Expert Systems with Applications 38 (2011) 14899–14906

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Data mining modeling on the environmental impact of airport deicing activities

Huiyuan Fan [a], Prashant K. Tarun [b], Dachuan T. Shih [c], Seoung Bum Kim [d,*], Victoria C.P. Chen [e], Jay M. Rosenberger [e], Dan Bergman [f]

[a] Rolls-Royce Energy Systems Inc., Mount Vernon, OH 43050, USA
[b] Steven L. Craig School of Business, Missouri Western State University, St. Joseph, MO 64507, USA
[c] PFS, Tenet, 13737 Noel Road, Suite 100, Dallas, TX 75240, USA
[d] School of Industrial Management Engineering, Korea University, Seoul, Republic of Korea
[e] Department of Industrial and Manufacturing Systems Engineering, University of Texas at Arlington, Arlington, TX 76019-0017, USA
[f] Dallas-Fort Worth International Airport, 3200 East Airfield Drive, DFW Airport, TX 75261, USA

ARTICLE INFO

Keywords:
Airplane deicing and anti-icing
Water quality
Data mining
Decision trees
Glycol
Dissolved oxygen
Chemical oxygen demand

ABSTRACT

This paper presents a statistical analysis on the environmental impact of airport deicing activities at Dallas-Fort Worth (D/FW) International Airport. The focus of this paper is on aircraft deicing, which typically uses a spray of aircraft deicing and anti-icing fluids (ADAF). ADAF has a high concentration of ethylene/propylene/diethylene glycol, which shears off airfoil surfaces during takeoff and drips to the runways during taxiing. A significant portion of the glycol runs off and mixes with the airport's receiving waters during heavy deicing periods, resulting in bacterial growth that causes an increase in chemical oxygen demand (COD) and a subsequent reduction in dissolved oxygen (DO) in the receiving waters. In this study, statistical methods for data mining were employed to evaluate the impact of airport deicing activities on COD and DO in the receiving waters immediately surrounding D/FW Airport. In particular, decision tree models were developed to determine important explanatory variables for predicting levels of COD and DO in the airport's waterways. The decision tree modeling and analysis of COD determined north–south wind, glycol usage at a specific deicing pad, and monitoring site to be significant explanatory variables. The impact of glycol usage on DO was apparent as every decision tree at least one group with a median DO below 4.0 mg/l, and these low-DO groups were associated with high glycol usage. These results are crucial to D/FW Airport in their goal to minimize the potential adverse impact of deicing activities on the water quality in waterways proximate to the airport. The advantages of data-driven modeling and analysis are its cost-effectiveness due to its potential to be implemented without making major changes in physical systems, ease of application, and usefulness in making future management decisions.

1. Introduction

Airplanes on the ground or in flight are susceptible to ice formation under various atmospheric and operational conditions, such as frost, snow, freezing precipitation, etc. (Corsi, Harwell, Geis, & Bergman, 2006; FAA Report, 1996; Leist et al., 1997; Revitt & Worrall, 2003; Revitt, Worrall, & Brewer, 2001; Switzenbaum et al., 1999). Ice that adheres to the surface of the airplane wing will hinder the smooth flow of air, thereby greatly degrading the ability of the wing to generate lift. Large pieces of ice that dislodge while the airplane is in motion can get caught in a turbine engine or may impact moving propellers with a potential to cause catastrophic failure. A thick layer of ice can also lock up the control surfaces impairing its functionality. Due to these potentially dangerous consequences, deicing and anti-icing are performed meticulously at airports during winter conditions.

The application of glycol-based aircraft deicing and anti-icing fluids (ADAF) has been the worldwide standard for airplane deicing/anti-icing at airports. These fluids contain ethylene/propylene/diethylene glycol, water, and proprietary additives (the additive packages). Fluid that drips onto the ground or shears off the airplane during take-off can runoff to receiving surface waters or into the groundwater system. This has the potential to cause adverse environmental impacts in the form of an increased aquatic toxicity and oxygen depletion in the airport's receiving waters. Aquatic toxicity is potentially caused by the additive packages in ADAF, and oxygen depletion occurs due to a high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of glycols in ADAF (Corsi et al., 2006; US Environmental Protection Agency, 2000). BOD and COD are measures of water quality that quantify the amount of oxygen consumed in the biochemical and chemical oxidation processes, respectively (Masters, 1997). Thus, an increase in BOD and/or COD levels in water results in a decrease in the dissolved oxygen (DO)

* Corresponding author. Tel.: +82 2 3290 3397.
E-mail address: sbkim1@korea.ac.kr (S.B. Kim).

0957-4174/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2011.05.057

level due to consumption of oxygen in the oxidation process caused by the biochemical and chemical agents (Corsi et al., 2006).

Dallas/Fort Worth (D/FW) International Airport, located in north-central Texas, USA, is one of the world's largest and busiest international airports (Corsi et al., 2006). Typically, D/FW Airport witnesses sporadic deicing periods every winter season requiring airplanes to be deiced/anti-iced in compliance with Federal Aviation Administration (FAA) safety regulations. Deicing activities at D/FW Airport have received much attention in recent years, especially after an ecological mishap in 1999 when deicing led to a significant amount of glycol runoff into Trigg Lake (a local irrigation reservoir that receives D/FW Airport runoff), resulting in a fish kill in the lake.

In the wake of this mishap, D/FW Airport upgraded its ADAF collection facilities by constructing eight deicing source isolation pads at which spent ADAF runoff is channeled into the airport's reverse osmosis wastewater treatment system. This is hypothesized to capture about 80% of the spent ADAF runoff. The remaining 20% is due to "drip and shear" as airplanes taxi to the runway and take-off. Spent ADAF runoff due to drip and shear may discharge into local receiving waters, which can lead to a detrimental effect on the water quality and aquatic life. To compensate for the environmental impact of "drip and shear" in Trigg Lake, D/FW Airport installed 17 aerators in the lake to maintain proper DO levels and avoid any recurrence of the 1999 environmental mishap.

To monitor DO levels, D/FW Airport, in collaboration with the United States Geological Survey (USGS), implemented the collection of water quality data at nine sites in waterways surrounding the airport: an urban reference site at Blessing Branch (BLSN); an upstream reference site on Big Bear Creek at Euless/Grapevine road near Grapevine, TX (REF); an airport drainage site at Outfall #19 on an unnamed tributary to Big Bear Creek near Euless, TX (OF19); an airport site draining into Trigg Lake (IN); three sites within Trigg Lake (S1, S2, S3); a Trigg Lake outflow site (OUT); and a downstream site on Big Bear Creek at SH 183 near Euless, TX (DNST). BLSN and REF are reference sites because they are not affected by airport activities. DO levels at sites S1, S2, and S3 within Trigg Lake, and sites OUT and DNST downstream from Trigg Lake are impacted by the aerators in a Trigg lake. By contrast, sites IN and OF19 remain subject to airport activities without any remediation. Fig. 1 provides a schematic diagram of the locations of the USGS monitoring sites (dark circles) relative to the airport. The eight deicing pad locations (squares) are also shown. Each pad location has multiple slots for deicing airplanes.

With these data, D/FW Airport monitors its "end-of-pipe" BOD, COD, and DO levels to ensure that the airport's deicing/anti-icing practices are environmentally-friendly and state-of-the-art. The key to achieving the best deicing/anti-icing practice is to understand the interrelationships among deicing, water quality, meteorological, and several other relevant variables. This paper works toward identifying explanatory variables that significantly affect COD and DO levels in the airport's receiving waters, and thus assisting D/FW Airport to improve various aspects of the current practice.

2. Materials and methods

2.1. Data

The following data sets were employed for this study. The first two sets of data were collected by D/FW Airport in collaboration with the USGS. The third set was collected by the airport, and the fourth one was modified for the analysis.

1. *USGS Continuous Monitoring for six sites*: Table 1 shows the variables that were monitored at sites BLSN, REF, DNST, OF19, IN, and OUT along with the dates.

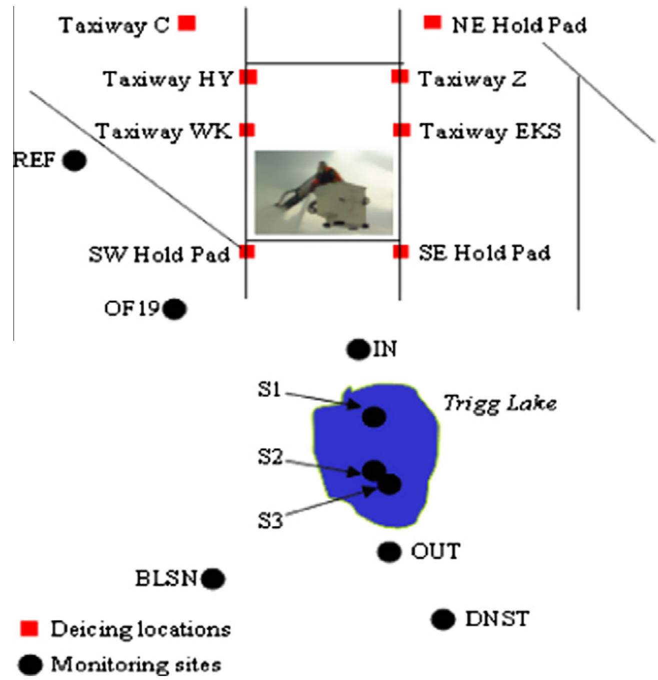

Fig. 1. Schematic diagram of monitoring sites and deicing pad locations at D/FW Airport. Circles represent the locations of the USGS monitoring sites and squares represent the deicing pad locations in D/FW Airport.

2. *USGS Manual Sampling*: The COD data were collected at sites REF, DNST, OF19, IN, and OUT, during deicing events. The major deicing periods considered were: Jan 2003: 01/12/03–01/13/03, Feb 2003: 02/26/03–02/28/03, and Feb 2004: 02/14/04–02/16/04. The minor deicing period considered was Dec 2002: 12/30/02–12/31/02, and the test deicing event was Aug 2003: 08/26/03.
3. *Airport deicing activities*: The daily ethylene and propylene glycol usage, and deicing pad usage at 8 deicing pad locations were recorded. Deicing pad locations and time durations are shown in Table 2.
4. *Airport meteorology*: The hourly data for temperature, precipitation, wind speed & direction were taken from TDL US and Canada Surface Hourly Observations (http://dss.ucar.edu/datasets/ds472.0/) for the DFW stations located at latitude from 32.5N to 33.5N and longitude from 96.5W to 97.5W for the interval 2002–2004.

The data for USGS Continuous Monitoring were automatically recorded via sensors approximately every 15–20 min. The sampling times for USGS Manual Sampling varied from several minutes to a few hours. Glycol usage from airport deicing activities was aggregated by airline and deicing pad location for each day. Meteorological data were recorded hourly. The following three data sets were constructed to conduct the analyses.

1. Data Set 1: Hourly-averaged USGS Continuous Monitoring data for the six sites.
2. Data Set 2: Merged data set consisting of DO data from USGS continuous sampling, airport deicing activities, and airport meteorology for days on which deicing occurred during the 2002–2003 and 2003–2004 deicing seasons.
3. Data Set 3: Merged data set consisting of COD data from USGS Manual Sampling, airport deicing activities, and airport meteorology for major deicing event days in December 2002, January and February 2003, and February 2004.