT SURVEY QUESTIONNAIRE SUMMARY

Category	**MSP**	**CMH**	**DSM**	**MCW**	**1G3**
General operations	360 aircraft operation in day	360 aircraft operation in day	220 aircraft operation in day	4 aircraft operation in day	Used only for flight training
Pavement deicing	225,000 gallons of potassium acetate used per winter	Potassium acetate and sodium formate are used	115 Ton NAFF; 10,000 gallons of RF-11 and 80 ton FAA Spec Sand used for deicing annually		
Pavement area	Ramp & apron-5 million ft^2; Entire airport 28 million ft^2	Ramp & apron-2.2 million f^{t2}; entire airport 9.4 million ft^2	Ramp & apron-1.5 million ft^2	Ramp & apron-600,000 ft^2; Entire airport 3 million ft^2	Ramp & apron-150,000 ft^2; Entire airport 641,680 ft^2
Snow removal equipment and personnel	Overall annual value provided only; more than 100 pieces of SRE with cost information; 110 laborers	Overall annual value provided only; around than 17 pieces of SRE; 16-22 laborers	Overall annual value provided only; more than 22 pieces of SRE; 28 laborers	around 5 pieces of SRE; 7 laborers	around 5 pieces of SRE
Recurring costs	SRE maintenance is $60,000; hourly labor rate is $25.60	$165 for clearing a priority 1 area once; hourly labor rate is $14-$50	$180,000 spent on SRE fuel; $100,000 R&M; annual labor costs are $60,000	Hourly labor rate $14-$20	Annual R&M cost $10,000; hourly labor rate is $10/h
Injury incidents of ground staff	Mentioned there are cases of injuries	No information	Mentioned there are cases of injuries	No information	No information
Delays	Usually airports do not track delays	Usually airports do not track delays	Usually airports do not track delays	Usually airports do not track delays	Usually airports do not track delays

APPENDIX F – RESPONSES TO E-MAIL QUESTIONNAIRE

This appendix presents the responses given by airport authorities to the survey questionnaires submitted.

Minneapolis-St. Paul International Airport (MSP), MN

FAA Sponsored Project on "Heated Airport Pavements"

Airport Survey Questionnaire

Response from Minneapolis-St. Paul International Airport

Paul Sichko, Assistant Director – MSP Operations

612.794.4381

paul.sichko@mspmac.org

General Operations

1-3. Airport statistics are available at www.mspairport.com under the 'About MSP' and 'statistics' tabs.

4. Four operational runways.

5. Two or three runways are maintained during snow events, depending on atmospheric conditions and direction of flight operations.

6. Per FAA regulations and air carrier contract of carriage agreements, neither the airport nor the airport operator are responsible for expenses or reimbursement of costs associated with weather-related events.

7. All MSP runways have been recently rehabilitated with PCC surfaces; no near-term renovations or repairs are scheduled.

Pavement De-icing

1. More specific information is necessary. MSP taxiways and ramps encompass almost 20 million square feet of pavement. Snow removal operations are constant during a snow event. The best measure may be the time on a 2 million square foot runway, which may be as little as 10 minutes or as many as 35 minutes depending on the situation.
2. Concrete surfaces are very robust and hold up well during snow removal operations. There is occasional damage joints and joint seal materials. Approximately $500,000 dollars is allocated for pavement maintenance in the annual operating budget. Anywhere from $5 million to $20 million is allocated in annual capital improvement (pavement repair/replacement) projects.
3. Potassium acetate (anti-icer) and sodium acetate (de-icer).

Pavement Area

1. Approximately 20 million square feet.
2. Approximately 28.4 million square feet.
3. Generally limited to runway surfaces – 8.4 million square feet.

Equipment required for clearing snow

1. MSP has one of the most comprehensive snow and ice control plans in the country with over 100 pieces of equipment dedicated to snow removal and a commensurate number of vehicles operators.

2. Aircraft parking position snow removal is the most critical issue. It is difficult to meet customer expectations for simultaneous snow removal operations in 125 gates. [Heated pavement may be more beneficial in aircraft parking gates than on runways]
3. MSP snow removal equipment is listed in the FAA-approved Snow and Ice Control Plan, which will be submitted as a separate document.

Initial costs

1. More specific information is necessary as each project is unique in design and scope. 6,200 square feet of apron is scheduled for rehabilitation this fall at a cost of $3.1 million. The project includes work on the airport's underground fuel delivery system. 550,000 square feet of runway was rehabilitated in 2009 at a cost of $17.3 million.
2. The five most common vehicles in the MAC's snow removal fleet are multi-function vehicles ($910,000), high-speed runway plows ($485,000), rotary runway brooms ($650,000), high-speed snow blowers ($875,000), and front-end loaders ($250,000). Refer to the snow removal equipment listing in the MSP Snow and Ice Control Plan.
3. Most snow removal vehicles are kept for 12-15 years, some vehicles up to 20 years.

Recurring costs

1. The annual snow removal vehicle repair budget is $600,000. Repair costs are unique to each vehicle, i.e., replacement of the broom components of a rotary runway broom is $13,000 per occurrence. Broom replacement is required at least once per winter, representing 2% of initial vehicle cost.

2. Fuel costs are not specifically broken down in that manner, as there are too many variable to consider, i.e., the number of vehicles available/assigned to a specific area.
3. 110 vehicle operators are routinely assigned to removal snow from airport surfaces.
4. The average hourly rate is $25.60 per hour straight time.
5. Standard application of potassium acetate is ½ gallon per 1,000 square feet.
6. Average potassium acetate use over the past three winter seasons is 225,000 gallons at $4.15/gallon.

Delays

All requested information in this section would have to be provided by air carrier and cargo operator tenants.

Safety issues

1. There have been no reported serious accidents or fatalities at MSP related to winter weather conditions and snow removal operations.
2. Several slip and fall accidents were experienced by MAC personnel and air carrier employees during the course of the previous winter. Each employer is responsible for equipping personnel for winter operations. For instance, the MAC distributes safety boot cleats to improve traction on contaminated surfaces.
3. There has been one runway excursion and three taxiway excursions at MSP in the last 20 years. There were no injuries, nor was there any damage to the aircraft involved in the incidents. In each event, the aircraft was towed out of areas adjacent to the paved surfaces and was returned to service.

4. Replacement of damaged edge lights and airport guidance signs was less than $10,000. Other repair cost information would have to be provided by the air carrier and cargo operator tenants.

Heating facility

1. An in-pavement, heated glycol system is installed in the MAC Field Maintenance Center. Small heating systems are also in operation at several garage approach and apron locations.
2. The Field Maintenance Center installation was part of a $7 million facility expansion project. A request was made of the project managers to provide costs for the heating system, but the information was not received prior to the questionnaire submission deadline.
3. Pavement heating system operates with three (3) 1.9 million BTU-rated boilers.
4. On-demand natural gas service that is run through a common building gas meter; unable to provide system-only hourly costs.

Port Columbus International Airport (KCMH), OH

FAA Sponsored Project on "Heated Airport Pavements"

https://www.pegasas.aero/projects.php?p=1

Technical Point of Contact:

Prof. Halil Ceylan (hceylan@iastate.edu)

Phone: 515-294-8051

Department of Civil, Construction and Environmental Eng.

Iowa State University

Ames, Iowa

Airport Survey Questionnaire

(KCMH) PORT COLUMBUS INTL AIRPORT

General Operations

1. What is the number of enplanements in a year?

2013: 3,114,695

2. Could you give the number of enplanements for different airlines using your airport? Do any of these airlines avoid using your airport in the winter months?

Southwest: 26% Delta: 23% US Airways 15% United: 15% American: 14% AirTran 6% Air Canada: .6%

3. What is the annual cargo handling capacity?

2013: 7,596,259 lbs

4. How many operational runways does the airport have?

Two Parallel Runways

10L/ 28R- 8000FT

10R/28L 10,113 FT

5. How many runways are open during snow storms? How does this effect on-time performance & schedules?

2 of 2 if snow fall rates allow. Delays are not usually attributed to exceeding runway capacity.

6. In case a flight is delayed or cancelled due to weather related events, would the airport cover any (or all) of the airline (aircraft) expenses related to the delay (such as cost of fuel, cost of crew, compensation to passengers)? If yes, how much and in what form?

No

7. Do you have any plans to extend, repair or renovate the existing runways in the next few years?

Yes: 2015, Runway rehabilitation of 10L/28R (8000ft). Primarily a mill and pave with new signage and lights.

***2012-2014 10R/28L and associated taxiways relocated and built from the ground up.**

Pavement De-icing

8. What is the time taken to clear a primary taxiway and ramp area?

Primary Taxiway(s) and Runway North Side: 32 mins

Primary Taxiway(s) and Runway South Side: 37 mins

9. What is the extent of damage on the pavements caused by snow or snow removal operations? How much do you spend on pavement maintenance annually?

Pavement is not consistently damaged from snow removal operations. Although, numerous lights and signs are damaged or destroyed during higher snowfall events

10. What types of pavement deicers do you use?

Potassium Acetate (Primarily on Runways)

Sodium Formate (Runways, Taxiways, Ramp Taxilanes)

Pavement area

11. What is the area of the primary taxiway and ramp?

Ramps, Ramp Taxilanes, Hold Pads, Parking areas, = Roughly 3.3 million sq/ft

12. What is the total area of the paved surfaces at the airport?

Roughly 9.4 million sq/ft

13. What is the total area of the paved surfaces typically de-iced during winter operations?

Runway 10R/28L – 1.5 million sq/ft

Runway 10L/28R – 1.2 million sq/ft

Taxiway B - 758k sq/ft

Taxiway C - 758k sq/ft

Taxiway C3 - 60k sq/ft

Taxiway C7 - 60k sq/ft

Taxiway D – 637k sq/ft

Taxiway E – 600k sq/ft

Taxiway J – 435k sq/ft

Taxiway H – 125k sq/ft

Taxiway K – 1500 sq/ft

Taxiway M – 38k sq/ft

TOTAL – 6.125 million sq/ft

Equipment required for clearing snow

14. What is the current state of snow and ice removal practice?

New snow removal routes and procedures will be in the 2nd year of a trial stage for the 2014/2015 winter. Data for clearance times and effectiveness are being gathered because of new airport layout and additional surfaces.

15. What are the issues encountered in the current state of practice?

- **Aging equipment**
- **Insufficient staffing levels**
- **Cost of chemicals**
- **Events exceeding 6 inches of accumulation**
- **Ramp clearance times during large events**

16. Typically what is the number of equipment required to clear a primary taxiway, ramp area and the entire paved surface, respectively, when an average snow fall of 10 inches per day occurs? Could you also please name them?

Typical snow event for KCMH is 4 inches or less. For this type of event we generally activate the following:

Equipment Type	**Year**	**Make**	**Capacity**
Runway Broom	1990	Oshkosh/Sweepster	16ft Broom head
Runway Broom	1990	Oshkosh/Sweepster	16ft Broom head
Runway Broom	2005	Oshkosh/Sweepster	18ft Broom head
Runway Broom	2005	Oshkosh/Sweepster	18ft Broom head
Runway Broom	2010	Oshkosh/Sweepster	18ft Broom head

Runway Broom	2011	Oshkosh/Sweepster	18ft Broom head
Runway Broom	2011	Oshkosh/Sweepster	18ft Broom head
Snow Blower	1996	Oshkosh/Wausau	3500 ton/ hr
Snow Blower	1997	Oshkosh/Wausau	3500 ton/ hr
6x6 Plow/Sander	1999	Oshkosh	22ft Plow/V-bed
6x6 Plow/Sander	2000	Oshkosh	22ft Plow/V-bed
6x6 Plow/Sander	2000	Oshkosh	22ft Plow/V-bed
6x6 Plow/Sander	2000	Oshkosh	22ft Plow/V-bed
Liquid De-icer Spray Truck	1999	Int'/Batts	2000g, 46ft boom
Liquid De-icer Spray Truck	1999	Int'/Batts	2000g, 46ft boom
Solid De-icer/Plow Truck	1999	Int'/Tandem Axle	14ft Plow/V-bed
Solid De-icer/Plow Truck	2000	Int'/Tandem Axle	14ft Plow/V-bed

Initial costs

17. What was the construction cost of the primary taxiway and ramp and in what was the construction year?

No response

18. What was the initial cost incurred on the purchase of the snow removal equipment (and the purchase year)? Could you please specify the cost of each equipment separately?

10.5 Million Dollars.

***New snow equipment is currently being shopped**

19. Generally, what is the time period after which you replace the equipment with new ones?

15-20 Years

Recurring costs

19. What is the annual maintenance cost of the snow removal equipment? Could you please specify it as a percentage relative to the initial cost of equipment?

20. How much is the fuel cost spent on running the snow removal equipment to clear a primary taxiway and ramp area and in total for the entire airport?

To follow our prescribed snow removal routes for priority 1 surfaces with a full snow team (7 Brooms, 2 solid chemical trucks, 1 liquid deicer, 1 blower)

Roughly 11 vehicles, 20 miles per piece plus idle time (estimated 5mpg) for a total of 44 gallons at $3.75 per gallon =

$165 per clearing of priority 1 surface

21. How many personnel are required to aid in clearing a primary taxiway and ramp area and in total for the entire airport?

Between 16-22 depending on snowfall rate and total accumulation

22. What is the labor rate (per hour per person) to run these equipment that aid in snow removal operations?

Between $14 - $50 / hr

***Cost/hr can greatly differ if OT is needed (depending on the time and day of the week that the snow occurs).**

23. What is the application rate of the de-icers you use?

800 Gallons (per application) Potassium Acetate for 10L/28R

1000 Gallons (per application) Potassium Acetate for 10R/28L

24. What is the quantity of de-icing agents required to clear the primary taxiway, ramp and the entire paved surface? How much do you spend on these approximately?

*Liquid deicer used primarily on runways:

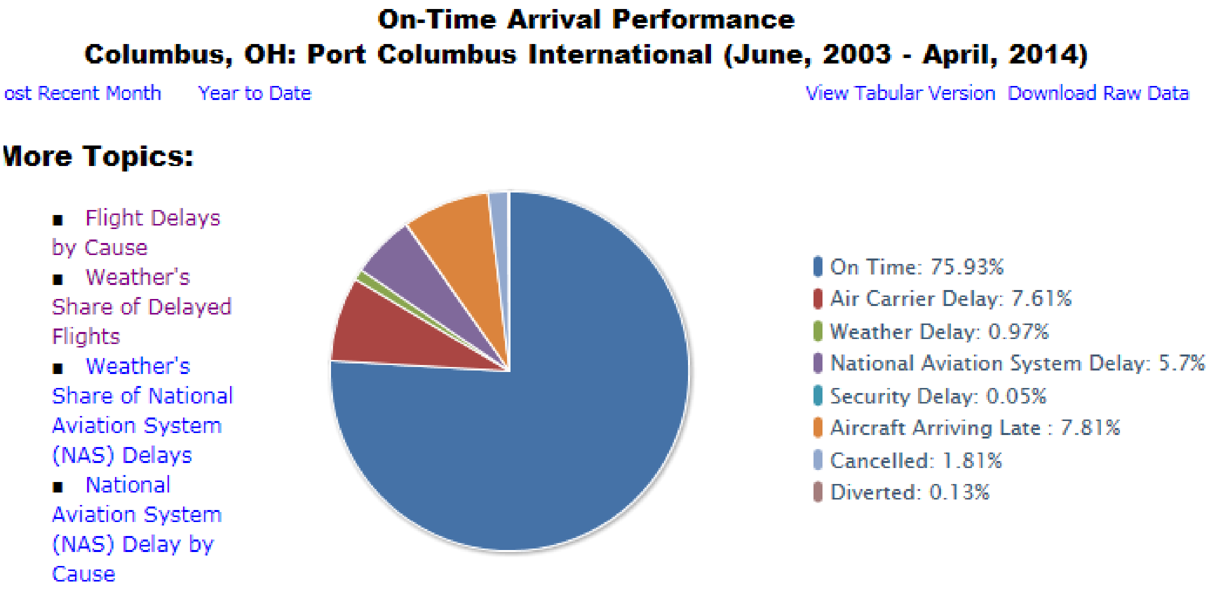
800 Gallons (per application) Potassium Acetate for 10L/28R

1000 Gallons (per application) Potassium Acetate for 10R/28L

*Solid deicer (Sodium Formate) applied primarily to runways, taxiways, and ramp taxilane

Delays

25. What is the average number of delays faced at the airport per year?



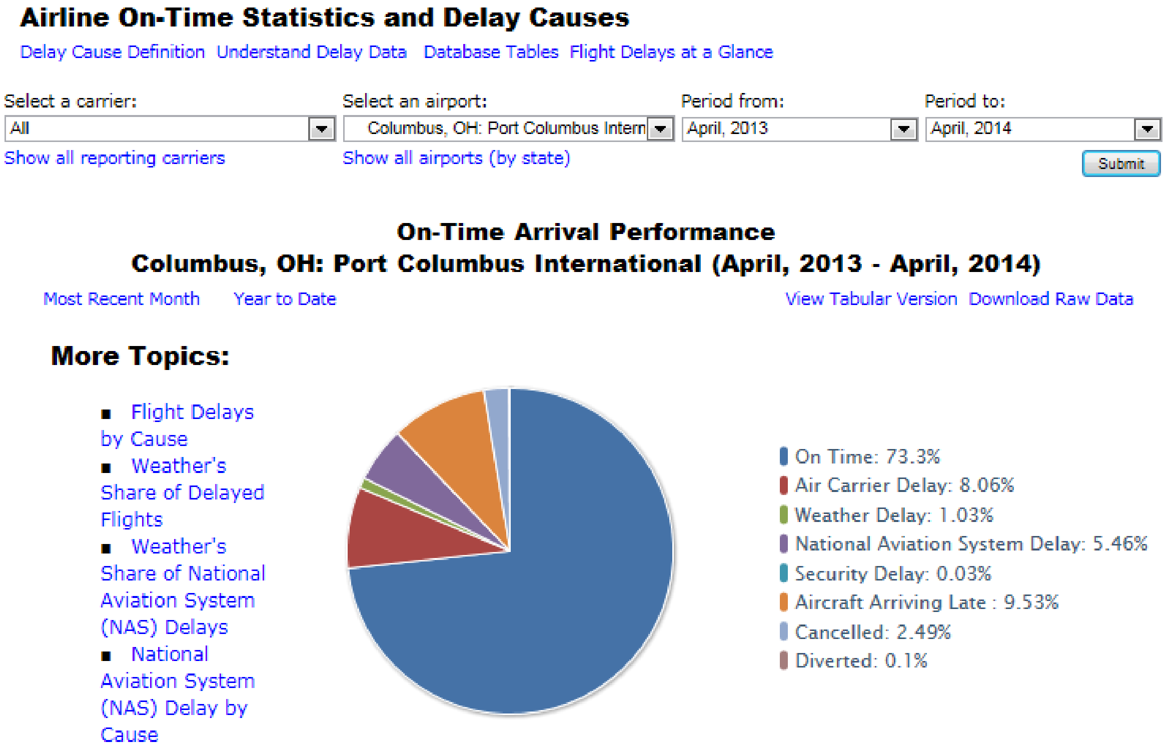
On-Time Arrival Performance
Columbus, OH: Port Columbus International (June, 2003 - April, 2014)

ost Recent Month   Year to Date   View Tabular Version Download Raw Data

Vlore Topics:

- Flight Delays by Cause
- Weather's Share of Delayed Flights
- Weather's Share of National Aviation System (NAS) Delays
- National Aviation System (NAS) Delay by Cause

▮ On Time: 75.93%
▮ Air Carrier Delay: 7.61%
▮ Weather Delay: 0.97%
▮ National Aviation System Delay: 5.7%
▮ Security Delay: 0.05%
▮ Aircraft Arriving Late : 7.81%
▮ Cancelled: 1.81%
▮ Diverted: 0.13%



Airline On-Time Statistics and Delay Causes

Delay Cause Definition Understand Delay Data Database Tables Flight Delays at a Glance

Select a carrier: All
Select an airport: Columbus, OH: Port Columbus Intern
Period from: April, 2013
Period to: April, 2014

Show all reporting carriers   Show all airports (by state)

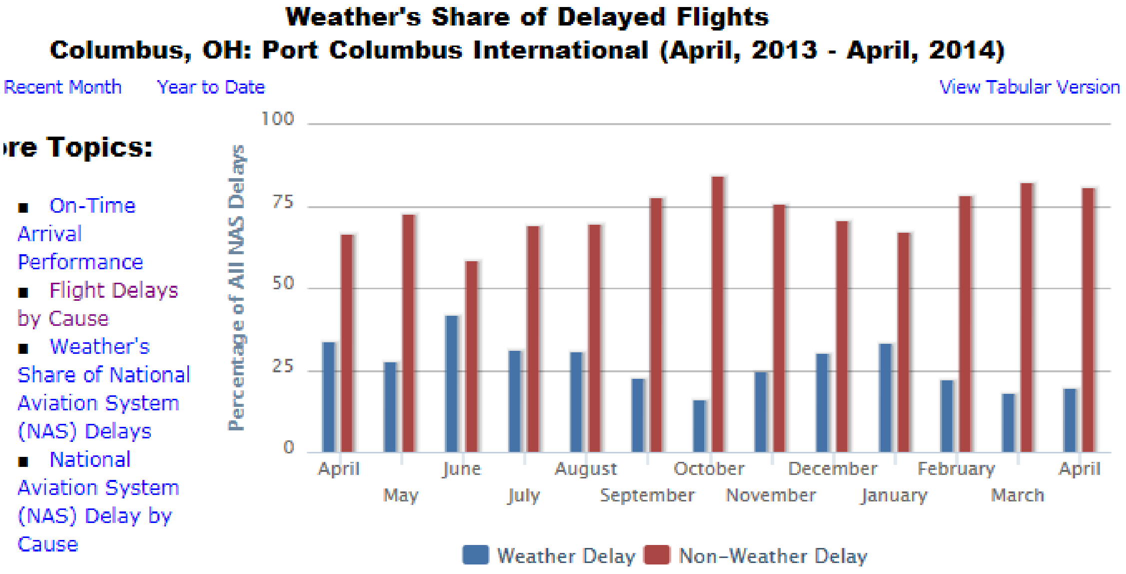
On-Time Arrival Performance
Columbus, OH: Port Columbus International (April, 2013 - April, 2014)

Most Recent Month   Year to Date   View Tabular Version Download Raw Data

More Topics:

- Flight Delays by Cause
- Weather's Share of Delayed Flights
- Weather's Share of National Aviation System (NAS) Delays
- National Aviation System (NAS) Delay by Cause

▮ On Time: 73.3%
▮ Air Carrier Delay: 8.06%
▮ Weather Delay: 1.03%
▮ National Aviation System Delay: 5.46%
▮ Security Delay: 0.03%
▮ Aircraft Arriving Late : 9.53%
▮ Cancelled: 2.49%
▮ Diverted: 0.1%



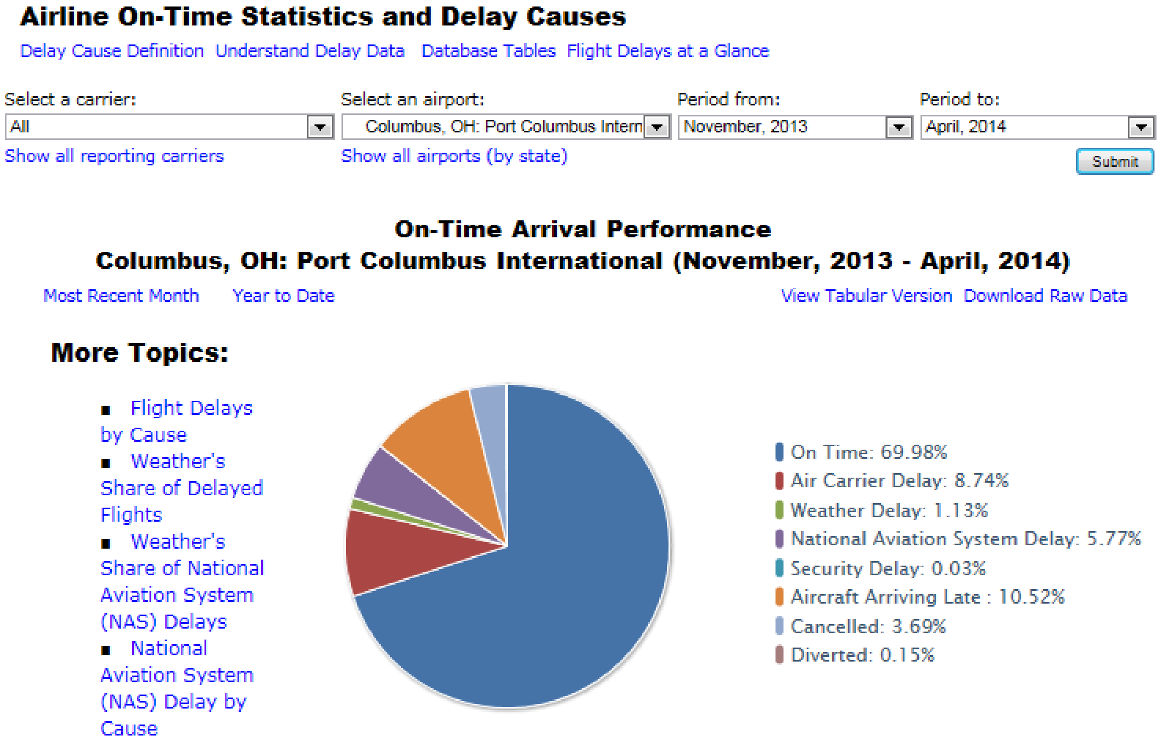
Weather's Share of Delayed Flights
Columbus, OH: Port Columbus International (April, 2013 - April, 2014)

Recent Month Year to Date View Tabular Version

re Topics:

- On-Time Arrival Performance
- Flight Delays by Cause
- Weather's Share of National Aviation System (NAS) Delays
- National Aviation System (NAS) Delay by Cause

26. What percentage of outbound flights out of the total operations are delayed and cancelled during the winter months?



Airline On-Time Statistics and Delay Causes

Delay Cause Definition Understand Delay Data Database Tables Flight Delays at a Glance

Select a carrier: All
Show all reporting carriers
Select an airport: Columbus, OH: Port Columbus Intern
Show all airports (by state)
Period from: November, 2013
Period to: April, 2014

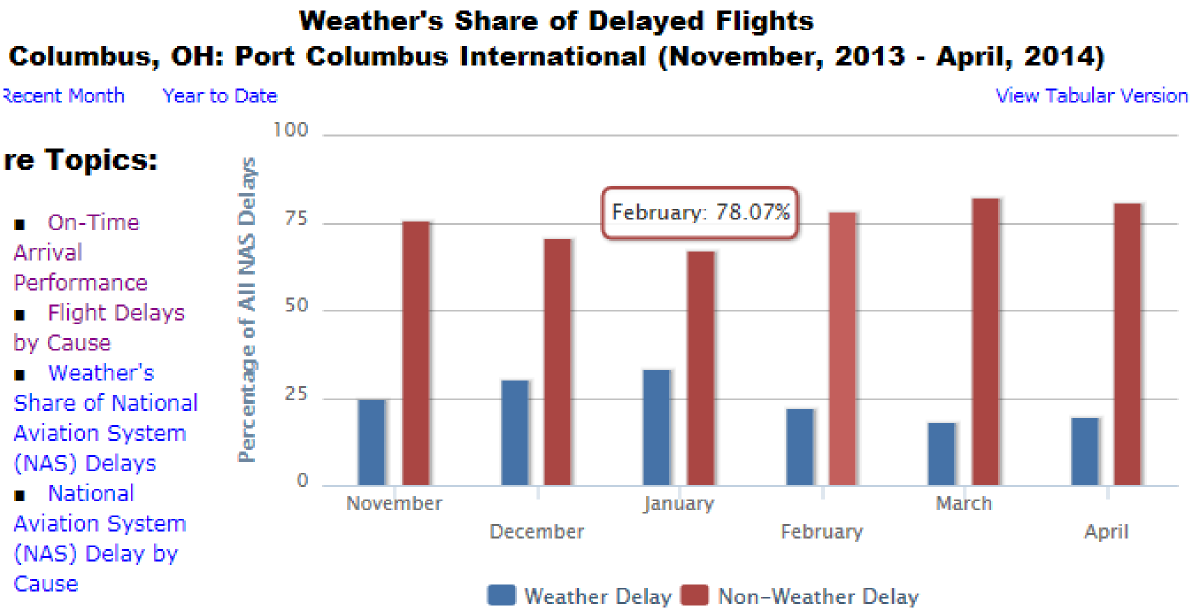
On-Time Arrival Performance
Columbus, OH: Port Columbus International (November, 2013 - April, 2014)

Most Recent Month Year to Date View Tabular Version Download Raw Data

More Topics:

- Flight Delays by Cause
- Weather's Share of Delayed Flights
- Weather's Share of National Aviation System (NAS) Delays
- National Aviation System (NAS) Delay by Cause

On Time: 69.98%
Air Carrier Delay: 8.74%
Weather Delay: 1.13%
National Aviation System Delay: 5.77%
Security Delay: 0.03%
Aircraft Arriving Late : 10.52%
Cancelled: 3.69%
Diverted: 0.15%



Weather's Share of Delayed Flights

Columbus, OH: Port Columbus International (November, 2013 - April, 2014)

27. Could you categorize and provide an approximate percentage of the number of outbound flights being delayed due to each of the causes like runway closure, heavy winds, low visibility or any other cause?

UNKNOWN

28. Could you give an approximate value as to how much these delays (closing of runways due to extreme snow) would cost you per annum?

UNKNOWN

29. How does severe weather affect cargo operations at your airport? Could you give an approximate value as to how much cargo delays (due to extreme snow) would cost you per annum?

***Cargo operations are primarily PAX airliners carrying cargo aboard on normally scheduled flights**

Safety issues

30.

a. Any accidents or fatalities caused to the personnel aiding in snow removal and cargo handling by exposure to winter weather conditions and snow removal operations?

No response

b. Are there any known costs related to work related accidents? Who is responsible for it? What is the airport policy to deal with such accidents?

No response

c. Any aircraft accidents reported in the last 20 years due to icy pavements?

Yes: 2008 - Aircraft slid off Runway 10L on arrival

d. If yes, how severe was the accident? How much was the cost of repair or compensation and who was responsible for paying for it?

Minimal damage occurred

Heating facility

31. Is the airport currently using a geothermal or hydronic heating system to heat pavements, terminal building or parking area to clear ice/snow (could also you provide the name of the construction contractor)?

TWY H has some portion of the infrastructure necessary to pump heated glycol under the surface. This system has not been utilized and may be incomplete.

32. If yes, what are the installation and operation costs?

UNKNOWN

33. What is the capacity of the system?

UNKNOWN

34. What is the energy demand per hour?

UNKNOWN

Des Moines International Airport (DSM), IA

A. What is the number of flight operations per day?
   a. Approximately 220 total operations per day
   b. Approximately 120 airline operations per day

B. What is the current state of snow and ice removal practice?
   a. The airport currently uses displacement plows and rotary blowers are used to throw the snow over the lights to eliminate issues with windrows that can impede aircraft operations.
   b. The airport uses approved airside chemicals, both solid and liquid, for anti-ice and deice operations. Additionally, the airport will use sand to improve braking

action.

c. Airfield Snow Removal Equipment
    i. 9 Displacement Plows
    ii. 6 Rotary Brooms
    iii. 3 Blowers
    iv. 2 Loaders with ramp blades
    v. 1 Sprayer/Sander Truck
    vi. 1 Deicer Truck

d. Staffing
    i. 21 Airfield Equipment Operators
    ii. 7 Personnel responsible for condition reporting and coordination of the snow removal operation

C. Issues encountered in the current state of practice.

a. Due to the airport configuration combined with staffing and equipment limitations, the airport is only able to keep one runway open during winter weather events.

b. The longer it takes to clear the runway the less time the runway is available for arrivals and departures.

c. The cost of airside deicing chemicals is extremely high which requires precise timing of application to maximize their effectiveness.

d. The holdover time of airside approved chemicals can be very short, which requires reapplication. This requires constant monitoring by airport staff and also reduces the time that the runway is available for aircraft operations.

e. The measurement of the friction coefficient does not necessarily correlate to pilot reports of braking action. When the friction coefficient drops below a specified level the runway must be closed to aircraft operations.

D. What is the estimated cost per area ~~(ft^2)~~ to clean snow and ice in winter season?

i. Estimated equipment operation cost

$180,000 Fuel

Equipment Depreciation - % of total $10,000,000

ii. Estimated labor cost

$300,000 wages, salaries, benefits

iii. Estimated deicing agents cost

$250,000

iv. Amount of deicing agents used ~~per ft^2~~

115 Ton NAFF

10,000 gallons of RF-11

80 ton FAA Spec Sand

v. Brand of deicing agent used

RF-11 Chors Alpine Solution

New Deal NAFF (Sodium Formula-acetate bled)

E. If using a radiant snowmelt system; n/a

i. What are the installation and operation costs?
ii. Hassles in operation?
iii. Are they energy efficient?

F. What is the estimated maintenance cost for snow and ice removal in winter season?

i. Estimated equipment maintenance cost

$100,000 R&M

ii. Estimated labor cost

$60,000

iii. Any other costs related to maintenance

$3,000 per month building utilities

G. Any plans to extend repair or renovate the existing runways in the next ten years?

In CY 2014 we will be performing an Engineering Analysis on our 9,000 ft Runway 1331 to determine if a rehabilitation or full reconstruction is required. Plans are to phase in the construction in 3 consecutive years, from 2015 to 2017.

H. Documentation available on the extent of damage caused by snow or snow removal operations?

We plan within our normal budget to perform misc pavement maintenance each year. This budget ranges from $300,000 to $500,000/year.

I. Average number of flight cancellations or delays per day during the winter events?

  a. It is rare that a flight is cancelled or delayed by snow removal operations in Des Moines. Most aircraft departing Des Moines are flying to a large hub airport such as Chicago, Denver, Minneapolis, Detroit, etc. It is likely that the delay or cancellation is caused by weather at the destination airport.

J. Any accidents or fatalities caused by winter weather conditions and snow removal operations. None

K. Whether they are interested in being a part of the FAA funded research? Yes

Kent State University Airport (1G3), OH

General Operations

1. What is the number of enplanements in a year?
   - Zero; KSU Airport is a GA facility used primarily for flight training operations.
2. Could you give the number of enplanements for different airlines using your airport? Do any of these airlines avoid using your airport in the winter months?
   - Kent State University Airport does not provide air carrier service.
3. What is the annual cargo handling capacity?
   - Kent State University Airport is not equipped to support cargo operations.
4. How many operational runways does the airport have?
   - One: Runway 1/19

5. How many runways are open during snow storms? How does this effect on-time performance & schedules?
    - 1G3 maintains operational use of our single runway during all storm events.
    - Our primary tenant, the Kent State University's Aeronautics program, has a 30 aircraft fleet that cycles every 90 minutes. Delays caused by storm events or snow removal operations have a compounding effect. If the first few flight periods are delayed, the program is forced to maintain that delay for the duration of the day. This conflicts with regularly scheduled courses that are inflexible. Students either miss their flight period to go to traditional classroom courses or vice versa.
6. In case a flight is delayed or cancelled due to weather related events, would the airport cover any (or all) of the airline (aircraft) expenses related to the delay?
    - No
7. Do you have any plans to extend, repair or renovate the existing runways in the next few years?
    - Consistent with our pavement maintenance plan, all airport surfaces will need to be rehabilitated within the next five to ten years. Despite significant preventative maintenance, we are at the end of the useful life of our flexible asphalt surfaces which were previously rehabilitated in 1999.

Pavement De-icing

1. What is the time taken to clear a primary taxiway and ramp area?
    a. All surfaces, including the runway, are regularly cleared from an initial snow event with1" precipitation in approximately 90 minutes.

2. What is the extent of damage on the pavements caused by snow removal operations? How much do you spend on pavement maintenance annually?
    a. In the last four fiscal years, we have spent on average approximately $16,000/ year on sealcoating, crack sealing, and markings.
3. What type of pavement de-icers do you use?
    a. We do not use chemical pavement de-icers. We have mechanical de-icers if necessary and rely on our displacement blades to remove as much material as possible.

Pavement Area

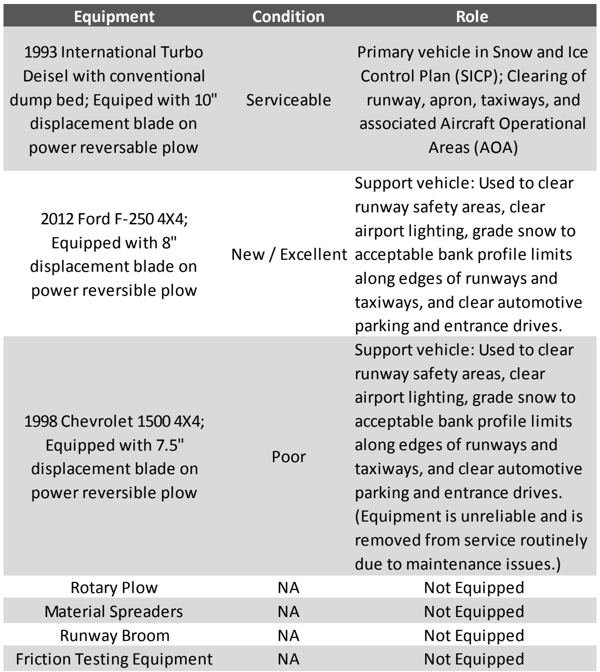
1. What is the area of the primary taxiway and ramp?
    a. Primary taxiway and ramp only: 348,000 square feet.
2. What is the total are of the paved surfaces at the airport?
    a. Total of all airside improved surfaces: 641,680 square feet.
3. What is the total area of the paved surfaces typically de-iced during winter operations?
    a. All airside surfaces: 641,680 square feet.

Equipment required for clearing snow

1. What is the current state of snow and ice removal practice?
    a. We are in the process of turning over our SRE. We are currently equipped with two medium displacement blades, one large high speed displacement blade, a 3 yard front end loader, and two open cab tractors. Outside contractors are available

if necessary. We are currently adding a New Holland TV6070 with a full SRE package. (blower, displacement blade, bucket, air blower, runway broom)

2. What are the issues encountered in the current state of practice?
    a. Damage to airport lighting fixtures, inability to clear all surfaces down to bare pavement, and clearing RSAs to appropriate grade.
3. Typically what is the number of equipment required to clear a primary taxiway, ramp area, and the entire paved surfaces?
    a. All equipment is deployed to clear surfaces simultaneously with exception to the front end loader which is only deployed as required to clear the RSAs.
    b.



Equipment	Condition	Role
1993 International Turbo Deisel with conventional dump bed; Equiped with 10" displacement blade on power reversable plow	Serviceable	Primary vehicle in Snow and Ice Control Plan (SICP); Clearing of runway, apron, taxiways, and associated Aircraft Operational Areas (AOA)
2012 Ford F-250 4X4; Equipped with 8" displacement blade on power reversible plow	New / Excellent	Support vehicle: Used to clear runway safety areas, clear airport lighting, grade snow to acceptable bank profile limits along edges of runways and taxiways, and clear automotive parking and entrance drives.
1998 Chevrolet 1500 4X4; Equipped with 7.5" displacement blade on power reversible plow	Poor	Support vehicle: Used to clear runway safety areas, clear airport lighting, grade snow to acceptable bank profile limits along edges of runways and taxiways, and clear automotive parking and entrance drives. (Equipment is unreliable and is removed from service routinely due to maintenance issues.)
Rotary Plow	NA	Not Equipped
Material Spreaders	NA	Not Equipped
Runway Broom	NA	Not Equipped
Friction Testing Equipment	NA	Not Equipped

Initial Cost

1. What was the construction cost of the primary taxiway and ramp and in what year was the construction?
    a. All surfaces were rehabbed in 1999 at a total project cost of $643,500.00

2. What was the initial cost incurred on the purchase of the snow removal equipment?
    a. The TV6070 is the only dedicated FAA funded SRE equipment. All other equipment has dual roles. The TV6070 has a local match of approximately $26,000.
3. What is the time period after which you replace equipment with new ones?
    a. We anticipate a 10-15 year service life with the TV6070.

Recurring costs

1. What is the annual maintenance cost of the snow removal equipment ?
    a. N/A
2. How much is the fuel cost spend on running the snow removal equipment to clear the airport?
    a. For a storm event which requires continual clearing, we budget 40 gallons of diesel and 35 gallons of auto for an 8 hour period.
3. How many personnel are required to aid in clearing?
    a. Three equipment operators and two general laborers are required to clear the field during a storm event.
4. What are the labor rates for equipment operators.
    a. We have student equipment and labor which runs $9.50/ hour and $8.50/hour respectively.
5. What is the application rate of dicers?
    a. N/A
6. What is the quantity of de-icing agents required to clear?

    a. N/A

Delays

1. What is the average number of delays per year?
    a. N/A
2. What percentage of outbound flights out of the total operations are delayed or canceled during the winter months?
    a. N/A
3. Could you categorize delays?
    a. N/A
4. Cancelation Costs?
    a. N/A
5. How does sever weather affect cargo operations?
    a. N/A

Safety Issues

1. Any accidents or fatalities caused to by exposure?
    a. No
2. Are there any known costs related to work related accidents?
    a. No
3. Any aircraft accidents reported in the last 20 years due to icy pavement?
    a. No
4. If yes…
    a. N/A

Heading facility

1. Is the airport currently using geothermal or hydroninc heating systems to heat pavement?
    a. No
2. If yes..
    a. N/A
3. What is the capacity of the system
    a. N/A
4. What is the energy demand of the system per hour?
    a. N/A

Mason City Municipal Airport (MCW), IA

General Operations

1. What is the number of enplanements in a year?

Avg 10,000 -12,000, Last year was 3,600 due to airline issues.

2. Could you give the number of enplanements for different airlines using your airport? Do any of these airlines avoid using your airport in the winter months?

We only ever have one airline. No airline avoids our airport during winter, but we were designated a Special Winter Operations airport by Delta.

3. What is the annual cargo handling capacity?

None.

4. How many operational runways does the airport have?

Two.

5. How many runways are open during snow storms? How does this effect on-time performance & schedules?

One. We have a low volume of aircraft operations and coordinate snow removal around any operations.

6. In case a flight is delayed or cancelled due to weather related events, would the airport cover any (or all) of the airline (aircraft) expenses related to the delay (such as cost of fuel, cost of crew, compensation to passengers)? If yes, how much and in what form?

No.

7. Do you have any plans to extend, repair or renovate the existing runways in the next few years?

No.

Pavement De-icing

1. What is the time taken to clear a primary taxiway and ramp area?

One hour.

2. What is the extent of damage on the pavements caused by snow or snow removal operations? How much do you spend on pavement maintenance annually?

Minimal.

3. What types of pavement de-icers do you use?

Sand only.

Pavement area

1. What is the area of the primary taxiway and ramp?

1.8 million Sq Ft

2. What is the total area of the paved surfaces at the airport?

3.0 million Sq Ft (estimated)

3. What is the total area of the paved surfaces typically de-iced during winter operations?

None

Equipment required for clearing snow

1. What is the current state of snow and ice removal practice?

Do not understand the question.

2. What are the issues encountered in the current state of practice?

Minimal staffing available during snow removal.

3. Typically what is the number of equipment required to clear a primary taxiway, ramp area and the entire paved surface, respectively, when an average snow fall of 10 inches per day occurs? Could you also please name them?

1 Broom or plow clearing the primary runway and taxiway areas, 1 loader with plow clearing ramps and landside areas. Additional staff in a snowblower may assist when needed with larger snowfalls.

Initial costs

1. What was the construction cost of the primary taxiway and ramp and in what was the construction year?

$2 million in 2005.

2. What was the initial cost incurred on the purchase of the snow removal equipment (and the purchase year)? Could you please specify the cost of each equipment separately?

Latest snow plow/broom purchased in 2013 for $410,000.

3. Generally, what is the time period after which you replace the equipment with new ones?

20 years.

Recurring costs

1. What is the annual maintenance cost of the snow removal equipment? Could you please specify it as a percentage relative to the initial cost of equipment?

Unknown

2. How much is the fuel cost spent on running the snow removal equipment to clear a primary taxiway and ramp area and in total for the entire airport?

$10,000 estimated

3. How many personnel are required to aid in clearing a primary taxiway and ramp area and in total for the entire airport?

2

4. What is the labor rate (per hour per person) to run these equipment that aid in snow removal operations?

$14-20 per hour, plus possible overtime.

5. What is the application rate of the de-icers you use?

N/A

6. What is the quantity of de-icing agents required to clear the primary taxiway, ramp and the entire paved surface? How much do you spend on these approximately?

N/A

Delays

1. What is the average number of delays faced at the airport per year?

Unknown, we do not track

2. What percentage of outbound flights out of the total operations are delayed and cancelled during the winter months?

Unknown, we do not track

3. Could you categorize and provide an approximate percentage of the number of outbound flights being delayed due to each of the causes like runway closure, heavy winds, low visibility or any other cause?

Unknown, we do not track

4. Could you give an approximate value as to how much these delays (closing of runways due to extreme snow) would cost you per annum?

Unknown, we do not track

5. How does severe weather affect cargo operations at your airport? Could you give an approximate value as to how much cargo delays (due to extreme snow) would cost you per annum?

Not applicable, we do not have cargo operations.

Safety issues

1. Any accidents or fatalities caused to the personnel aiding in snow removal and cargo handling by exposure to winter weather conditions and snow removal operations?

None

2. Are there any known costs related to work related accidents? Who is responsible for it? What is the airport policy to deal with such accidents?

All accidents dealt with through normal work comp or insurance policies.

3. Any aircraft accidents reported in the last 20 years due to icy pavements?

None.

4. If yes, how severe was the accident? How much was the cost of repair or compensation and who was responsible for paying for it?

Heating facility

1. Is the airport currently using a geothermal or hydronic heating system to heat pavements, terminal building or parking area to clear ice/snow?

No.

APPENDIX G – SPREADSHEET TOOL USERMANUAL

1. INTRODUCTION

Common practices for removing ice and snow from transportation infrastructure surfaces include spraying large quantities of anti-ice chemicals on the ground and deploying a great number of snowplowing vehicles. However, these methods are labor intensive and have environmental concerns with possible contamination of nearby water bodies for highway and airport pavements. Heated pavement systems have gained attention as desirable alternatives to current ice and snow removal practices, and make practical and economic sense for airport pavements frequently impacted by snow/ice during winter months.

Alternate snow removal strategies like heated pavement systems (HPS) may have the potential to keep airports operational during severe winter months. The estimation of potential costs and benefits related to this alternative snow removal method have been discussed in the final report. This work focusses on the description and documentation of an economic analysis tool that was developed specifically to serve as a guide to airports. Ideally, the airports can use this tool for examining the feasibility of heated pavements for application on any paved areas of the airport (not only in the aprons). This tool can be used for both, commercial and general aviation airports. The developed spreadsheet tool can be tailored according to the needs of the airports by using data specific to their airport. As an example, values for Minneapolis-St. Paul International Airport, Minnesota have been fed into the tool. These can be easily changed depending on the airport's needs.

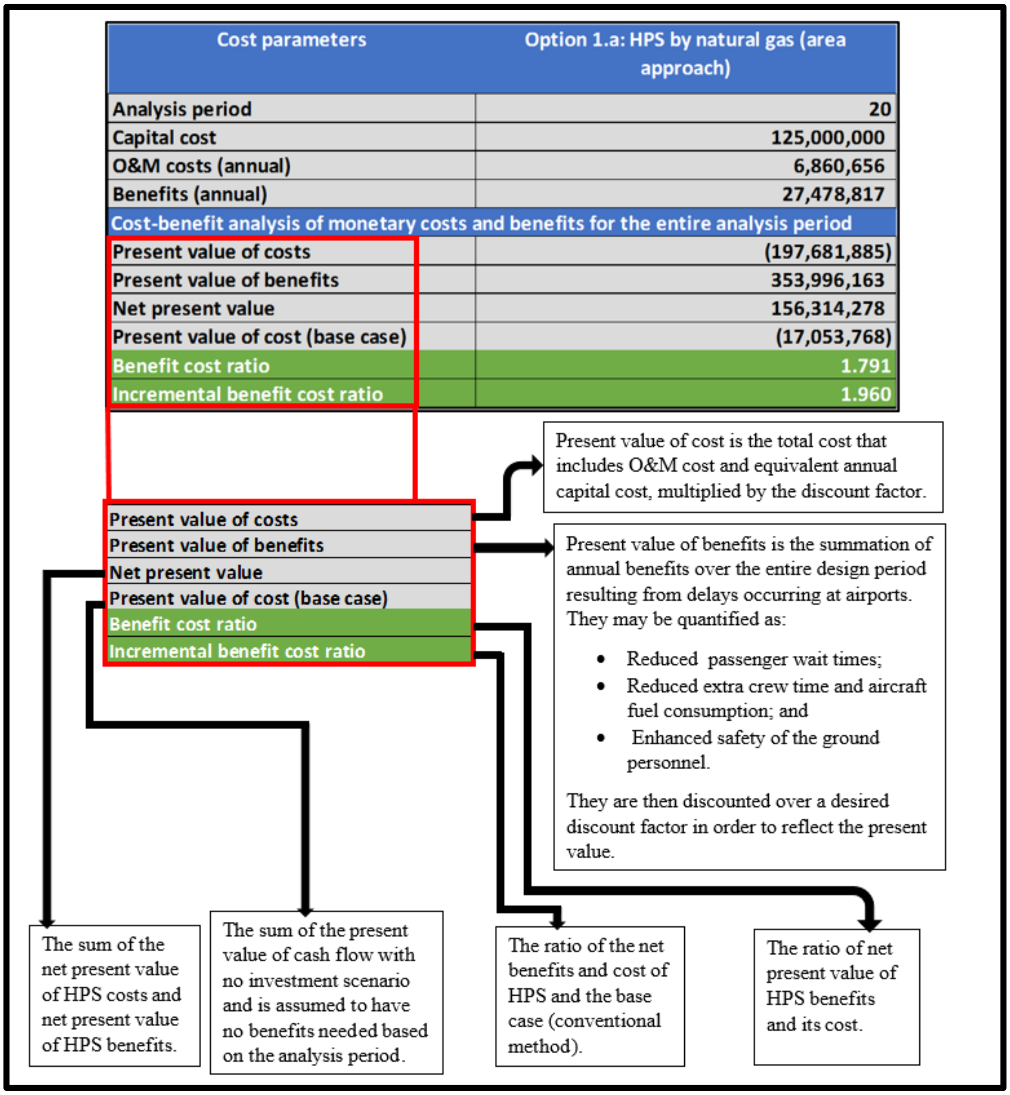
This tool is user friendly and has been modified so that any airport can use it to calculate their benefit cost ratio based on the system they want to deploy. This tool also allows the airport to predict the future cost associated with the implementation of such strategies by varying factors that might cause uncertainties.

2. SPREADSHEET 1 -SUMMARY

The summary Sheet is the first Sheet of the economic analysis tool. It consists of two main tables. The first table is shown in Figure 1 and the second table is shown in Figure 2.

The condensed results of the analysis are shown in Figure 1. It presents the capital cost required to install HPS for a given area and the summed value of annual costs and benefits incurred with the use of HPS. It then compares the net benefit and cost for a period of 20 years to show the benefit cost ratio (BCR). A comparison is also drawn between HPS and conventional methods by means of an incremental BCR. The definitions and equations to calculate BCRs can be found in the report.

If any input value changes in Figure 2, the new results are reflected in Figure 1. The purpose of benefit-cost analysis is to compare the benefits and costs associated with a policy or investment and is generally used for a public project. If the ratio of the sum of the net benefits of a project or policy and the costs exceed 1, then the project is deemed feasible. The value of the analysis period for analyzing benefits of HPS can be changed. In this chart, the analysis period is 20 years. The discount factor is also listed and 7% is used as a base value to analyze the Net Present Value (NPV).



Cost parameters	Option 1.a: HPS by natural gas (area approach)
Analysis period	20
Capital cost	125,000,000
O&M costs (annual)	6,860,656
Benefits (annual)	27,478,817
Cost-benefit analysis of monetary costs and benefits for the entire analysis period	
Present value of costs	(197,681,885)
Present value of benefits	353,996,163
Net present value	156,314,278
Present value of cost (base case)	(17,053,768)
Benefit cost ratio	1.791
Incremental benefit cost ratio	1.960

Present value of cost is the total cost that includes O&M cost and equivalent annual capital cost, multiplied by the discount factor.

Present value of benefits is the summation of annual benefits over the entire design period resulting from delays occurring at airports. They may be quantified as:

- Reduced passenger wait times;
- Reduced extra crew time and aircraft fuel consumption; and
- Enhanced safety of the ground personnel.

They are then discounted over a desired discount factor in order to reflect the present value.

The sum of the net present value of HPS costs and net present value of HPS benefits.

The sum of the present value of cash flow with no investment scenario and is assumed to have no benefits needed based on the analysis period.

The ratio of the net benefits and cost of HPS and the base case (conventional method).

The ratio of net present value of HPS benefits and its cost.

Figure 36. Screen-shot of summary table taken from Sheet 1 “Summary” of the tool

2.1 Basic input parameters

The input values that are red in color in Figure 2 are the values that may be changed specific to each airport. The feasibility results shown in Figure 1 will be updated automatically once any changes are made. However the values that are in black are suggested values which may or may not be changed depending upon the airport. They are flexible and act as a reference. The numbers that are in purple are fixed values. Lastly, the numbers that are in blue depict the calculation after the input values (red color) are keyed in. The various input values have been discussed below.

2.1.1 Common Input Values

These include the basic values that are used to carry out the economic analysis such as analysis period, discount factor and area of HPS installation.

2.1.2 Cost of Conventional Methods

Conventional snow removal methods consists of both mechanical and chemical methods. The cost of the conventional methods includes:

- Cost of snow removal equipment,
- Deicing agents,
- Labor cost per hour, and
- Fuel cost for snow removal equipment

Note that the costs of equipment cannot be changed through Figure 2 but it may be changed using Sheet 3 – “Cost of conventional methods”. This was done to facilitate ease of use of the spreadsheet as the purchasing cost of equipment will not vary a lot at different airports.

2.1.3 HPS Indirect Benefits

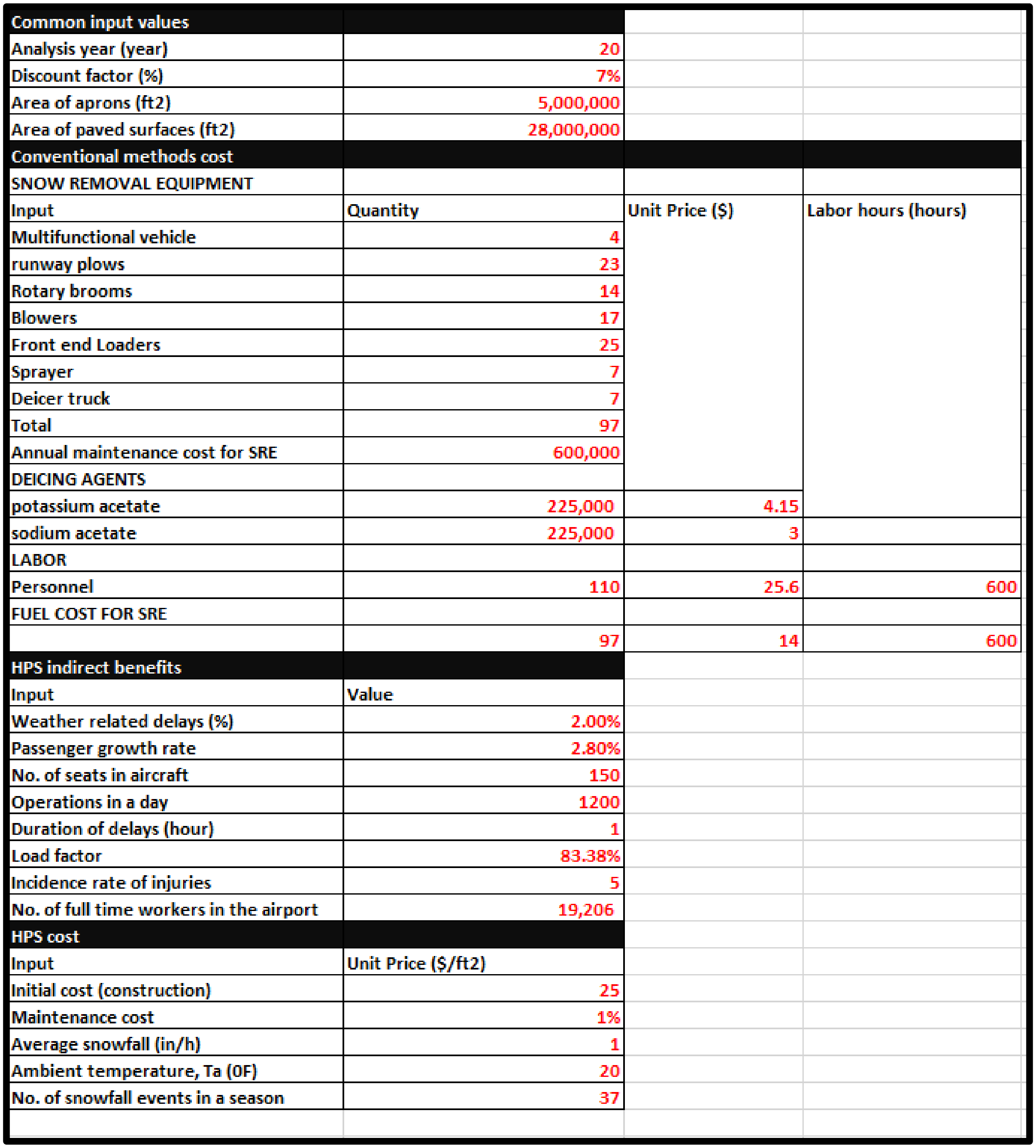
Indirect benefits for heated pavement system (HPS) are the costs that are not directly accountable to a cost object and can be either fixed or variable. The inputs are:

- Duration of delayed flights,
- Number of seats in the aircraft, and
- Number of operations per day

- Load factor
- Injury data

2.1.4 HPS Cost

Heated pavement system costs includes the initial construction cost and the operating & maintenance cost.



Common input values			
Analysis year (year)	20		
Discount factor (%)	7%		
Area of aprons (ft2)	5,000,000		
Area of paved surfaces (ft2)	28,000,000		
Conventional methods cost			
SNOW REMOVAL EQUIPMENT			
Input	Quantity	Unit Price ($)	Labor hours (hours)
Multifunctional vehicle	4		
runway plows	23		
Rotary brooms	14		
Blowers	17		
Front end Loaders	25		
Sprayer	7		
Deicer truck	7		
Total	97		
Annual maintenance cost for SRE	600,000		
DEICING AGENTS			
potassium acetate	225,000	4.15	
sodium acetate	225,000	3	
LABOR			
Personnel	110	25.6	600
FUEL COST FOR SRE			
	97	14	600
HPS indirect benefits			
Input	Value		
Weather related delays (%)	2.00%		
Passenger growth rate	2.80%		
No. of seats in aircraft	150		
Operations in a day	1200		
Duration of delays (hour)	1		
Load factor	83.38%		
Incidence rate of injuries	5		
No. of full time workers in the airport	19,206		
HPS cost			
Input	Unit Price ($/ft2)		
Initial cost (construction)	25		
Maintenance cost	1%		
Average snowfall (in/h)	1		
Ambient temperature, Ta (0F)	20		
No. of snowfall events in a season	37		

Figure 37. Screen-shot of the basic input parameters taken from Sheet 1 “Summary” from the tool

3. SPREADSheet 2 - HPS indirect benefits

This section deals with the estimation of benefits related to the installation of HPS. The benefits are due to passenger time savings, reduced fuel wastage and loss of crew time, and enhanced safety of ground staff.

3.1 VALUE OF LOST PASSENGER TIME

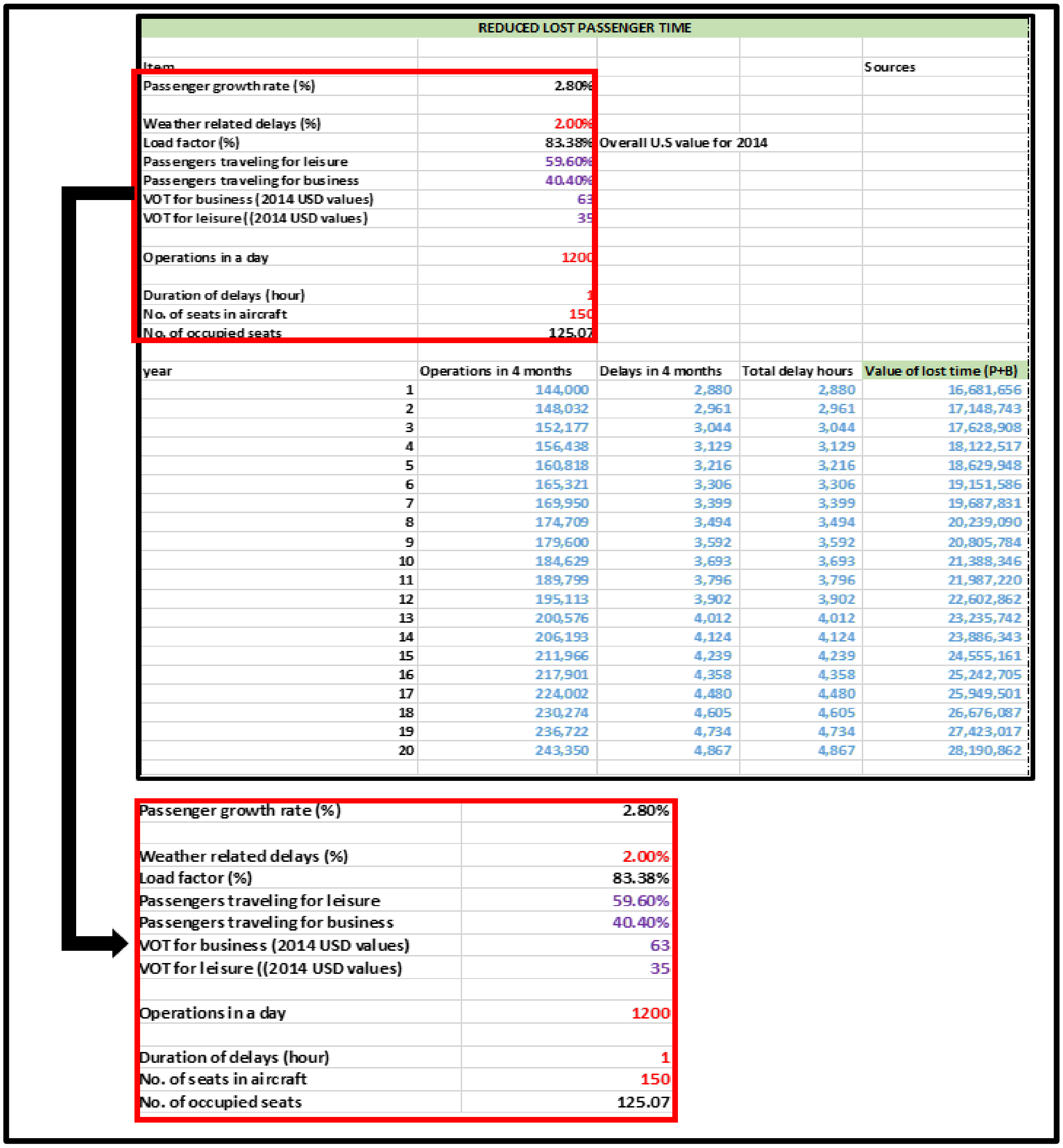
The following are the steps to calculate the value of lost passenger time:

- Determine the seasonal percentage of delays.
- The percentage of weather related delays is assumed to be 2% of total number of operations.
- Four months (Nov-Feb) in a year are considered.
- By knowing the daily number of operations, operations for four months was calculated.
- The value of time (VOT) for passengers travelling for business is $63/h and for passengers travelling on leisure is $35/h.
- 40.40% of the total passengers fly for business purposes and 59.60% are leisure travelers.
- Total number of seats in a mid-sized aircraft is about 150 and the average overall load factor for domestic flights was 83.38%.
- By multiplying the number of seats in aircraft with the average load factor, the number of occupied seats was determined.
- By multiplying the total number of passengers (each case) by the value of time and the number of delays in four months, the value of lost time can be found.

The above steps may be summarized my means of the following Equations 1 and 2, and can be seen in Figure 3.

Total delay hours in a season = No. of daily operations ×30 (days) × 4 (months) × 2% of snow related delays × Passenger growth rate × Average duration of one delay (hours) (1)

Annual monetary value of lost passenger time = (Total no. of seats in an aircraft × Load factor × Total delay hours in a season) × [(Percentage of passengers traveling for leisure × VOT for leisure) + (Percentage of passengers traveling for business × VOT for business)] (2)



REDUCED LOST PASSENGER TIME

Item				Sources
Passenger growth rate (%)	2.80%			
Weather related delays (%)	2.00%			
Load factor (%)	83.38%	Overall U.S value for 2014		
Passengers traveling for leisure	59.60%			
Passengers traveling for business	40.40%			
VOT for business (2014 USD values)	63			
VOT for leisure ((2014 USD values)	35			
Operations in a day	1200			
Duration of delays (hour)	1			
No. of seats in aircraft	150			
No. of occupied seats	125.07			

year	Operations in 4 months	Delays in 4 months	Total delay hours	Value of lost time (P+B)
1	144,000	2,880	2,880	16,681,656
2	148,032	2,961	2,961	17,148,743
3	152,177	3,044	3,044	17,628,908
4	156,438	3,129	3,129	18,122,517
5	160,818	3,216	3,216	18,629,948
6	165,321	3,306	3,306	19,151,586
7	169,950	3,399	3,399	19,687,831
8	174,709	3,494	3,494	20,239,090
9	179,600	3,592	3,592	20,805,784
10	184,629	3,693	3,693	21,388,346
11	189,799	3,796	3,796	21,987,220
12	195,113	3,902	3,902	22,602,862
13	200,576	4,012	4,012	23,235,742
14	206,193	4,124	4,124	23,886,343
15	211,966	4,239	4,239	24,555,161
16	217,901	4,358	4,358	25,242,705
17	224,002	4,480	4,480	25,949,501
18	230,274	4,605	4,605	26,676,087
19	236,722	4,734	4,734	27,423,017
20	243,350	4,867	4,867	28,190,862

Passenger growth rate (%)	2.80%
Weather related delays (%)	2.00%
Load factor (%)	83.38%
Passengers traveling for leisure	59.60%
Passengers traveling for business	40.40%
VOT for business (2014 USD values)	63
VOT for leisure ((2014 USD values)	35
Operations in a day	1200
Duration of delays (hour)	1
No. of seats in aircraft	150
No. of occupied seats	125.07

Figure 38. Screen-shot for calculating value of lost passenger time taken from Sheet 2 “HPS indirect benefits” of the tool

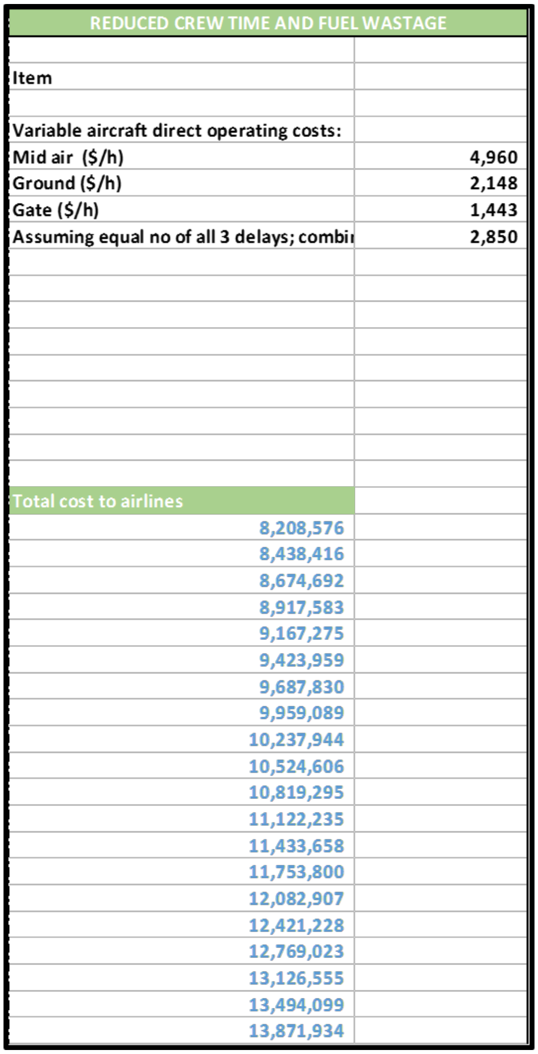
3.2 FUEL AND CREW COSTS

The cost of annual additional aircraft operating cost can be calculated using Equation 3 and is presented in Figure 4.

Annual additional aircraft operating cost due to delays=Total delay hours in a season × *Operating cost of aircrafts (mid, ground and gate delays)* (3)

Equation 3 is based on the following.

- Aircrafts can have delays in three possible ways: midair, gate and ground delays.
- The mid-air delays will have the most amount of fuel wastage while the others will draw only idling fuel wastages.
- Mid-air delays are assigned a value of $4,960/h, ground delays as $2,148/h and gate delays as $1,442/h according to the ACRP Report 123 “A Guidebook for Airport Winter Operations”.
- By assuming that all the delays were in an equal proportion, this gave an average value of $2,850/h suffered by airlines in weather delays.
- Annual (four concerned months) cost to airlines due to weather related delays can be computed by multiplying this value by the total number of operations in four months.



REDUCED CREW TIME AND FUEL WASTAGE	
Item	
Variable aircraft direct operating costs:	
Mid air ($/h)	4,960
Ground ($/h)	2,148
Gate ($/h)	1,443
Assuming equal no of all 3 delays; combi	2,850
Total cost to airlines	
8,208,576	
8,438,416	
8,674,692	
8,917,583	
9,167,275	
9,423,959	
9,687,830	
9,959,089	
10,237,944	
10,524,606	
10,819,295	
11,122,235	
11,433,658	
11,753,800	
12,082,907	
12,421,228	
12,769,023	
13,126,555	
13,494,099	
13,871,934	

Figure 39. Screen-shot for calculating fuel and crew costs taken from Sheet 2 “HPS indirect benefits” of the tool

3.3 ENHANCED SAFETY

Enhanced safety benefits are calculated based on the following.

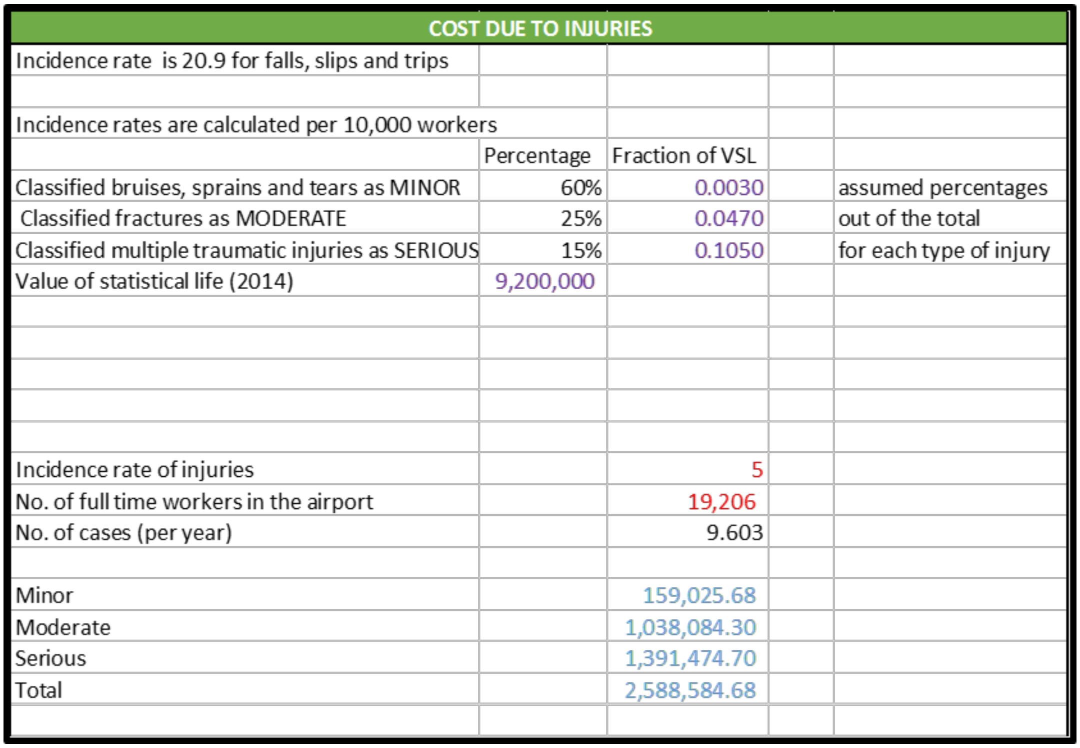
- Data for categorizing injuries for this level of detail is not available at the BLS. The available data as per the BLS report on occupational injuries has been made use of and certain assumptions have been established to quantify cost due to injuries.

- The ground staff may be employed by the airport or the airlines and they will be financially responsible for any injuries. It is assumed that slips and fall will not result in critical and un-survivable injuries and hence are not taken into consideration.
- Only three classes of injuries were assumed minor, moderate and serious.
- Bruises and strains were classified as minor, fractures as moderate and multiple traumatic injuries as serious.
- Minor injuries were assumed to have maximum cases and were assumed as 60% of total injuries. ‘Moderate’ were assumed as 25% and ‘Serious’ as 15%.
- Based on the above data, the injury costs were calculated by multiplying the percentage of each injury by its contributing fraction of the Value of Statistical Life VSL. The VSL is set as 9.2 million USD (2014 dollar value) (Trottenberg, P., & Rivkin, R. S. (2013). Guidance on treatment of the economic value of a statistical life in U.S. Department of Transportation analyses.). The summed value of all the injury cases for MSP for the concerned four months was calculated.

This can be better understood by means of Equation 4 and Figure 5.

Annual cost due to injuries =Percentage of a type of injury (minor, moderate, serious)

× *VSL* ×*Fraction of VSL for injury type* ×*Incidence rate* ×*No. of full time employees* (4)

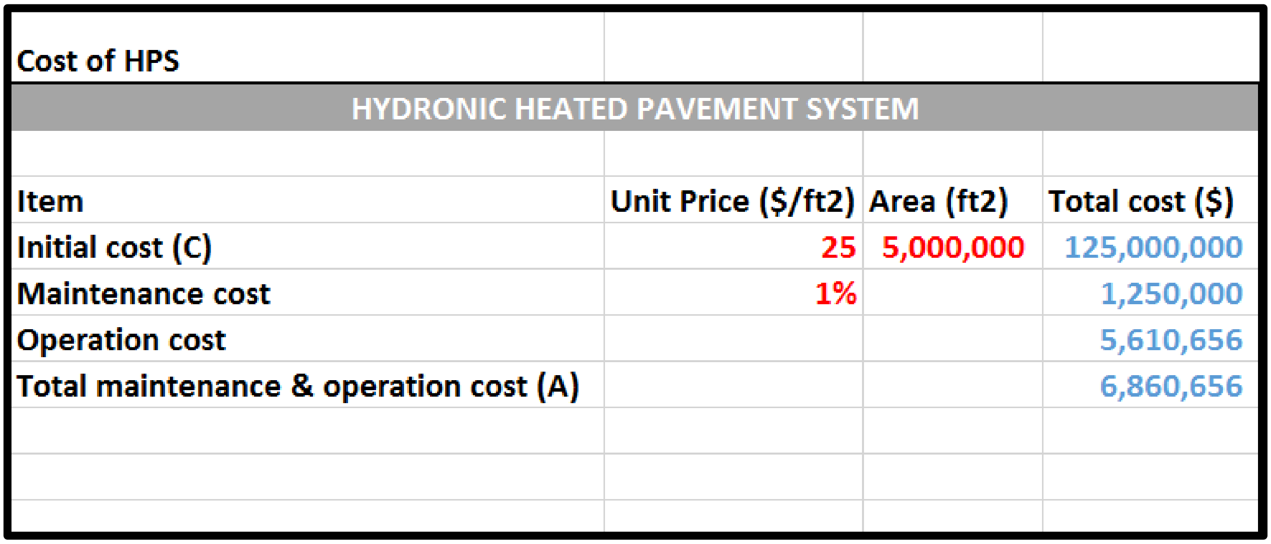


COST DUE TO INJURIES				
Incidence rate is 20.9 for falls, slips and trips				
Incidence rates are calculated per 10,000 workers				
	Percentage	Fraction of VSL		
Classified bruises, sprains and tears as MINOR	60%	0.0030		assumed percentages
Classified fractures as MODERATE	25%	0.0470		out of the total
Classified multiple traumatic injuries as SERIOUS	15%	0.1050		for each type of injury
Value of statistical life (2014)	9,200,000			
Incidence rate of injuries		5		
No. of full time workers in the airport		19,206		
No. of cases (per year)		9.603		
Minor		159,025.68		
Moderate		1,038,084.30		
Serious		1,391,474.70		
Total		2,588,584.68		

Figure 40. Screen-shot for calculating cost due to injuries taken from Sheet 2 “HPS indirect benefits” of the tool

4. SPREADSHEET 3 - HPS COST

The initial cost of the hydronic heated pavement consists of installing the hydronic pipes in or below the pavement along with the heating system facility including control systems. As the installation costs of hydronic hated pavement systems would play a crucial role in estimating their economic usefulness, it was decided to analyze various cost scenarios ranging from $15/ft^2 to $45/ft^2 taking $25/ft^2 as the base value. Operation costs consist of the cost of natural gas needed to heat anti-freeze circulating in the pipes and electricity needed to power the control system. These can be seen in Figure 6. To quantify the amount of natural gas needed, the energy required to melt snow or the design heat load was first calculated (see Sheet titled "Snow melt calculations")

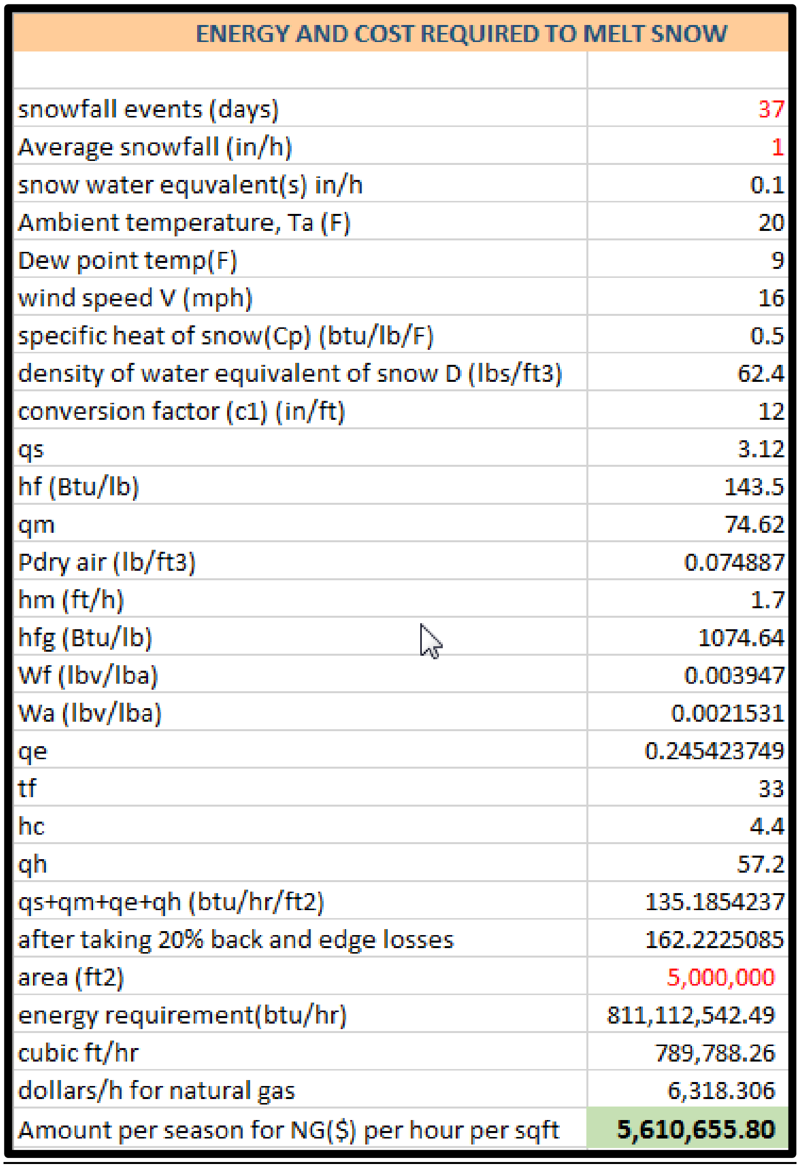


Cost of HPS			
HYDRONIC HEATED PAVEMENT SYSTEM			
Item	**Unit Price ($/ft2)**	**Area (ft2)**	**Total cost ($)**
Initial cost (C)	25	5,000,000	125,000,000
Maintenance cost	1%		1,250,000
Operation cost			5,610,656
Total maintenance & operation cost (A)			6,860,656

Figure 41. Screen-shot for calculating cost of HPS taken from Sheet 3 "HPS costs" of the tool

4.1 SPREADSHEET 4 – SNOW MELT CALCULATIONS

Using the equations provided in the FAA Advisory Circular AC 150/5370-17 and ASHRAE Handbook 2003, energy to melt snow was calculated. Once the energy was calculated for the area under consideration the cost was calculated by price and amount of natural gas. This can be seen in the Figure 7 below.



ENERGY AND COST REQUIRED TO MELT SNOW	
snowfall events (days)	37
Average snowfall (in/h)	1
snow water equvalent(s) in/h	0.1
Ambient temperature, Ta (F)	20
Dew point temp(F)	9
wind speed V (mph)	16
specific heat of snow(Cp) (btu/lb/F)	0.5
density of water equivalent of snow D (lbs/ft3)	62.4
conversion factor (c1) (in/ft)	12
qs	3.12
hf (Btu/lb)	143.5
qm	74.62
Pdry air (lb/ft3)	0.074887
hm (ft/h)	1.7
hfg (Btu/lb)	1074.64
Wf (lbv/lba)	0.003947
Wa (lbv/lba)	0.0021531
qe	0.245423749
tf	33
hc	4.4
qh	57.2
qs+qm+qe+qh (btu/hr/ft2)	135.1854237
after taking 20% back and edge losses	162.2225085
area (ft2)	5,000,000
energy requirement(btu/hr)	811,112,542.49
cubic ft/hr	789,788.26
dollars/h for natural gas	6,318.306
Amount per season for NG($) per hour per sqft	**5,610,655.80**

Figure 42. Screen-shot for calculating the energy and cost required to melt snow

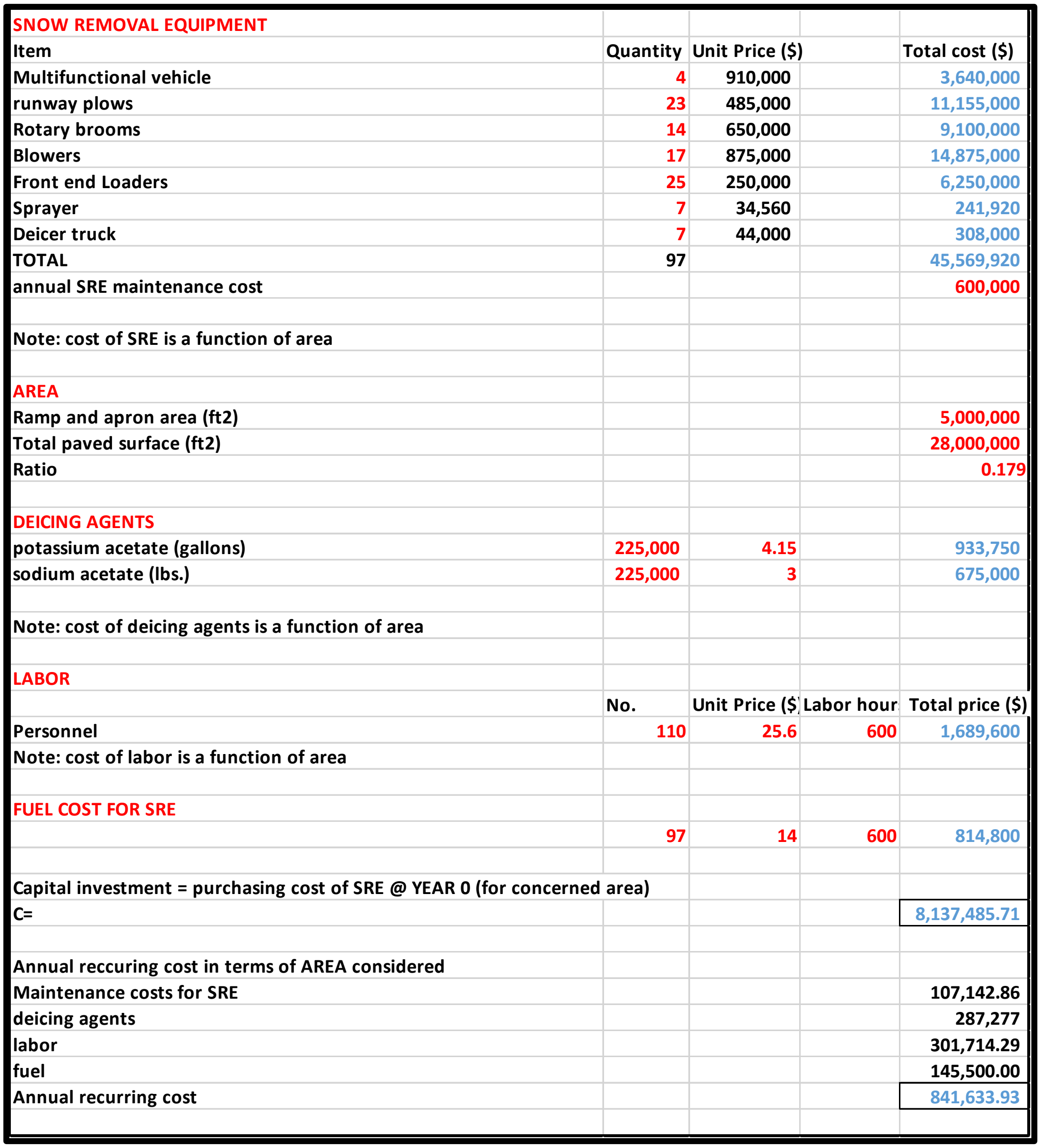
5. SPREADSHEET 5 - COST OF CONVENTIONAL METHODS

Cost of conventional methods may be calculated using Equations 5 and 6. The snapshot of the spreadsheet is shown in Figure 8 below.

Capital cost =Purchasing cost of entire SRE fleet × (Area of pavement under consideration/Total pavement area) (5)

The recurring costs associated with snow removal using conventional strategies consist of the fuel consumed by the equipment, labor, deicing agents, and maintenance of the equipment and can be calculated using Equation 2. The labor costs involved in snow removal operations at commercial airports may range from $14/h to $50/h. The higher values indicate work during late nights, early mornings and overtime. For simplicity a value of $27 per hour per person was adopted for calculations (values were provided by the airport managers through airport site visits and survey). These values may be changed as per the airport's discretion. Equation 6 and Figure 7 can be used to calculate the costs.

Annual recurring cost=Total cost of (labor + fuel + deicing agents + O&M costs of SRE) × (Area of pavement under consideration/Total pavement area) (6)



SNOW REMOVAL EQUIPMENT				
Item	Quantity	Unit Price ($)		Total cost ($)
Multifunctional vehicle	4	910,000		3,640,000
runway plows	23	485,000		11,155,000
Rotary brooms	14	650,000		9,100,000
Blowers	17	875,000		14,875,000
Front end Loaders	25	250,000		6,250,000
Sprayer	7	34,560		241,920
Deicer truck	7	44,000		308,000
TOTAL	97			45,569,920
annual SRE maintenance cost				600,000
Note: cost of SRE is a function of area				
AREA				
Ramp and apron area (ft2)				5,000,000
Total paved surface (ft2)				28,000,000
Ratio				0.179
DEICING AGENTS				
potassium acetate (gallons)	225,000	4.15		933,750
sodium acetate (lbs.)	225,000	3		675,000
Note: cost of deicing agents is a function of area				
LABOR				
	No.	Unit Price ($)	Labor hour	Total price ($)
Personnel	110	25.6	600	1,689,600
Note: cost of labor is a function of area				
FUEL COST FOR SRE				
	97	14	600	814,800
Capital investment = purchasing cost of SRE @ YEAR 0 (for concerned area)				
C=				8,137,485.71
Annual reccuring cost in terms of AREA considered				
Maintenance costs for SRE				107,142.86
deicing agents				287,277
labor				301,714.29
fuel				145,500.00
Annual recurring cost				841,633.93

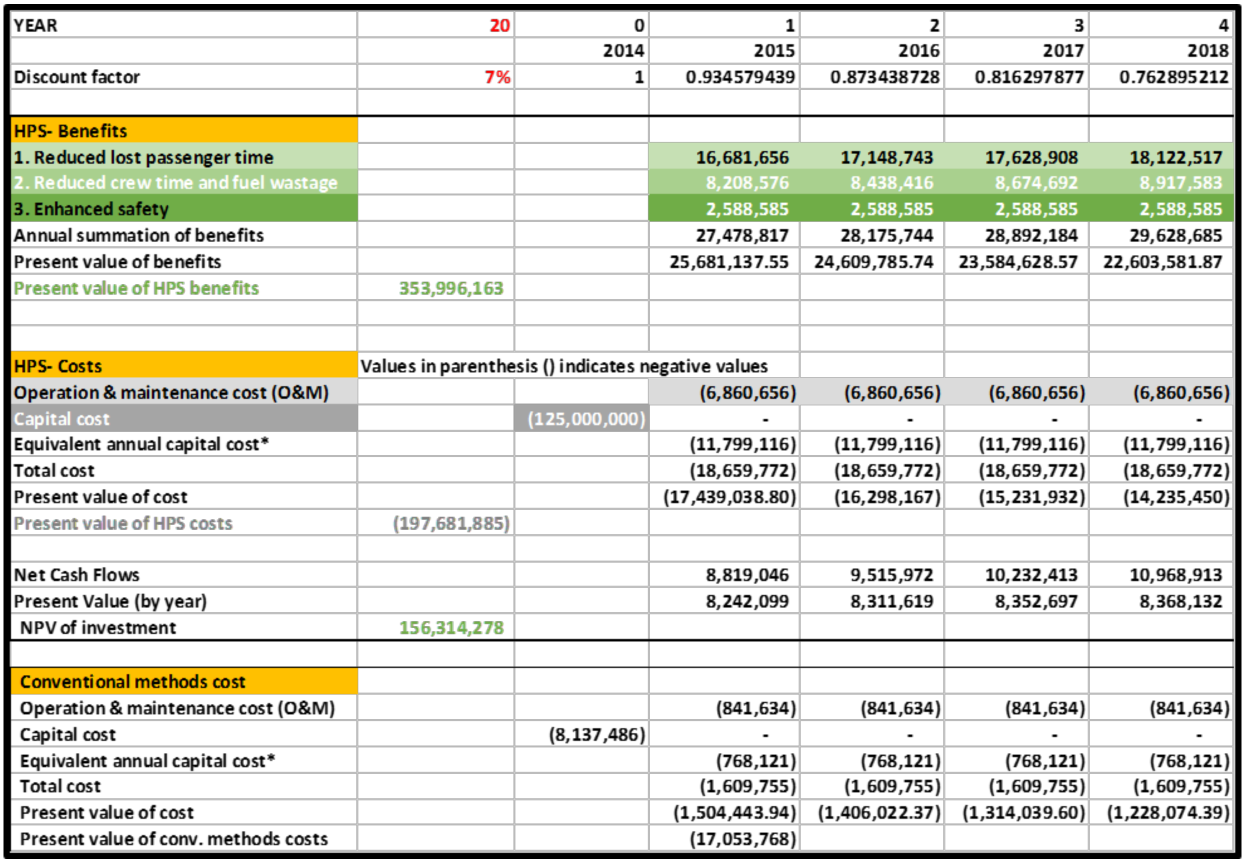
Figure 43. Screen-shot for calculating cost of using conventional methods to remove snow taken from Sheet 4 “Conventional methods cost” of the tool

6. SPREADSHEET 6 - ECONOMIC ANALYSIS

To assess the financial viability of heated pavements there are many tools that could be made use of. These include net present value, annual value, future worth, incremental rate of return etc. In this study, benefit cost analysis (BCA), Incremental BCA and net present value (NPV) have been used. The value of the analysis period for analyzing benefits of HPS can be changed. In this chart, the analysis period is 20 years. The discount factor is also listed and 7% is used as a base value to analyze the NPV.

Annual benefits and costs of HPS and cost of conventional methods of snow removal as calculated above are listed in this Sheet as seen in Figure 8. Analysis period and discount rate are also listed in this Sheet. The annual values are discounted for 20 years to get the present value of costs and benefits. The present value is taken in terms of 2014 dollar values which is assumed to be year zero. This value may be changed depending upon each airport. After the discounted values are calculated for each year they are summed to get the present value over the entire analysis period.

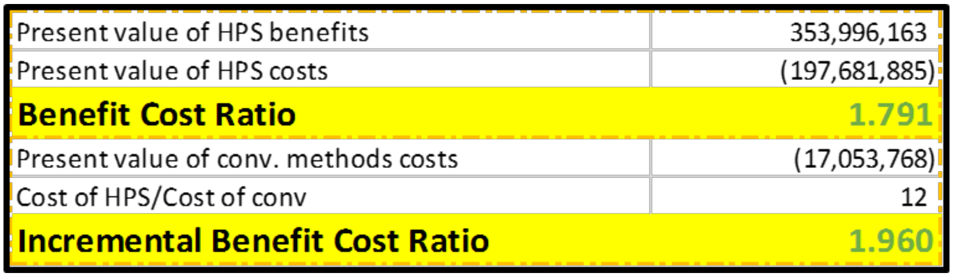
As seen in Figure 9, the value of analysis period (20 years) and discount factor (7%) can be changed from Sheet 1- “summary”. The various costs and benefits are calculated from Sheets 2, 3, 4 and 5.



YEAR	20	0	1	2	3	4
		2014	2015	2016	2017	2018
Discount factor	7%	1	0.934579439	0.873438728	0.816297877	0.762895212
HPS- Benefits						
1. Reduced lost passenger time			16,681,656	17,148,743	17,628,908	18,122,517
2. Reduced crew time and fuel wastage			8,208,576	8,438,416	8,674,692	8,917,583
3. Enhanced safety			2,588,585	2,588,585	2,588,585	2,588,585
Annual summation of benefits			27,478,817	28,175,744	28,892,184	29,628,685
Present value of benefits			25,681,137.55	24,609,785.74	23,584,628.57	22,603,581.87
Present value of HPS benefits	353,996,163					
HPS- Costs	Values in parenthesis () indicates negative values					
Operation & maintenance cost (O&M)			(6,860,656)	(6,860,656)	(6,860,656)	(6,860,656)
Capital cost		(125,000,000)	-	-	-	-
Equivalent annual capital cost*			(11,799,116)	(11,799,116)	(11,799,116)	(11,799,116)
Total cost			(18,659,772)	(18,659,772)	(18,659,772)	(18,659,772)
Present value of cost			(17,439,038.80)	(16,298,167)	(15,231,932)	(14,235,450)
Present value of HPS costs	(197,681,885)					
Net Cash Flows			8,819,046	9,515,972	10,232,413	10,968,913
Present Value (by year)			8,242,099	8,311,619	8,352,697	8,368,132
NPV of investment	156,314,278					
Conventional methods cost						
Operation & maintenance cost (O&M)			(841,634)	(841,634)	(841,634)	(841,634)
Capital cost		(8,137,486)	-	-	-	-
Equivalent annual capital cost*			(768,121)	(768,121)	(768,121)	(768,121)
Total cost			(1,609,755)	(1,609,755)	(1,609,755)	(1,609,755)
Present value of cost			(1,504,443.94)	(1,406,022.37)	(1,314,039.60)	(1,228,074.39)
Present value of conv. methods costs			(17,053,768)			

Figure 44. Screen-shot presenting the calculations of present values of costs and benefits taken from Sheet 6 "Economic analysis" of the tool

After the present values of cost and benefits of HPS are calculated the BCR and incremental BCR are calculated which are also presented in the "summary" Sheet as shown in Figure 10.



Present value of HPS benefits	353,996,163
Present value of HPS costs	(197,681,885)
Benefit Cost Ratio	**1.791**
Present value of conv. methods costs	(17,053,768)
Cost of HPS/Cost of conv	12
Incremental Benefit Cost Ratio	**1.960**

Figure 45. Screen-shot presenting BCRs taken from Sheet 6 "Economic analysis" of the tool

The data presented in Figure 11 can be seen on the chart titled "Cash flow" in the spreadsheet and is shown below in Figure. It represents cash flow for 20 years and the distribution of the cost and benefits related with the installation of HPS. In this example, it is evident that the delays affect passengers the most. This may vary among different airports. Figure 1 represents the cash flow of the likely benefits and costs related to HPS. The benefits are due to reduction in lost passenger time, lost crew hours and aviation fuel. The costs include the installation, operation, and maintenance costs. The benefits of hydronic pavement far exceed their cost of installation, operation and maintenance.

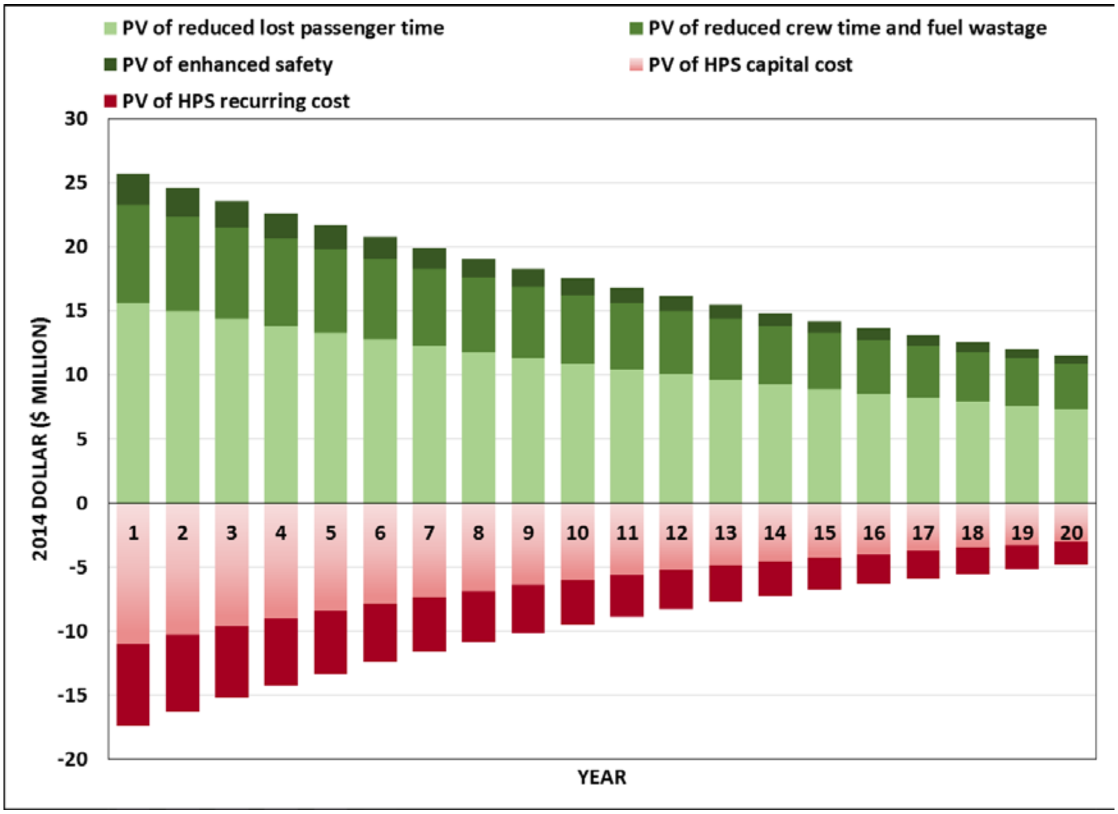


Figure 46. Cash flow of the various costs and benefits of using HPS to clear snow taken from Sheet 7 “Cash flow” of the tool

7. Summary

This document aims to serve as a user manual for the economic analysis tool developed for examining the feasibility of heated pavement surfaces. This document should be reviewed along with the main report in order to envisage the methodology adopted to carry out the analysis. The developed tool can be used to overcome the limitations due to data unavailability listed in the report as the airport managers may have access to more accurate data for their airport. They may also be able to establish more reasonable assumptions specific to their airport. The report focuses on the installation of the HPS at aprons but the tool can be used to investigate the feasibility at any airport location as each airport has unique characteristics.