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Cost comparison of alternative airfield snow removal methodologies

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Abstract
Maintaining operational safety and status of airport runways during snowfall events is a challenging issue that many airports are grappling with. 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. Most transport category aircraft are prohibited from operating on runways covered by untreated ice or by more than ½ inch of snow or slush. Hence, it is imperative that both small and large airports maintain operational status during snowfall events to support the existing operations. Conventional ice and snow removal practices are labor intensive and have environmental concerns such as possible contamination of nearby water bodies for highway and airport pavements. This preliminary study aims at identifying and establishing cost parameters for an ongoing research project on energy and economic analyses of alternative ice and snow removal strategies. One such alternative approach is the use of a heated pavement system using either conventional or renewable energy as a heat source, to keep the surface temperature of concrete pavements above freezing so that any frozen precipitation melts upon contact. Based on the limited data available, the costs incurred due to melting snow by hydronic heated pavements were calculated and compared with the operating costs of conventional snow removal strategies under specific case scenarios. A case study is carried out using limited data from Des Moines International (DSM) airport in Iowa to demonstrate the methodology.

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COST COMPARISON OF ALTERNATIVE AIRFIELD SNOW REMOVAL METHODOLOGIES

By

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ABSTRACT

Maintaining operational safety and status of airport runways during snowfall events is a challenging issue that many airports are grappling with. 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. Most transport category aircraft are prohibited from operating on runways covered by untreated ice or by more than ½ inch of snow or slush. Hence, it is imperative that both small and large airports maintain operational status during snowfall events to support the existing operations. Conventional ice and snow removal practices are labor intensive and have environmental concerns such as possible contamination of nearby water bodies for highway and airport pavements. This preliminary study aims at identifying and establishing cost parameters for an ongoing research project on energy and economic analyses of alternative ice and snow removal strategies. One such alternative approach is the use of a heated pavement system using either conventional or renewable energy as a heat source, to keep the surface temperature of concrete pavements above freezing so that any frozen precipitation melts upon contact. Based on the limited data available, the costs incurred due to melting snow by hydronic heated pavements were calculated and compared with the operating costs of conventional snow removal strategies under specific case scenarios. A case study is carried out using limited data from Des Moines International (DSM) airport in Iowa to demonstrate the methodology.

INTRODUCTION

Air transportation provides a ready access to global markets, people, capital and services. A study conducted by the International Air Transport Association (IATA) shows that there will be a 31% rise in air travel demand by 2017 [1]. This shows that air transportation is swiftly becoming the preferred choice for travel. Commercial aviation helps generate more than 5% of the United States (U.S.) Gross domestic product (GDP) and more than 10 million U.S. jobs [2]. On the other hand, airports in the U.S. are regularly impacted by snow and ice in winter. In early 2014, for example, there were more flight cancellations than in the previous 25 years with approximately 5.5% of scheduled flights being cancelled [3]. It is possible that during certain situations the pilot needs to rely on their eyesight during landing or taxi operations and it would be nearly impossible and likely fatal to do so in severe weather conditions [4].

Removal of snow and ice from the airport pavements is essential for maintaining safe operations for both aircraft and ground operations, and for keeping the airport functional. Snow and ice removal should also be efficient to reduce cost. Commercial airports with annual airline operations of more than 40,000 are required to clear snow/ice from the priority areas within half an hour of 1 inch of snowfall. Areas 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, Priority 2 generally consists of secondary runways and their associated areas [5].

It is generally the duty of the airport to monitor and respond to the weather to ensure safe, non-slip conditions for vehicles using runways and taxiways. In a recent news article covering snow storms in the mid-west and eastern belt of the U.S., an airline spokesperson reported that the ground workers and bag handlers could not stay outside for more than 15 minutes at Chicago's O'Hare Airport which led to more delays and commotion [6]. There were many instances wherein the baggage arrived a day or two after the passengers arrived to their destinations.

Airports typically employ chemical deicers in combination with snow plows to remove snow and ice from ramps, runways and taxiways. 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, propylene glycol. Acetate is gradually replacing other deicers. Acetate can impact aquatic environments through consumption of dissolved oxygen in the water but are also considered less corrosive. Acetates do not have widespread effects on plants but can be detrimental if used in high concentrations. Urea forms ammonia after decomposition and is toxic to aquatic life and can also cause biological overgrowths unless the amount of ammonia generated is held within the limits [7, 8].

The use of heated airport pavement systems as a means of removing ice and snow has reportedly been successful in European airports. The benefits include a reduction in environmental effects of deicers, cost of fuel and energy, and impacts to travelers. Before such approaches are implemented in the U.S.A, it is desirable to study the cost and energy impacts of such systems compared with conventional approaches.

In this paper, parameters and costs are identified for an ongoing study to assess the energy and financial viability of installing such a heated pavement system at airports and its cost comparison with the conventional snow removal strategies. The case of Des Moines International (DSM) airport in Iowa is used as an example. We are focusing our efforts on the ramp area for our project and the total costs would be computed only for the ramp area.

ICE AND SNOW REMOVAL STRATEGIES

Ice and snow removal activities require complex machinery, significant manpower and detailed planning. De-icing is the process of removal 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 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 Strategies

Conventional strategies include both mechanical strategies and chemical strategies. Mechanical methods include use of snow plows/blowers, snow brooms, and sweepers (Figure 1). Snow plows basically push aside the snow and ice towards the shoulders which is later on disposed. Snow brooms use a rotating circular broom that helps to brush the compacted snow and ice that might be hidden in the inaccessible areas of the taxiways and runways. Mechanical strategies of snow removal might be very time consuming as they operate at relatively slow speeds and may interfere with aircraft operations. Wet snow and ice can develop a strong bond with the pavement which reduces the efficiency of snow removal equipment greatly. A major drawback of mechanical snow removal strategies is that they remove snow from the surface and do not focus at the point of bonding [9]. Mechanical strategies can also damage the pavement and embedded lighting fixtures. Increasing labor needs raises costs and safety concerns.

Figure 1. A Typical Snow Plow [10]

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.

Heated Pavement Systems

An overview of airport heated pavement systems is provided in Federal Aviation Administration (FAA) Advisory Circular AC 150/5370-17 [9]. Heated pavement systems remove snow and ice using the heat provided by embedded electric cables or hydronic tubing. Heated pavement systems offer an alternative strategy for mitigating the effects of winter weather by melting snow and preventing bonding to the pavement surface. The benefits of such systems may entail:

- Positive impact on capacity during winter operations.
- Reduction in environmental impacts of chemical deicers.
- Reduction in time required to clear priority areas.
- Improving operational status of airports.

The disadvantages of heated pavement systems typically include high initial costs and complex installation procedures and maintenance issues for the equipment. Costs may be equalized or reduced in the long run by a reduction in using more snow clearing and deicing equipment and personnel. It will also improve safety of the personnel involved with snow/ice removal operations and reduce passenger delays due to closed airports or runway downtime.

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. The basic principles of these systems are described below.

Hydronic Pavement Heating

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 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 [11]. Hydronic heating systems use metal or cross-linked polyethylene (PEX) pipes. The fluid can be heated by a variety of sources from burning fossil fuels to more environmentally friendly options like 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 [12]. Hydronic refers to the use of heated fluid as the transfer mechanism.

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 [9].

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. The scope of this paper is limited to the energy and costs analysis of hydronic heated pavement systems.

ENERGY REQUIREMENTS FOR HEATED PAVEMENT SYSTEMS

The design of the heated pavement systems should meet both the system performance and design load requirements [9]. The required system performance includes maintaining a surface condition of "no worse than wet", by maintaining a surface temperature above the freezing point before and during snow accumulation. The required heat design load can be determined considering the expected rate of snowfall, air temperature, humidity, wind speed, dimensions and material characteristics of the pavement. These design requirements indicate that the pavement heat output required is one of the critical parameters to establish the cost of heated pavement system.

The steady-state energy balance equation for required pavement heat output (q_o) in BTU/ h•ft^2 as presented in FAA Advisory Circular AC 150/5370-17 [9]

$$q_o = q_s + q_m + A_r\,(q_e + q_h) \qquad \text{(Eq.1)}$$

Where:

q_s = sensible heat transferred to the snow (BTU/ h·ft^2)
q_m = heat of fusion (BTU/ h·ft^2)
A_r = snow-free area ratio must equal 1 for areas with aircraft operations
q_e = heat of evaporation (BTU/ h·ft^2)
q_h = heat transfer by convection and radiation (BTU/h·ft^2)

The calculations related to each of 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 FAA Advisory Circular AC 150/5370-17 [9]. 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. To meet the expectations of Class II, when determining the solution for general equation q_o, the snow-free area ratio A_r will be 1 although the recommended value is 0.5. This is done because the snow and ice are to be melted immediately while falling but the pavement is allowed to remain wet and the heat output required is also in correlation to the class II systems.

For hydronic heating systems, the temperature of the fluid can be calculated using Equation 2 [9]:

$$t_m = 0.5q_o + t_f \qquad \text{(Eq.2)}$$

Where:
t_m = average fluid temperature, °F
t_f = water film temperature (°F), accepted as 33°F

Table 1 presents the annual weather data for the year 2012-2013 used for estimating the required heat outputs (q_o) for Des Moines International (DSM) airport in Iowa. The values of wind speed and ambient temperature are average values during days when a snowfall event had been reported. In addition, a set of 4 case scenarios of hourly snowfall events was established. These scenarios are 1, 2, 3, and 4 inches of snowfall in an hour (in/hr.), respectively. The values of heat output requirement and its related parameters calculated from Equation 1 for each of the snowfall case scenarios for a unit area (1 ft^2) have been summarized in the Table 2.

Table 1. Weather Data for Des Moines International Airport

Snowfall events (days)	Snowfall (inches)	Wind speed (mph)	Ambient temperature (°F)	Annual snowfall (hours)
26	35	10	20	127

Table 2. Required Heat Outputs for Four Case Scenarios of Hourly Snowfall Events in DSM

Snowfall in an hour (in/h)	Sensible heat (BTU/ h·ft^2)	Heat of fusion (BTU/ h·ft^2)	Heat of evaporation (BTU/ h·ft^2)	Heat transfer by convection and radiation (BTU/h·ft^2)	Pavement heat output (qo) BTU/ h·ft^2	Average fluid temperature °F
1	3.12	74.62	0.25	57.20	135.19	114
2	6.76	149.24	0.25	57.20	213.45	114
3	10.14	223.86	0.25	57.20	291.45	114
4	13.52	298.48	0.25	57.20	369.45	114

COST ANALYSIS FRAMEWORK: METHODOLOGY AND RESULTS

Methodology

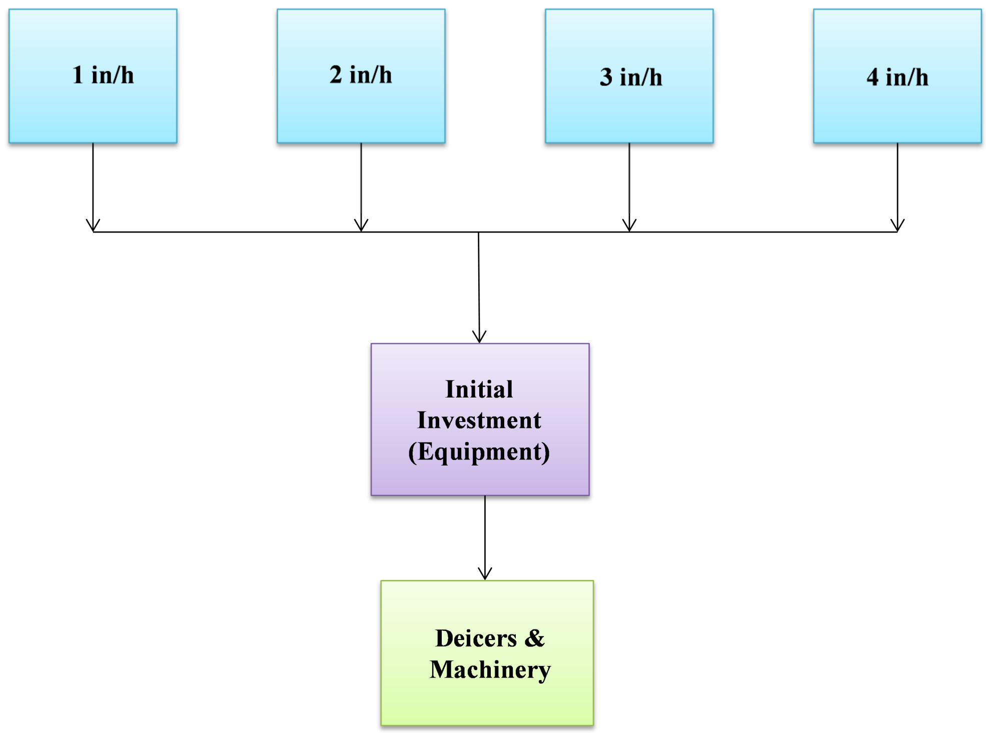
This paper compared the apparent costs involved with using a conventional de-icing method and a hydronic heated pavement for an approximate ramp area of 4.1 million ft^2 of DSM airport in Iowa. Table 3 lists cost items included in this study with descriptions. The costs have been computed for a 20 year period. These costs are generalized for various stakeholders (airlines, passengers and airports) and presented as combined costs but are calculated separately for the analysis. It is assumed that the maintenance cost is 1% of the total operation and installation cost for both the alternatives. The salvage value is assumed as 10 % of the initial cost.

Table 3. Description of Cost Items.

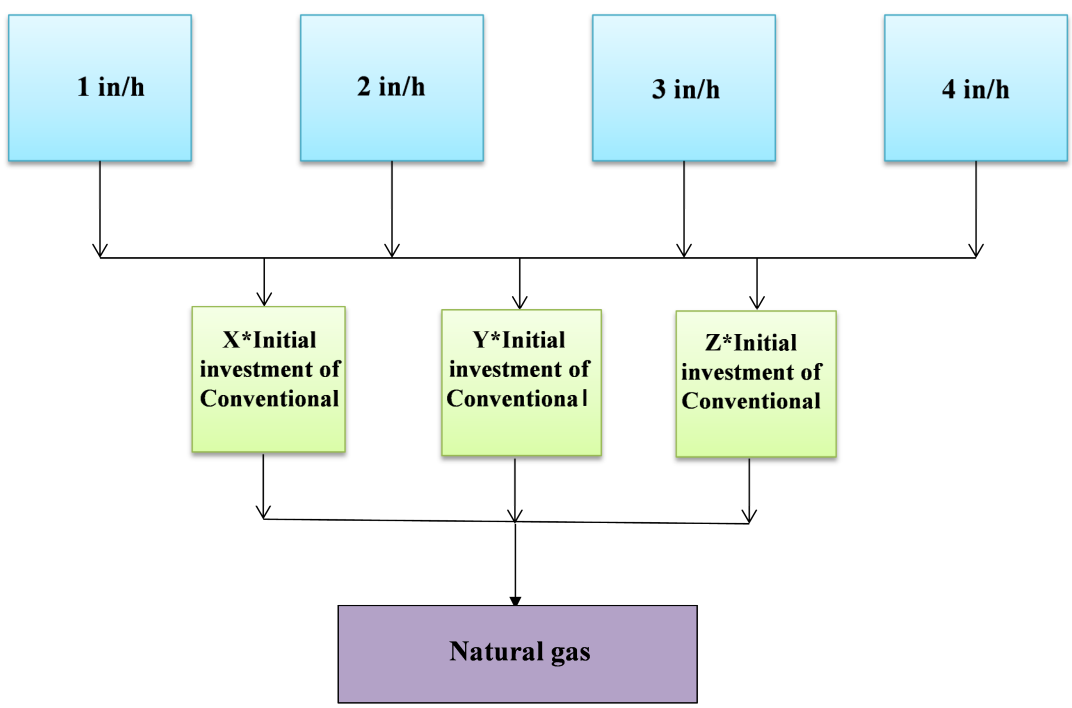
Cost/Benefit category	Conventional	Hydronic heated pavement
Initial cost	Snow removal equipment purchase	Hydronic heating system installation
Operation cost	Labor , fuel and deicing agents	Energy source cost (fuel, natural gas, and etc.)
Maintenance cost	Maintenance for system	Maintenance for system
Soft cost	Aircraft, passenger, and cargo delay costs.	Aircraft, passenger, and cargo delay costs are minimized.

A set of various case scenarios with associated cost items was established in Table 3 for comparison (See Figure 2). Four of those main case scenarios are related to different intensities of snowfall (Table 2).

In the case of conventional strategies, snow is cleared using the same strategies regardless of the snowfall rates. The number of personnel and equipment maybe increased but the strategy remains essentially the same. Whereas, in the heated pavements systems initial costs were assumed to be related to the initial costs of conventional strategies, varying from two times, three times and four times. The energy source was assumed to be natural gas or electricity and the costs of using both of these have been analyzed. In this paper, a total of twenty four sub cases have been identified and considered in the cost analysis.



(a) Conventional



(b) Hydronic heated pavements

Figure 2. Scenarios Considered in this Study.

Conventional strategies

Machinery, deicing salts/ chemicals and labor are the units required for deicing pavements. For simplicity, an airport runway/taxiway/ramp area of about 4.1 million ft^2 was considered for analysis and the amount of equipment required to deice this area was estimated. That would serve as the initial cost (cost at year 0) for the conventional strategies. The PCC pavement construction cost was not considered as a part of the analysis in this study. The various types of snow removal equipment were identified after discussions with the Director of Engineering & Planning at DSM airport and are shown in Table 4.

The initial costs only consist of equipment purchase and are assumed to be the same for all the four cases listed above. Using google maps the approximate area of the paved surfaces of the DSM airport was calculated as 6.7 million ft^2 approximately and the total ramp area including some parking areas was calculated as about 4.1 million ft^2. The costs for the ramp area can be computed using the ratio between the ramp area and total area (0.605).

Table 4. Purchasing Cost of Snow Removal Equipment

Item	Quantity	Unit price	Total price of item
Displacement plows	9	\$485,000	\$4,365,000
Rotary brooms	6	\$650,000	\$3,900,000
Blowers	3	\$875,000	\$2,625,000
Loaders	2	\$250,000	\$500,000
Sprayer truck and spreader	1	\$34,000	\$34,000
Deicer truck	1	\$44,000	\$444,000
Total price for entire paved surface		\$12,000,000	
Total price for ramp area		\$12,000,000× 0.605 = \$7,260,000	

The recurring costs associated with deicing are the cost of fuel consumed by the equipment, labor and maintenance of the equipment. RF-11, a commonly used deicer at the DSM airport costs \$25 per gallon and its recommended dosage is 3 gallons per 1,000-ft^2 for 1 inch of snowfall [13].

The diesel price in Iowa (2014) was included as \$3.65 per gallon [14]. The labor cost involved in snow removal operations was estimated to be \$25 per hour [15]. The labor cost of \$25 is the value corresponding to transportation and material moving operations. While the number of personnel, amount of deicing agents and fuel required for the operation of equipment will increase as the storm intensity increases, herein it is assumed that the number of snow removal vehicles remains constant even though they may have to make more number of passes to clear the snow. The duties of personnel responsible for removing snow are limited to operating machines to clearing out snow and dumping the snow in the designated areas

Hydronic heated pavement system

Since the initial cost for the hydronic heated pavement systems have not been published we can approximate the cost by using the breakeven analysis. The initial cost of the conventional method consists of purchasing the snow removal equipment only. As with the conventional strategies, the construction costs associated with PCC pavements was not included in the analysis; it is anticipated that the construction costs for PCC pavements will be approximately the same for the two strategies. Therefore, the initial cost of the hydronic heated pavement consists of installing the hydronic pipes in the pavement and the complete installation of the heating system facility.

It was assumed that the hydronic system would be operated by means of valves and switching equipment (automated) and hence, would involve no labor cost. No deicing agents and snow removal equipment would be required for the ramp area as well. Thus, right at the outset the operation cost of the hydronic heated pavement system would be expected to be much lower than those of conventional snow removal strategies.

Cost of hydronic heating

The cost of commercial natural gas in Iowa (April 2014) is \$7.44 per 1,000-ft^3 [16]. According to the 2003 ASHRAE handbook HVAC applications, Des Moines receives 127 hours of snowfall so we can approximate the results for a season (1 year). The heat requirement for an area of about 4.1 million ft^2 is 670 million BTU/h and natural gas supply is required at the rate of 652,000-ft^3 per hour.

Estimation of soft (or indirect) costs

Heated pavement systems can improve safety for ground crews servicing the aircraft at the gate area, improve safety of passengers embarking/disembarking the aircraft, reduce air carrier delays due to plowing operations or flight cancellations, as well as delays in aircraft ground support because of slippery pavements. Herein, the analysis is limited to the estimation of costs incurred due to flight delays. These costs consist of the cost of fuel, cost of crew that aircraft operators undergo, and the added passenger and cargo delay cost [17].

Installations of hydronic pavements aim to reduce if not eliminate the above costs which make a large part of the annual delay costs. A Boeing 737-800 with a flight time of six hours that suffered a delay of one hour with the following specifications was used for this study. The relevant specifications for Boeing 737-800 are summarized in Table 5. Load factor represents the proportion of seats available that are actually purchased; it is essentially a ratio between revenue passenger miles (RPMs) and available seat miles (ASMs) [18]. Load factor for a single flight can be calculated by dividing the number of passengers by the number of seats. It is a measure of utilization usually expressed as a percentage, and should be as higher as possible for lower airline costs per passenger [19]. In this analysis we assume a load factor of 83.53% as reported by RITA [20].

The cost analysis herein refers to the costs incurred due to flight delay, such as the cost of fuel, cost of crew and passenger delay cost. Cargo related delay costs, while important, have not been accounted for due to data unavailability. As the maintenance of an aircraft is independent of the method of snow removal, aircraft maintenance costs were ignored in the cost analysis.

The average daily operations taking place at the DSM airport are 220 (as reported by the DSM personnel). So the total operation in the 4 winter months would be approximately 26,400 (seasonal fluctuations have been ignored herein). The data provided by Bureau of Transportation Statistics [21] reports that there have been 1.82% delays for the four months starting from

November 1, 2013 to February 28, 2014 due to weather. We assume that 2% delays have been caused due to weather for ease of calculation. Out of the total 2% delays, we can assume that 1 % are gate delays and the other 1 % are midair delays. All the delays are considered to be 1 hour only for ease in calculation. 2 percent of the total operations are 528. Hence, there have been 528 delayed flights in Des Moines over a period of 4 months.

Winter weather delays are not only caused due to runway closure but an array of other factors such as low visibility, high winds, malfunctioning of the navigation systems, etc. Heated pavements will not be able to reduce delays and its related costs resulting from all these factors. This might be a limitation of these systems

Table 5. Boeing 737-800 Specifications [22]

Aircraft	Boeing 737-800
Flight duration (hrs.)	6
Maximum take-off weight (lbs.)	174,200
Number of seats	175
Number of flight crew	2
Number of cabin crew	5
Load factor (%)	83.53 [20]
Number of passengers	123

Fuel Cost

Fuel is considered to be an airline's second largest expense. Short haul airlines typically get lower fuel efficiency because take-offs and landings consume high amounts of jet fuel. The aviation fuel price (2014) in Des Moines is $ 3.05 per gallon [23].Cost of fuel can be calculated by using the equation provided in [24]. The model assumes that for each minute of delay 100% of the fuel burn of the aircraft contributes to the delay cost and the coefficient of fuel is set as zero for gate delays and 1 for both, taxi and airborne delay cost [24].

Crew Cost

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 takeoff weight of the aircraft. The flight attendants or cabin crew cost is based on an assumed pay rate of 60 U.S $ per hour and have been calculated for a block hour of one. 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 [18]. The fuel and crew costs are summarized in Table 6.

Table 6. Estimation of Indirect Costs

Variable	Description	Unit cost per hour	Annualized value
Fuel Cost	*cfuel ×fuel burn rate ×fuel price*	*$ 2604/hour*	*$687,640*
	cfuel	Fuel burn coefficient , 1(for taxi delay cost)	
	Fuel burn rate	Fuel consumption rate of Boeing 737-800, $ 4.88 U.S gallons per seat per hour	
	Fuel price	$ 3.05/gallon (2014)	
Crew Cost	*Flight crew + cabin crew*	*$ 833/ hour*	*$439,824*
Flight Crew	(440 + 0.532 × (Wgross/1000))	$ 533/ hour	
	Block Hour	1	
	# of flight crew	2	
	Wgross	174,200 lbs.	
Cabin Crew	Cabin Crew = 1 hour (# of seats/35) × 60	$300/ hour	
	BH	1	
	# of cabin crew	5	

Passenger Delay Costs

Passenger delay costs herein consist of the opportunity costs of time lost due to weather-related delays at the airports. These do not represent direct costs as in general, aircraft operators do not offer any form of compensation due to weather related delays.

The time that the passengers are spending waiting at the airport due to snow clearing operations using conventional strategies needs to be accounted for in monetary terms. This will constitute a benefit of the hydronic heated pavement systems. Table 7 shows the opportunity cost of time (2014) for passengers in the case of a 1 hour delay. There are different values available for passengers traveling for business purpose or leisure [25]. The values are converted to 2014 dollar values by using the consumer price index. According to a study by the U.S. Department of transportation 59.60% of passenger travel is for personal reasons and 40.40% travel is for business. [26].

Table 7. Opportunity Cost of Time for Passengers on a Delayed Flight

Value of time (per hour)	Cost per hour	Number of delayed flights	Number of passengers in a flight	Number of passengers for each case	Cost distribution per year
Personal	$31.96	528	123	38,707	$901,867
Business	$55.00	528	123	26,237	$105,120

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 aircraft [27].

Although air cargo ideally remains in the airport for a relatively short time, it is necessary to provide storage facilities. Bonded facilities are required for imports and international transshipment cargo. For perishable cargoes, it is necessary to provide cold rooms. For outbound cargo, it is necessary to provide X-ray scanners to inspect the cargo.

Air cargo brings in a huge amount of revenue and severe weather affects its operation and handling. The loss in revenue associated with cargo operations has not been dealt with in this paper due to limited data availability but it is a major factor to be considered [27].

Cost Comparison

As described above, four snow storm scenarios were considered. Present value of the costs of the conventional and hydronic heating systems are calculated for a 20 year design period using a discount rate of 5 percent and assuming constant demand. The benefit cost ratio was calculated to examine the feasibility of the project. The cost comparisons between the hydronic heated pavements and conventional strategies of snow removal for different snow fall intensities for the DSM airport can be seen in Figures 3, 4, 5 and 6. The benefit-cost ratios are also shown. It is seen that if the costs are approximated over a 20 year analysis period the overall costs for hydronic heated pavements are generally but not always lower than the conventional method.

Figure 7 shows that as the initial cost of the hydronic system increases, the benefit cost ratio decreases. This shows that the initial construction cost is a major factor to be considered for economic viability of the heated airport systems. It is also seen that the project is feasible only if the initial costs of the hydronic system are lower than the initial costs calculated at the break-even point. Note that in this study only ramps were considered for installation of hydronic heated systems. The airport authorities would still have to depend on the conventional strategies of snow removal for other areas and will need to purchase a good amount of machinery. This might add extra costs to the airport.

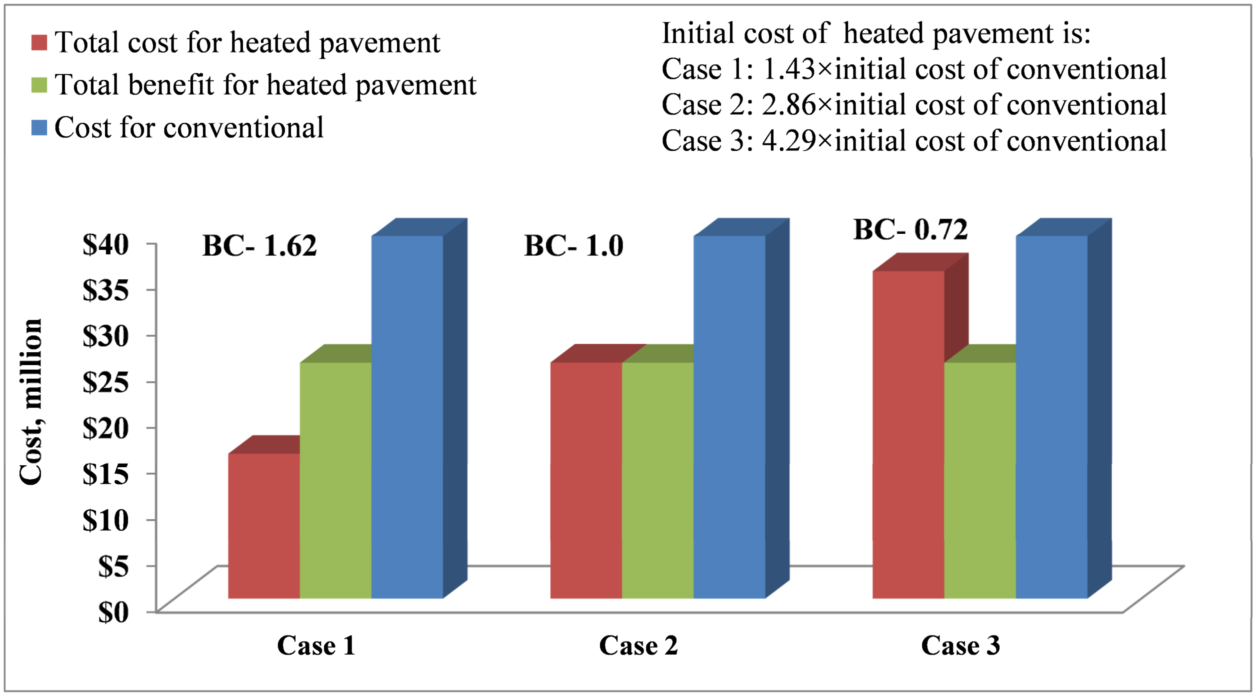


Figure 3. Costs comparisons and Benefit-Cost Ratio for a Conventional and Hydronic Heated Pavement for a Snowfall of 1 in/h.

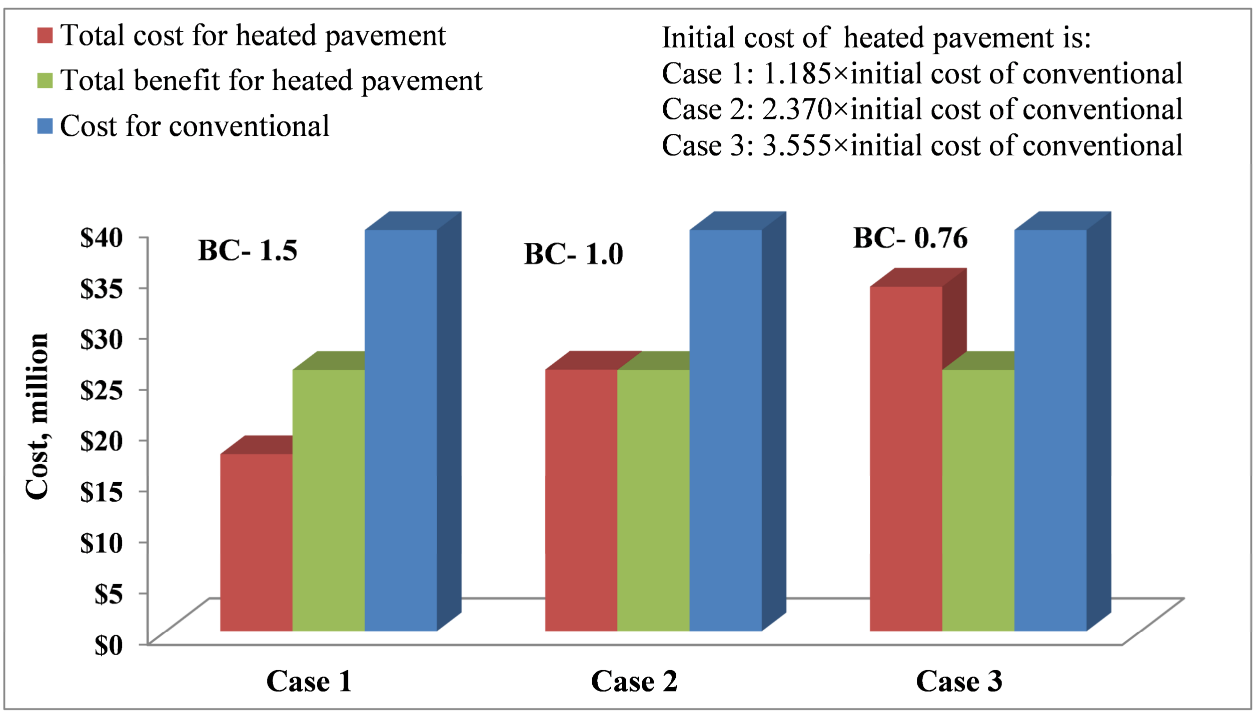


Figure 4. Costs comparisons and Benefit-Cost Ratio for a Conventional and Hydronic Heated Pavement for a Snowfall of 2 in/h.

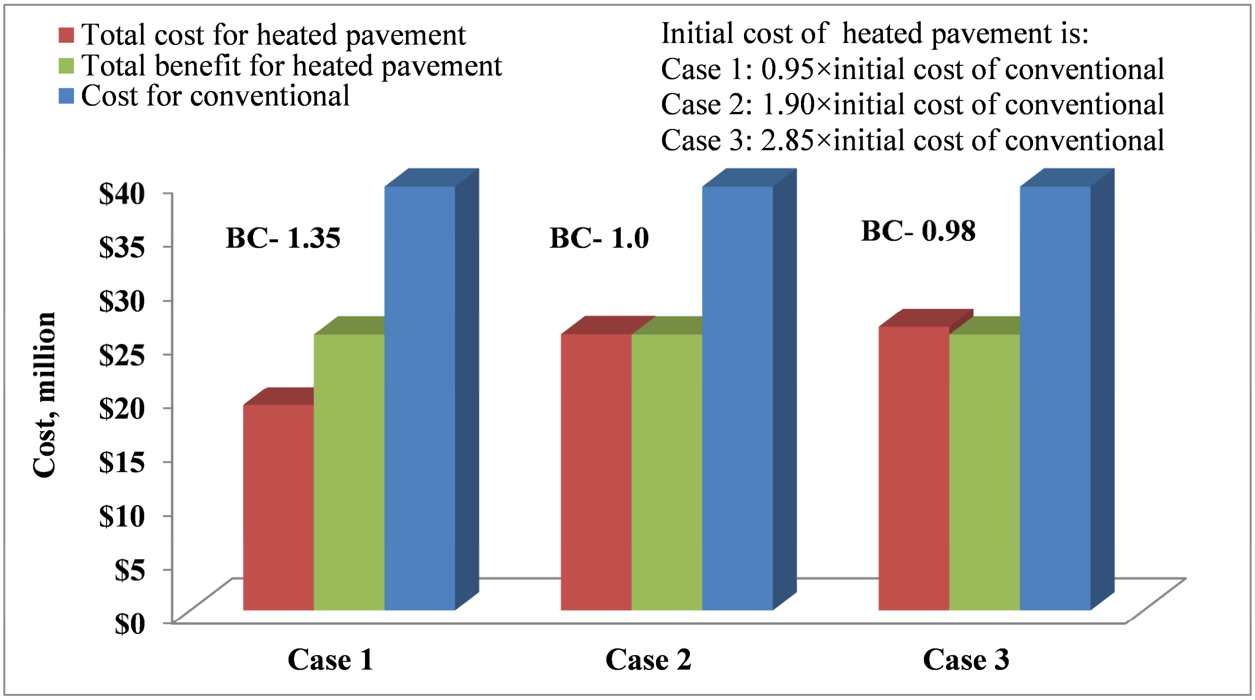


Figure 5. Costs comparisons and Benefit-Cost Ratio for a Conventional and Hydronic Heated Pavement for a Snowfall of 3 in/h.

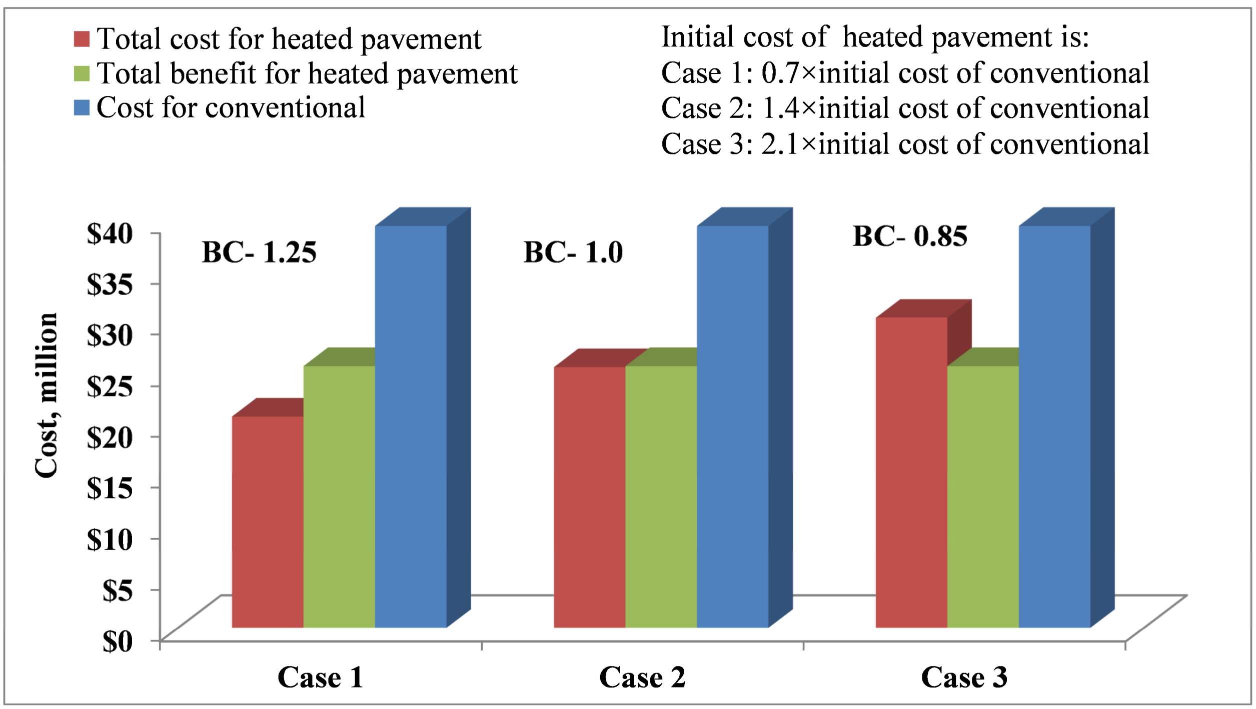


Figure 6. Costs comparisons and Benefit-Cost Ratio for a Conventional and Hydronic Heated Pavement for a Snowfall of 4 in/h.

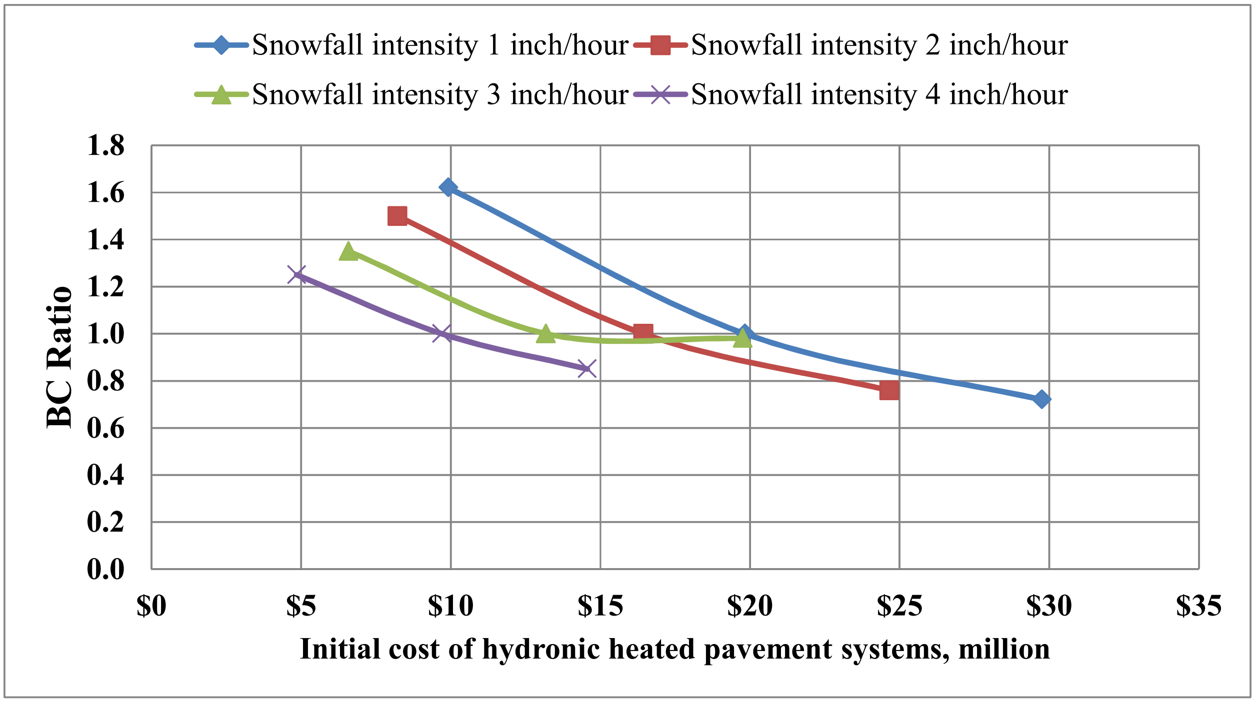


Figure 7. Plot between the Benefit Cost Ratio and Initial Cost of Hydronic Heated Pavement Systems for Different Intensities of Snowfall.

FINDINGS AND FUTURE RECOMMENDATIONS

This preliminary study aimed at identifying and establishing cost parameters for an ongoing research project on energy and economic analyses of alternative snow removal methodologies. Limited data from Des Moines International Airport were used to support the case study. In establishing this initial framework a number of assumptions were made.

Key Findings

- Hydronic heated pavements will have a low operation cost but high installation cost compared to the conventional method.
- The indirect or soft costs related to delays or cancellations which are borne by airlines, airports and passengers would greatly reduce with the use of heated pavement systems as they comprise of a major share in the total delay cost.

Future Recommendations

- Future studies may focus on weather conditions at different airports to assess the financial viability of installing such heated pavements at respective airports.
- More accurate installation costs of the hydronic heated pavements could be estimated to get a close approximation of the viability of such heated pavement systems

- Additional soft benefits will be considered such as additional detailed delay costs (e.g., cost of cargo delay), safety and environmental benefits, and others.
- A comprehensive cost comparison of the use of heated pavement systems for taxiways, ramps and gates compared to conventional strategies is recommended.
- The economic analysis framework developed in this study could be extended to a life cycle cost analysis (LCCA) framework using a benefit cost ratio methodology as suggested by the FAA [17].

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REFERENCES

1. ATA Airline Industry Forecast 2013-2017 [Online] Available: (http://www.iata.org/pressroom/pr/pages/2013-12-10-01.aspx) Date accessed: April, 2014.
2. Airlines for America [Online] Available: (http://www.airlines.org/Pages/Econ_Aviation_Economy.aspx).
3. Dallas news [Online] Available: (http://www.dallasnews.com/business/airline-industry/20140214-airlines-scrap-most-flights-in-25-years.ece), Date accessed: March, 2014.
4. Lichliter, A., "Study of Airport Snow and Ice Removal and Its Economic Implications", M.S. Thesis, Department of Civil Engineering, University of Delaware, Newark, DE, 2012.
5. Federal Aviation Administration, Office of Airport Safety and Standards, "Airport Winter Safety and Operations," Advisory Circular AC 150/5200-30C, 2008.
6. New York Times [Online] Available: (http://www.nytimes.com/2014/01/07/business/frigid-weather-cripples-air-travel-system.html?_r=0), Date accessed: February, 2014.
7. U.S. Environmental Protection Agency, Office of Water (4303T) Engineering and Analysis Division, "Environmental Impact and Benefit Assessment for the Final Effluent Limitation Guidelines and Standards for the Airport Deicing Category," April, 2012.
8. Fay, L.; and Shi, X., "Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge". Water Air Soil Pollution, Vol. 223, pp. 2751-2770, 2012.
9. Federal Aviation Administration, Office of Airport Safety and Standards, "Airside Use of Heated Pavement Systems," Advisory Circular AC 150/5370-17, 2011.

10. Al-jon Manufacturing [Online] Available: (http://www.aljon.com/snow-removal-equipment/).
11. Lund, J.W., “Pavement Snow Melting”, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR, 2000.
12. Minsk, D.L., “Heated Bridge Technology”, Publication No. FHWA-RD-99-158, U.S. Department of Transportation, Federal Highway Administration, Office of Bridge Technology, Washington, DC, USA, July 1999.
13. Orison Marketing [Online] Available: (http://www.orisonmarketing.com/RF11.html)
14. U.S Department of Energy [Online] Available: (https://www.fueleconomy.gov/feg/gasprices/states/IA.shtml) - (http://www.desmoinesgasprices.com/), Date accessed: April, 2014.
15. U.S. Bureau of Labor Statistics, “National Occupational Employment and Wage Estimates," May 2013 [Online] Available: (http://www.bls.gov/oes/current/oes_nat.htm).
16. U.S Energy Information Administration [Online] Available: (http://www.eia.gov/dnav/ng/NG_PRI_SUM_A_EPG0_PCS_DMCF_M.htm), Date accessed: April, 2014.
17. Federal Aviation Administration, Office of Aviation Policy and Plans, “Airport Benefit-Cost Analysis Guidance”, 1999.
18. Boeing: The Boeing Company [Online] Available: (http://www.boeing.com/assets/pdf/commercial/startup/pdf/Glossary.pdf).
19. Wensveen, J.G., 2011, Air Transportation, “A Management Perspective”, 7th edition, Ashgate Publishing Company, Burlington, VT, USA, 2011.
20. U.S. Bureau of Transportation Statistics, [Online] Available: (http://www.transtats.bts.gov/Data_Elements.aspx?Data=1), Date accessed: July, 2014.
21. U.S. Bureau of Transportation Statistics [Online] Available: (http://www.transtats.bts.gov/OT_Delay/OT_DelayCause1.asp?pn=1), Date accessed: July, 2014.
22. Boeing : The Boeing Company [Online] Available: (http://www.boeing.com/boeing/commercial/737family/pf/pf_800tech.page)
23. U.S. Bureau of Transportation Statistics [Online] Available: (http://www.transtats.bts.gov/fuel.asp) Date accessed: July, 2014.
24. Ferguson, J.; Qadar, K.A.; Hoffman, K.; and Sherry, L., “Estimating Domestic U.S. Airline Cost of Delay based on European Model” George Mason University, Center for Air Transportation Research, VA, USA, August, 2013.
25. GRA, Incorporated, “Economic Values for FAA Investment and Regulatory Decisions, A Guide”, Final Report for U.S. Federal Aviation Administration, Jenkintown, PA, 2011.
26. U.S Department of Transportation, Office of the Secretary of Transportation, “Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis”, 2003. [Online] Available: (http://www.dot.gov/sites/dot.gov/files/docs/USDOT%20VOT%20Guidance_0.pdf).
27. The World Bank Group, Transportation Papers, “Air Freight: A Market Study with Implications for Landlocked Countries”, 2009. [Online] Available: (http://siteresources.worldbank.org/EXTAIRTRANSPORT/Resources/515180-1262792532589/6683177-1268747346047/air_cargo_ch3.pdf).