

Identifying Effective Method to Collect and Recycle Aircraft De-icing
Fluids for Non-hub Primary Airports

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Design Challenge: Airport Environmental Interactions

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Executive Summary

In the ACRP (Airport Cooperative Research Program) University Design Competition Guidelines, the Airport Environmental Interactions Challenge includes improvements in containment and cleanup of anti- and de-icing products used for aircraft de-icing operations at the airports.

Airports and airlines operating during icing conditions must perform de-icing and anti-icing of aircraft in order to ensure passenger and cargo safety (EPA, 2019). EPA regulation affecting new airports, require that airports in cold climate zones handling about 10,000 annual departures must collect 60% of de-icing fluid runoff. De-icing fluids that contaminate water discharged by airports into the waters of the United States, must meet the requirements for biochemical oxygen demand (BOD). Since stormwater contamination due to de-icing agents is an environmental hazard, our team developed an effective method to collect and recycle de-icing fluid runoff at non-hub primary airports. In this project, the team reviewed the potential solutions for minimizing waste during de-icing operations on commercial aircraft. The project provides potential revenue generation that is about 1.22 times of the costs during a span of 10 years, from recycling aircraft de-icing fluids.

Non-hub primary airports typically have over 10,000 departures but may not have active glycol recycling programs. In this proposal method, the de-icing fluid containment and recycling program is based on the 24 non-hub primary airports in the states of Indiana, Illinois, Ohio, Michigan and Wisconsin. It is expected to be applicable to other airports with similar climates as well.

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1. Background and Problem Statement

This project focuses on a solution to collect and recycle de-icing fluids from de-icing operations in non-hub primary airports. The primary purpose of de-icing operations is to remove ice build-up from the control surfaces (Switzenbaum et al., 2001). According to Switzenbaum et al (2001), even small amounts of ice formation can cause significant detrimental effects on the aerodynamics of wings, tails, propellers, and flight controls. Such effects include, but are not limited to, increased drag, loss of lift, and increased stall speed.

There are multiple types of de-icing fluid that may be used in aircraft de-icing operations:

1. Type I fluids have a low viscosity. These fluids are intended to be applied for the initial removal of ice and snow accumulation on aircraft surfaces. Type I fluids have a short holdover time (HOT), the time between applications, and therefore are used as an aircraft de-icing fluid (ADF) whereas types II, III, and IV are used as an aircraft anti-icing fluid (AAF). This fluid is utilized at an operating range of 130-180 degrees Fahrenheit. Type I fluids are typically orange in appearance (Ritter, 2001).
2. Type II fluids contain a polymeric thickening agent, which prevents the fluid from instantly flowing off from sprayed on surfaces. This fluid film will usually remain in place until the aircraft achieves speeds of 100 knots or higher (Ritter, 2001). Type II fluids are currently being substituted by Type IV fluids instead, due to the longer HOT of Type IV, 30 minutes vs. 80 minutes (Ritter, 2001). Type II fluids are typically dyed light yellow.
3. Type III fluids are primarily intended for slower aircraft, with a rotation speed of less than 100 knots. This fluid is not commonly used in current practices (Ritter, 2001). Type III fluids are typically light yellow in color.
4. Type IV fluids are being used in favor of Type II fluids, primarily because they provide a longer HOT (Ritter, 2001). Type IV fluids are usually dyed green in color.

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According to NASEM (2009), all ADFs and AAFs are required to meet the Aerospace Materials Specifications published by SAE: 1424 De-icing/Anti-Icing Fluid, Aircraft, SAE Type I and 1428 Fluid, Aircraft De-icing/Anti-icing, Non-Newtonian, SAE Types II, III, and IV.

De-icing operations for large commercial aircraft, on average, requires approximately 1 gallon of fluid per 1000 square feet of aircraft surface in order to properly de-ice an aircraft. At some airports, up to 40 percent of this fluid ends up being discarded (EPA, 2012). This can be due to the lack of a collection system as well as a procedure for recycling the fluid. The primary problem being investigated is the pollution caused by poor stormwater management and the current need for a more effective collection methods of aircraft de-icing fluid for small hub commercial airports.

Potential solutions for this problem include the construction of centralized de-icing pads, installation of on-site glycol recycling plant, construction of aeration ponds for stormwater filtration glycol vacuum vehicles, storm drain inserts, use of temporary aircraft de-icing pads to name a few. Each of these solutions have advantages and disadvantages that will be thoroughly discussed throughout this report. In this design project, the design of ADF and AAF collection systems is based on the operations size of airport. We had primarily designed a system design for non-hub primary airports, because of their operation size. Our team has also developed safety risk assessment, cost-benefit assessment, and potential impacts of the proposed design as shown in this report.

2. Summary of Literature Review

ADF and AAF fluids primarily consist of ethylene and propylene glycols (ACRP Fact Sheet 1, 2009). Diluted ethylene and propylene glycols are less toxic in water but the additives in the ADF and AAF solutions can be more toxic to lifeforms in water whereas, ethylene glycol is toxic for mammals. Since ethylene and propylene glycols are organic hydrocarbon chemicals, they consume oxygen proportional to the amount of oxygen consumed by organic matter of the same mass in order to oxidize. The amount of oxygen used during this process is referred to as biochemical oxygen demand (BOD) (Dow Chemicals, 2017). BOD values are high for ADF's. Hence, collecting de-icing fluid runoff is important in order to control pollution of vegetation and ground water table. Comprehensive Environmental Response, Compensation and Liability Act (CERLA) requires reporting of the usage of ethylene glycol.

During winter operations at the airports, airlines or fixed-based operators may use ADF and AAF fluids to deice aircraft. The ADF and AAF runoff is collected and disposed into the stormwater management system of the airport. To ensure protection of water quality and to control environmental impacts due to de-icing runoff, federal and state regulators have made it mandatory to collect and treat ADF runoff (Switzenbaum et. al., 2001). According to the Environmental Protection Agency (EPA) (2000, p. 1-4), "21 million gallons of ADF (50 percent glycol concentration) are discharged to surface waters annually from airport de-icing operations across the country, and an additional 2 million gallons are discharged to publicly owned treatment works (POTWs)". To control pollutant discharge from airport de-icing operations, the EPA had signed for publication in the Federal Register technology based effluent limitations guidelines. Under Title III of the Clean Water Act, effluent guidelines are issued to existing sources and new sources by EPA and implemented by National Pollutant Discharge Elimination System (NPDES) (EPA, 2012).

In order to comply with the EPA's 1990 stormwater program and state regulations, airports have implemented apron collection systems as a stand-alone approach or along with additional collection practices such as glycol collection vehicles. The rate of collection is dependent on the local weather conditions and drainage system of the airports. Also, increased volumes of de-icing activities increase the scope of increased stormwater contamination. Even though structural stormwater collection and filtration systems, infiltration trenches and bioretention areas are implemented to improve water quality, there are also non-structural practices used that could improve stormwater management at airports (North Carolina Department of Environment and Natural Resources, 2012)

2.1 Glycol Collection Methods and Filtration (Alternatives)

This section contains information of the glycol collection and recycling alternatives used across the airport in the United States.

2.1.1 Centralized De-icing pads

“Centralized de-icing pads restrict aircraft de-icing to a small area, minimizing the volume and allowing for the capture of de-icing waste” (EPA, 2002). De-icing pads are designed such that the captured spent ADF is sent to storage tanks or filtration units. Usually these de-icing facilities are located at head of runways mostly or near gate areas, such that de-icing operations will be done just before aircraft take-off. The location selected is such that less ADF and AAF will be used for de-icing operations, thereby reducing the amount of glycol entering the environment. Also, spent fluids captured could be reused in de-icing operations due to higher glycol concentrations, provided they deem fit for use as per the FAA requirements.

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According to the EPA (2002), large airports like Denver International Airport, Salt Lake City International Airport, Pittsburgh International Airport, Baltimore Washington International Airport, Dayton International Airport, Minneapolis St. Paul International Airport, and Detroit Metropolitan Wayne County Airport are presently using centralized de-icing pads for glycol collection and filtration processes. These centralized de-icing pads have a concrete or asphalt platform, a drainage collection system and wastewater storage facilities. The platforms are grooved such that the drainage of fluids is smooth without any excess retention of these fluids. The downside of this alternative is that they cost a lot. For example, it costed Denver International Airport about \$2 million per pad. This huge investment for a non-hub primary airport is impractical as they have a comparatively smaller operation size.

2.1.2 Apron Collection System

“This practice provides a means of collecting deicer-laden runoff from terminal and freight apron surfaces by modifying existing drainage infrastructure or installing new conveyance infrastructure to allow de-icing runoff to be diverted to containment and storage” (ACRP Report 14, Fact Sheet 21, 2009, p. 1). To prevent exfiltration of the ADF runoff into the ground, potentially polluting the vegetation and groundwater, sanitary sewer technologies are applied to the existing stormwater drainage systems. Most of the airports use storm drain inserts which can be manually closed during aircraft de-icing operations such that the de-icing runoff will not be mixed with the stormwater. Usually when storm drain inserts are closed, glycol vacuum vehicles are used to collect the de-icing fluid runoff from the apron. Once the de-icing operations and glycol collection are completed, the valves can be opened such that uncontaminated stormwater can pass through the drain into the stormwater drainage system. The downside of making modifications to apron collection system is that they are comparatively costly and cause disruptions to the airport operations due to construction works.

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The stormwater is then filtered and released into the Publicly Owned Treatment Works (POTW). Few airports also have detention ponds, tanks or underground basins to separate the solids and decrease the oxygen demand before the runoff is diverted to nearby water bodies. Some of the airports generating higher volumes of ADF runoff into the stormwater have aeration ponds. In these aeration ponds, glycol runoff is treated by addition of oxygen to the stormwater as the BOD of the glycols is higher. By aerating the stormwater, aquatic life and vegetation will not be affected in the areas into which the treated stormwater has been released into.

2.1.3 Glycol Recovery Vehicles (GRV)

As previously mentioned in the report, GRV's are also known as sweeper vacs or mobile collection units are used in combination with other passive glycol collection practices. These vehicles have access to any place where an aircraft has been deiced on the ramp. Depending upon the requirement of the glycol collection program, these vehicles collect as much as ADF runoff or they target only the most concentrated runoff.

Typically, these vehicles help recover about 23 to 53 percent of glycol on an annual basis from the collection areas (EPA, 2000). The more the number of collection vehicles, more is the effectiveness of the glycol collection program. The glycol collected from these operations could also be used for effective glycol programs as the concentration of glycol would be more in the collected runoff. As this method is inexpensive when compared to centralized de-icing pads or making modifications to apron collection systems, most of the airports are actively used these vehicles. "Several U.S. airports currently use vacuum vehicles, including Minneapolis-St. Paul International Airport, Baltimore Washington International Airport, Indianapolis International Airport, Bradley International Airport, Portland International Airport, Washington Dulles International Airport, Ronald Reagan Washington National Airport, and General Mitchell International Airport. The U.S. Air Force

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has also experimented with glycol vacuum vehicles and currently uses them at several bases” (EPA, 2000, p. 6-32).

2.1.4 Temporary Aircraft De-icing Pads

“Temporary aircraft de-icing pads are specially designed platforms used to collect contaminated wastewater generated during aircraft de-icing and anti-icing operations” (EPA, 2000, p. 6-34). These temporary de-icing pads are mats made out of reinforced rubber or polypropylene. They tend to tolerate temperatures ranging from -50 °C to 50 °C (-58 °F to 122 °F) and are capable of collecting 75% of the sprayed ADF which has higher concentrations of glycol ranging from 25.8% to 32.5% (EPA, 2000). These mats also have vacuum pumps which transfer the liquid from the containment area to storage tanks. Depending upon the glycol concentration, the liquid in the storage tank could be treated, recycled or disposed. The largest available containment mat can accommodate an aircraft as big as Boeing 747 (EPA, 2000).

3. Regulations

The team identified seven regulations that may be necessary for the proposed solution.

- a. Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) – “The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was enacted by Congress on December 11, 1980. This law created a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment” (EPA, 2018).
- b. “Storage and handling protocols are frequently incorporated as requirements of SWPPPs and written deicer management program plans, and may be explicitly required by

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National Pollutant Discharge Elimination System (NPDES) permit conditions” (ACRP Report 14 – Fact Sheet 2, 2009, p. 2)

- c. *AC 150/5300-14C - Design of Aircraft De-icing Facilities* – “This advisory circular (AC) provides standards, specifications, and guidance for designing aircraft de-icing facilities.” (FAA, 2013).
- d. *29 CFR 1910.134* - “Chemical goggles, hand gloves, and clean body protection (rain suits) are required for handling of glycol; describes respiratory protection requirements for airborne exposure (specifically for ethylene glycol)” (ACRP Report 14, Fact Sheet 10, 2009, p. 1).
- e. *AC 150/5300-13A – Airport Design* – “The FAA recommends the standards and recommendations in this AC for use in the design of civil airports. The standards and recommendations contained in this AC may be used by certificated airports to satisfy specific requirements of Title 14 Code of Federal Regulations (CFR) Part 139, Certification of Airports, subparts C (Airport Certification Manual) and D (Operations). Use of this AC is mandatory for all projects funded with federal grant monies through the Airport Improvement Program (AIP) and/or with revenue from the Passenger Facility Charges (PFC) Program.” (FAA, 2014).
- f. *AC 150/5320-5D - Airport Drainage Design* – “This AC provides guidance for engineers, airport managers, and the public about the design and construction of airport surface storm drainage systems; and subsurface drainage systems for paved runways, taxiways, and aprons” (FAA, 2017).
- g. “Assurance that the location of the frac tanks does not violate FAR Part 77 imaginary surfaces” (ACRP Report 14, Fact Sheet 27, 2009, p. 2)

4. Problem Solving Approach

The team's approach to addressing stormwater contamination issue due to the Aircraft de-icing fluid (ADF) runoff at non-hub primary airports is to collect and recycle the spent fluids. Since, Northern and Midwest regions in U.S. receive higher snowfall amounts and have lower temperatures during winters, it is imperative that active aircraft de-icing operations be performed in this region during winter operations. Most of the airports in this region already have an ADF runoff collection, filtration and recycling systems in place, especially large hub airports. There are 24 non-hub primary airports in the states of Indiana, Illinois, Ohio, Michigan and Wisconsin whose operational size may limit the cost-effectiveness of collection and recycling process.

Typically, a medium sized airport located in the Midwest region of the U.S. would have to spend about \$3 to \$5 million to construct glycol recycling plants, \$20 million to \$25 million for construction of centralized de-icing pads and retention ponds and about \$100,000 to \$500,000 for treatment charges to a POTW (DOT/FAA/AR-00/55). As glycol based ADF's have a high BOD, POTW's either charge higher fees for treatment or refuse to accept the contaminated stormwater from airport stormwater drainage systems. Hence, collection of ADF runoff is necessary to decrease the contamination and meet with NPDES permit requirements for wastewater disposal limits.

In order to suggest a cost-effective glycol collection method for non-hub primary airports, the team suggests using a temporary de-icing pad. In this project, the team suggests using a Latimat or Kyoto containment mat that is offered by Juniper Aircraft Service Equipment ("The Juniper", n.d.; Latimer, 2020¹). The containment system consists of a polyurethane material containment mat, a motorized hose reel to store and dispense the mat, and stainless-steel tank for storage. The dimensions of the containment can be customized

¹See References for Mr. Latimer's Patents and Errata on page 37

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depending on the aircraft size. The containment system also has a vacuum unit which has a vacuum motor head powered by batteries, and this helps inflate the sides of the mat to contain the ADF runoff. The containment system also has a vacuum floor tool to collect the ADF runoff, and it is stored in the stainless-steel tank. Portable weights are provided to secure the containment mat in windy conditions. The unit is additionally supplied with a battery charger, rubber squeegee, and a repair kit in case of punctures or tears to the mat.

Post collection of the spent ADF runoff, the fluids can be collected by the industrial glycol recyclers or antifreeze recyclers available in the vicinity of the airport locations. The chemical composition of automobile antifreeze and aircraft de-icing fluid is mostly glycols (Uekusa, Matsuzaki, 1995; Wiesenfeld, Meyers, Leicht, 1999). According to FAA (1994, p.14), “Use of automotive antifreeze for de-icing is not approved as its holdover time and its effects on aircraft aerodynamic performance are generally unknown”. However, the glycols in the spent ADF’s can be recycled by the glycol recyclers. For example, we have chosen the non-hub primary airport for our case study to be South Bend International Airport (SBN) based on its location and operation size. Using google maps, the team had identified 8 glycol and antifreeze recyclers within a 5-mile radius around SBN namely:

1. O’Reilly Auto Parts
2. AutoZone Auto Parts
3. NAPA Auto Parts
4. Kowalski Auto Parts City Inc
5. OmniSource Corporation
6. LKQ Pick Your Part – South Bend
7. Paul’s Auto Yard
8. Ridge NAPA Auto Parts and Paint

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We used a flowchart to show the steps included in the process map using inputs, outputs, decisions as well as process steps. A process map of the system design proposed by the team is shown in figure 4.

ADF and AAF Containment Mat Flowchart

Viewpoint: Fluid Containment Operations Team

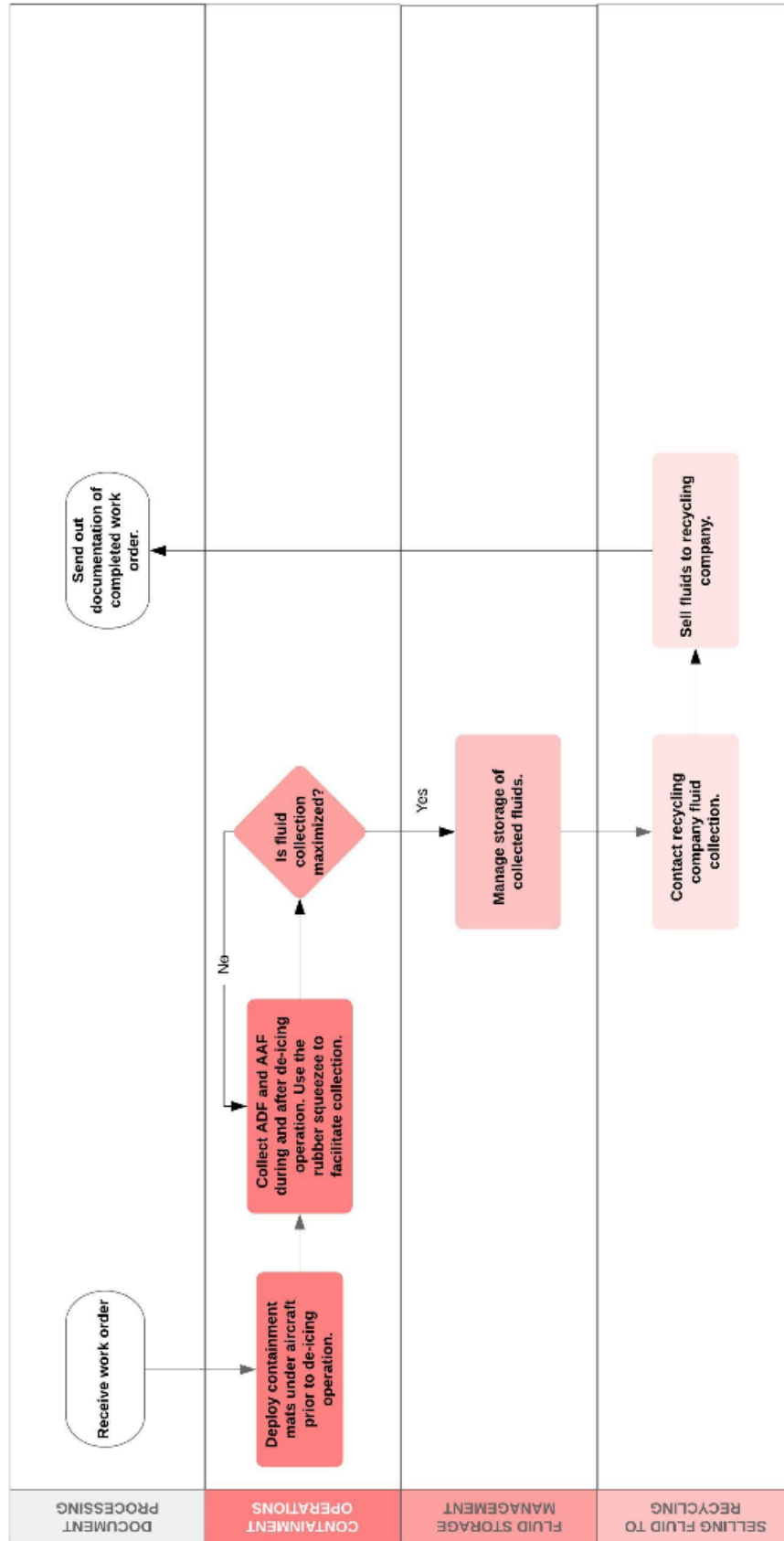


Figure.1 ADF and AAF Containment Mat Flowchart

5. Safety Risk Assessment

According to the Advisory Circular 150-5200-37 (FAA, 2012), the safety risk is defined as the composite of the likelihood (risk) of the potential effect of a hazard, and predicted severity of that effect. The key word ‘hazard’ here is “defined as any existing or potential condition that can lead to injury, illness, or death to people; damage to or loss of a system, equipment, or property; or damage to the environment” (FAA, 2012). Building upon these concepts and to ensure the safe operation and contain the associated risk at a minimum level, our team used the FMEA (Failure Mode & Effects Analysis) metrics to conduct our safety risk assessment. FMEA is a methodology that allows organizations to anticipate potential failure modes and their occurrence frequency during the design stage of a project. It also takes into consideration the current control in place that can detect or prevent the potential failure. Based on the nature of our project, our team identified several potential failure modes. We used scales for severity, occurrence and detection, to rate the failure modes. We calculated the RPN (Risk Priority Number) for each of the item using the formula: $RPN = \text{Severity} \times \text{Occurrence} \times \text{Detection}$. The 3 scales we developed are shown in Figure.2, Figure.3 and Figure.4.

Occurrence Scale			
Probability of Failure	Time Period	Per Item Failure Rates	Ranking
Very High: Failure is almost inevitable	More than once per day	≥ 1 in 2	10
	Once every 3-4 days	1 in 3	9
High: Generally associated with processes similar to previous processes that have often failed	Once every week	1 in 8	8
	Once every month	1 in 20	7
Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions	Once every 3 months	1 in 80	6
	Once every 6 months	1 in 400	5
	Once a year	1 in 800	4
Low: Isolated failures associated with similar processes	Once every 1 - 3 years	1 in 1,500	3
Very Low: Only isolated failures associated with almost identical processes	Once every 3 - 6 years	1 in 3,000	2
Remote: Failure is unlikely. No failures associated with almost identical processes	Once Every 7+ Years	1 in 6000	1

Figure.2 Occurrence Scale referred from SAE J1739 (2009)

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Detection Scale		
Detection	Criteria: Likelihood the existence of a defect will be detected by process controls before next or subsequent process, -OR- before exposure to a client	Ranking
Almost Impossible	No known controls available to detect failure mode	10
Very Remote	Very remote likelihood current controls will detect failure mode	9
Remote	Remote likelihood current controls will detect failure mode	8
Very Low	Very low likelihood current controls will detect failure mode	7
Low	Low likelihood current controls will detect failure mode	6
Moderate	Moderate likelihood current controls will detect failure mode	5
Moderately High	Moderately high likelihood current controls will detect failure mode	4
High	High likelihood current controls will detect failure mode	3
Very High	Very high likelihood current controls will detect failure mode	2
Almost Certain	Current controls almost certain to detect the failure mode. Reliable detection controls are known with similar processes.	1

Figure.3 Detection Scale referred from SAE J1739 (2009)

Severity Scale		
Effect	Criteria: Severity of Effect	Ranking
Hazardous	May expose operators to danger, life threat, or death	9~10
Very High	Major disruption of service involving material loss, resulting in either associate maintenance or harm to operators	8
High	Minor disruption of service involving material loss and resulting in either associate maintenance or harm to operators	7
Moderate	Major disruption of service not involving material loss and resulting in either associate maintenance or harm to operators	6
Low	Minor disruption of service not involving material loss and resulting in either associate maintenance or harm to operators	5
Very Low	Minor disruption of service involving material loss that does not result in either associate maintenance or harm to operators	4
Minor	Minor disruption of service not involving material loss and does not result in either associate maintenance or harm to operators	3
Very Minor	No disruption of service noticed by the operators and does not result in either associate maintenance or harm to operators	2
None	No Effect	1

Figure.4 Severity Scale referred from SAE J1739 (2009)

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To evaluate the whole process in a detailed and comprehensive manner, we first divided the process into 3 parts: de-icing operation, collection & storage, and transporting. After that, we identified as many potential failure modes as possible under each part. Then we listed the failure effects, potential causes and current controls for each potential failure mode and gave each of them a rating based on the 3 scales. The final results are shown in the following Figure.5.

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact if the failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?		
Deicing Operation	Workers Slippage	<i>Physical Bodily Harm</i>	5	<i>Carelessness, worn out footwear</i>	6	<i>Slip-resistant shoes, training</i>	2	60
	Inhalation of deicing fluid vapor	<i>Chemical Bodily Harm</i>	5	<i>Insufficient Equipment Protection (mask)</i>	7	<i>No controls/PPE in place</i>	1	35
	Ergonomic strain	<i>Physical Bodily Harm</i>	5	<i>Improper Handling</i>	7	<i>Training</i>	2	70
	Electric shock	<i>Physical Bodily Harm</i>	10	<i>Glycol Recovery Vehicle - live wire end</i>	2	<i>Rubber gloves, insulated footwear</i>	1	20
	Ingestion of deicing fluid (larger amounts/intentional)	<i>Chemical Bodily Harm</i>	5	<i>Carelessness</i>	4	<i>Training</i>	2	40
	Deicing fluid splashed in eye	<i>Chemical Bodily Harm</i>	6	<i>Improper handling of Spray boom</i>	4	<i>Training</i>	2	48
Storage (at airport)	Storage tank leakage	<i>Wastage of collected fluids</i>	4	<i>Wear and tear</i>	3	<i>Pressure Monitor System / Alarm system</i>	1	12
	Storage Tank Breakage	<i>Contamination of environment</i>	8	<i>Improper Handling</i>	2	<i>Pressure Monitor System / Alarm system</i>	2	32
Transporting Collected Fluids	Spills during transportation	<i>Wastage of fluids / Public inconvenience</i>	7	<i>Mechanical Vibration</i>	2	<i>Pressure Monitor System / Alarm system</i>	2	28
	Car crash during transport	<i>Loss of fluids / Driver exposed to danger</i>	10	<i>Reckless driving</i>	4	<i>Safety Driving Training</i>	2	80
	Vehicle explosion	<i>Loss of fluids / Driver exposed to danger</i>	10	<i>Vehicle Design</i>	2	<i>Regular Vehicle Maintenance</i>	1	20
	Contamination of fluid	<i>Collected fluid is contaminated</i>	4	<i>Snowfall / Object falling / Animal activity</i>	2	<i>Protective Cover</i>	2	16

The major issues we addressed are harm to operators, disruption of service and material loss. We evaluated each of the failure modes listed in the table where any of the 3 issues exist. We then prioritized the potential failure mode by sorting the calculated RPN.

6. Cost-Benefit Assessment

In this section, the team estimated the costs involved and presented in a series of cost tables. The project is divided into four stages to illustrate the costs of the project development.

Initial alpha research and development: Table 1 shows the costs associated with the initial alpha research and development stage of the project. These costs include labor costs for system development and research at Purdue university. The time taken for this phase of the project is 4 months and it is a one-time cost.

Table 1				
<i>Research and development costs (Alpha)</i>				
Item	Rate	Quantity	Subtotal	Remarks
Labor - University Design Competition				
Student	\$25/h	168 h	\$4200	3 Students - 56 h each
Faculty Advisor	\$100/h	42 h	\$4200	1 Faculty Advisor
Subtotal			\$8400	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers,2016)				

Beta Research and Development: Table 2 shows the costs associated with the beta system research and development stage of the project. These costs include prototype purchases of containment mat, storage units and glycol collection vehicle, and the labor costs for airport planners, airport staff and ramp agents for prototype implementation and operations. The estimated amount of time taken for this phase of the project is one-month. If the airport doesn't already have a Glycol Collection Vehicle, a purchase could be made as it ensures additional collection of the ADF runoff on the ramp.

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Table 2				
<i>Pre-production Research and Development (Beta)</i>				
Item	Rate	Quantity	Subtotal	Remarks
Labor - On-site study and planning				
Airport Planner*	\$60/h	80 h	\$4,800	1 worker - 80 h each Environmental and safety assessment of the design, updating airport certification, emergency and security manuals, and also check with FAA airport design requirements
Ramp Agents	\$23/h	1,440 h	\$33,120	6 workers for 240 h each/month (8h/day) Containment mat handling and spent ADF collection
Airport Sr. Staff	\$50/h	240 h	\$12,000	Supervision (8 h/ day)
Containment Mat	\$175,000	1	\$175,000	De-icing pad including vacuum unit
Company Representative	\$75/h	20h	\$1500	To provide operational guidance
Project Manager	\$55/h	160 h	\$8,000	1 worker – 80 h each Supervision until project implementation
Glycol Collection Vehicle	\$65,000	1	\$65,000	510 gal capacity
Aircraft De-icing Fluid runoff storage	\$12,000	2	\$24,000	2 storage tanks of 10,000 gal
Training	\$1,400	2	\$2,800	4 trainers + 12 workers for 3 h – twice a month
Subtotal			\$326,220	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis(Byers,2016)				

System Installation and Implementation Costs: Table 3 shows the costs associated with the implementation process post successful beta testing. These costs include an additional containment mat to keep up with the departure operations at the airport. Also, a marketing team will be employed so as to spread the word of sustainable practices implementation at the airport contributing towards greener community benefits.

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Table 3				
<i>System Installation and Implementation</i>				
Item	Rate	Quantity	Subtotal	Remarks
On-site Installation (Airport)				
Containment mat	\$ 175,000	1	\$175,000	Need addl. unit for efficient operation
Company Representative	\$75 / h	20h	\$1,500	To provide operational guidance
Marketing				
Labor	\$60/h	320 h	\$19,200	Team of 2 for 8h/day (1 month) – green initiative
Total			\$195,700	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers,2016)				

System Operations and Maintenance costs: Table 4 shows the costs associated with the annual operations and maintenance costs. This table shows a detailed breakdown of elements involved in operation and maintenance procedures of the overall system. Except for containment mat and storage unit maintenance estimated costs, remaining estimated costs included in this table have been calculated over a time period of 8 months. The team had assumed winter operations time period to be 8 months (November – April).

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Table 4					
<i>System Operations and Maintenance</i>					
Item	Rate	Rate	Quantity	Subtotal	Remarks
System Operation and Maintenance (Annual Costs)					
Labor - Operation Personnel + Maintenance [On-site (Airport)]					
Ramp Agents		\$23/h	23,040 h	\$529,920	12 workers – 240 h/month
Airport Staff		\$50/h	1,920 h	\$96,000	Supervision (8 h/ day)
Battery charging		\$8/day/vacuum unit	2	\$3,840	240 days of operations
Battery replacement		\$120/battery	2batteries/year	\$240	
Storage Unit maintenance		\$300/month	12	\$7,200	2 units
Training		\$2,800/ month	8	\$22,400	4 trainers + 12 workers for 3 h – twice a month
Containment mat maintenance		\$500/month	12	\$12,000	Includes wear and tear of 2 containment units
Subtotal				\$671,600	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers,2016)					

Benefit Analysis

Our project proposes a solution so that higher glycol concentration volumes of the spent ADF collected. Since we had considered SBN for our case study, we had chosen the operation size of SBN for the benefit analysis calculations. Spent fluid with higher glycol concentration can fetch higher resale market value. Thereby, this could possibly be a main source of revenue generation for the airports. Benefit to cost assessment is shown in Table 5.

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Table 5				
<i>Benefit to cost assessment</i>				
Item	Subtotal	Qty	Total	Remark
Overall costs involve				
Alpha R&D	\$8,450	1	\$8,400	One-time costs
Beta Test	\$318,220	1	\$326,220	One-time costs
Installation & implementation	\$195,700	1	\$195,700	One-time costs
Operation and Maintenance	\$671,600	10	\$6,716,000	For a projected time period of 10 years
Total cost			\$7,246,320	
Return on Investment (Benefits)				
Collected glycol	\$885,938/year	10 years	\$8,859,380	Calculation shown in table 6
Benefit to cost		10 years	1.22	For a projected time period of 10 years

Table 6		
Item	Qty.	Remarks
ADF used for de-icing operations/aircraft*	250 gal	Estimated average/ aircraft
ADF collected/aircraft	175 gal	Assuming 70% vol. collected (EPA, 2000)
Price of spent ADF/usg	\$1.25/gal	
No. of aircraft/day	18	Assuming 18 out of 23 aircraft undergo de-icing operations
De-icing operations time/year	7.5 months	Assuming active de-icing operations don't occur for half month
Money received on spent ADF	\$885,938/year	
*Aircraft here is considered to be a Regional Jet (RJ) as this is the type of aircraft used for typical commercial operations at non-hub primary airports (SBN).		

7. Industry Interaction

The team contacted the following experts for guidance:

- a. Dr. Stewart W Schreckengast, PhD, FRAeS (Limited Term Lecturer – Purdue University)
- b. Ms. Stephanie Brown (Program Manager, Aviation Safety – Purdue University)
- c. Mr. Bill Kelly (CM, Delta Airport Consultants)

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- d. Mr. Richard Allabaugh (Airport Operations, Manassas Regional Airport)
- e. Mr. Jason Hart (Former Airport Manager – Delphi Municipal Airport)

From our conversation with Dr. Stewart Schreckengast, we understood that allocating a place away from the gate for the de-icing operations would be convenient, as placing an additional containment system on the ramp operations area would crowd the area. We also learned that by airports having existing contractual agreements with recyclers, disposal or recycling of jet engine oil could be actively implemented. Thereby, solving one more problem by decreasing the percentage of petroleum product contamination in the stormwater discharged by the airports.

When talking with Ms. Stephanie Brown, we learned that de-icing operations are not limited to cold regions but are also prevalent in the regions down south, such as Atlanta and Phoenix to name two. So, the proposed system could be implemented as a backup in major airports of two regions down South too. This encourages the implementation of sustainable ADF and AAF collection and recycling methods across most of the states in the country.

In discussions with Mr. Bill Kelly, we understood the importance of implementation of locally regulated Stormwater Pollution Prevention Plan, and about the spill containment of the fluids. We also learned that our solution has added benefits. If proved viable, it could be a means of provision of Clean County Commission grants for the airports encouraging sustainable practices. Similarly, in conversation with Mr. Jason Hart, we understood how important it is for an airport to rebrand itself as a greener venture so as to build a positive brand image in the community and the market too.

From our conversation with Mr. Richard Allabaugh, we understood that our solution cannot be scaled down, as it might not be a profitable venture for GA airport management to collect ADF runoff for recycling. We understood that it might be a bit impractical to scale

down as the glycol collected per annum is not more than few hundreds of gallons for most of the GA airports

8. Projected Impacts of Design

8.1 How this project meets ACRP goals

Application of de-icing fluids at airports plays an important role in the safe operation of flights during winter season. De-icing one commercial aircraft typically results in a pollution load approximately equivalent to the daily wastewater discharge of more than 5000 inhabitants (Backer, Smith & Habben, 1994). In the United States, most of the large airports already have an ADF recycling program in place. However, for many medium-sized or small-sized airports, it is not the case. The proposed project reduces the amount of de-icing fluids produced at non-hub primary and possibly small to medium size airports by recycling spent de-icing fluids. From a sustainability perspective, such a program fits the ACRP's goal well.

8.2 Sustainability Assessment

The sustainability assessment utilizes the EONS (economic vitality, operational efficiency, natural resources, and social responsibility) model to assess the sustainability impact of the proposed solution. This model is utilized by the FAA since 2017 (FAA, 2017). One definition of sustainability is “the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs” (SGF working paper). The solution has been designed to create a pathway to new revenue for the airport as well as help the airport be more sustainable overall. The following impacts will be discussed with this definition and the EONS model in mind.

8.2.1 Operational Impact

The usage of containment mats will make the overall process for ADF and AAF collection very easy to complete. The containment systems have a built-in storage capability

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and facilitate collection through a vacuum system. This being the case, the overall responsibility for airport ramp personal is greatly reduced and will allow for an easier implementation of the process. These mats are also foldable, allowing for easier mobility and storage of the mats when they are not in use.

8.2.2 Economic Impact

Of the four impacts, the economic impact will be the most immediate impact. With the implementation of de-icing pads, the airport will be able to generate revenue by selling the collected ADF and AAF. Revenue can be seen after the first batch of collected fluids is sold to the recycling company and, gradually, will result in an overall profit. In addition to a new source of revenue, the airport will also be able to see a reduction in personnel safety incidents during de-icing operations. The use of mats will result in a lower chance of personnel slipping on the fluids, which in turn will result in fewer safety incidents. This will overall result in a lower frequency of worker's compensation payment and potentially the insurance provided to employees.

8.2.3 Environmental Impact

The new solution will allow airports to greatly decrease contamination of stormwater. As mentioned before, through the collection method, the ADF and AAF runoff will largely be collected and sold. The airport will be helping the community by preventing further contamination of stormwater by glycols. This in turn will greatly reduce the pollution of the water bodies in the vicinity of the airport and will also decrease the negative impact on aquatic life, vegetation and ground water table.

8.2.4 Social Impact

The social impact is the reduction in contamination of stormwater in the community at large. Contaminated stormwater will eventually require further filtration by the county the

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airport resides in. With a reduction in the contaminated stormwater, it is possible for the county to save costs and utilize that money on helping improve the community. As there will be more work that needs to be completed with the need to deploy the mats at each de-icing operation, this could provide more jobs for others in the community. Overall, the implementation of the temporary containment system will reduce contaminated stormwater and provide more jobs in the community.

Appendix A: List of Complete Contact Information

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Appendix B: Description of the University

About Purdue University (www.purdue.edu)

“Purdue University is a vast laboratory for discovery. The university is known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It’s a place where those who seek an education come to make their ideas real — especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue’s role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that’s without rival.

About Purdue University’s School of Aviation and Transportation Technology

Purdue University’s School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue’s Aviation and Transportation Technology undergraduate majors are world-class educational programs. Take a virtual tour of the school, including Flight Operations, the Simulator Building, Terminal Building, Laboratories and Research Centers, and the Niswonger Building of Aviation Technology”.

Aviation and Transportation Technology Vision Statement

“The School of Aviation and Transportation Technology will be the recognized global leader in aviation technology education through excellence in faculty, students, curricula, laboratories, and mutually beneficial partnerships”.

Appendix C: Description of Non-University Partners Involved in the Project

Not Applicable

Appendix E: Evaluation of the Educational Experience Provided by the Project

Students (Suvarna Veeravalli, Sadat Ahsan, Can Jiang)

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

The competition provided a meaningful learning experience as our team was able to go through an in-depth assessment on implementing an improved solution for ADF and AAF containment at airports. The team was forced to learn how to delegate work amongst ourselves and adhere to deadlines we would set. Time management was key to our success. In addition, we became more familiar with proposal writing and benchmarking solutions. We felt as though the level of work needed to be higher than the typical level that would otherwise be acceptable in an educational setting. In order to provide a well thought out project, the team ensured the proper effort was put into each section and emphasized working on the important topics. Because of these lessons we feel that this project held a meaningful learning experience.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

The team had issues with meeting deadlines we would set for ourselves. At numerous points we would prioritize other work and some work meetings would not be as productive as we had hoped. In order to overcome this, we made sure to hold one another accountable for their work and double check each other's completed sections in order to make sure the information flows logically.

3. Describe the process you or your team used for developing your hypothesis.

The team's goal is to improve current stormwater management and de-icing fluid containment at airports. In order to develop an effective hypothesis, we developed a literature review of our problem and investigated the different solutions for ADF and AAF containment. After investigating the different solutions, we determined that the containment mats would be ideal for what we wanted to accomplish. As such this project was centered around the mobile containment mats.

4. Was participation by industry in the project appropriate, meaningful and useful?

Why or why not?

The industry interactions provided our team with valuable input. The industry experts provided useful viewpoints that we did not consider due to the lack of experience on the team.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

This project has increased our overall knowledge about project management and working in teams. We believe that the experiences gained throughout this project, both good and bad, will be important lessons that we can learn from for future projects of similar nature. The team learned an improved a variety of skills: time management, project management, and effective benchmarking of current solutions.

Faculty (Mary E. Johnson, Ph.D)

1. Describe the value of the educational experience for your student(s) participating in this competition submission.

For students in my aviation sustainability course, this competition has great value primarily due to the challenges and topics coming from real airports, the interactions with industry experts, and the structure of the project report being a proposal in response to the competition guidelines (a request for proposals). This competition encourages my students to

do deep dives into not only what to do to improve airports, but also to quantify the risks, costs, and for my students, to describe the impact that these projects may have on airport sustainability. One key to the educational value of the experience is the interactions with industry experts from airports, airlines, and consultants. These interactions energized the team as they realized that these airport challenges are truly important and that with some tweaking or changes, their proposed solution may become for a better solution.

2. Was the learning experience appropriate for the course level or context in which the competition was undertaken?

Yes. This is a graduate level applied aviation sustainability course where the airport improvement projects are also evaluated on the sustainability analysis. The required literature review was enlightening for this team as learned about de-icing and anti-icing at airports, and the different ways to collect and recycle the fluids.

3. What challenges did the students face and overcome?

The biggest challenge for this team was learning the details of de-icing and the specific roles of the airport and the airlines as they interact to serve the public. This team had to collect and read information from the FAA and the EPA, along with other sources.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes. This competition inspires students to learn more deeply, to seek out regulations and guidance, to read the available literature, and to learn how to learn - skills needed for the rest of their careers.

5. Are there changes to the competition that you would suggest for future years?

Yes, consider including a sustainability analysis as a required section of the report.

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Errata

Page 12. 'designed by' was replaced with 'offered by' Juniper; Latimat was added; Kyoto Containment was removed as a citation; a new citation was added to refer to Douglas Latimer; and a footnote was added to direct readers to this page.

Latimer, Douglas (2020). *Personal communication* from Mr. Latimer with Dr. Johnson regarding the patents related to the product offered by Juniper (April 2020). He is the holder of at least the three patents shown here. There may be other other Foreign Patents and other Pending patents that are not publicized. In accordance with his request, the following information is included here.

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Patent information found at <http://patft.uspto.gov/>

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