Regional Environmental Monitoring System for Air Traffic (REMSAT)

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Abstract— **In the past, environmental concerns at airports have primarily focused on aircraft noise. However, there is growing concern regarding the effects of aircraft emissions on humans and the environment. The Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) govern air pollutant emission levels. Therefore, many airports will eventually need a system designed to monitor both noise and emissions, and to communicate the results to the stakeholders. To satisfy these federal standards, the team designed a prototype noise and emissions monitoring system for Ronald Reagan Washington National (DCA) and Dulles International Airport (IAD), which are operated by the Metropolitan Washington Airport Authority (MWAA).**

The design alternatives consisted of the following sensor combinations: ground-fixed, ground-mobile, and a combination of ground-fixed and ground-mobile. All combinations consisted of co-located noise and emissions sensors for the purpose of identifying the correlation between the two quantities of pollutants. These alternatives were analyzed by surveying the stakeholders' preferences to sensor performance, availability, and cost. In addition, the flight track patterns, topographical layout, aircraft noise and emission dispersion patterns, and social-political factors (population patterns, community concerns, demographics, etc.) of the counties at and surrounding the airports were analyzed in order to determine the placement of the monitoring system sensors. Based on the evaluation of these alternatives and the stakeholders' value hierarchy, a robust alternative for a preliminary system design for monitoring airport noise and emissions was selected.

I. INTRODUCTION

As global environmental awareness efforts are growing around the world, many environmental agencies are implementing air quality standards to monitor and regulate air pollutant emission levels within a determined region. The United States Environmental Protection Agency (EPA) issues the National Ambient Air Quality Standards (NAAQS). These standards govern air quality levels for pollutants that are considered to be harmful to public health and public welfare [1]. The NAAQS takes into account all sources contributing to air quality, including airports. The air pollution that is contributed from airports, mainly through airport operations, such as flight arrivals and departures, is not fully understood and there currently exists no emissions monitoring system for air traffic in the United States to monitor these pollutants. However, all major airports have a noise monitoring system. Prior to the NAAQS, the airports primary concern was to monitor and regulate noise pollution generated from airport operations. Over time there have been many measures to reduce the noise pollution generated by airports. Both aircraft noise and emissions levels may be correlated such that, in order to satisfy the NAAQS and maintain good public relations, airports will need a system to monitor both noise and emissions.

This paper presents a design for a Regional Environmental Monitoring System for Air Traffic (REMSAT) that will monitor aircraft noise and emissions for major airports through a robust system design. REMSAT will consist of co-located noise and emissions sensors that will collect and store data over a period of time. The data will be analyzed and presented to the public in an easily understood manner, such as through color-coded graphics indicating levels and locations of pollution impact. The airports under the Metropolitan Washington Airport Authority (MWAA), Washington Dulles International Airport (IAD) and Ronald Reagan Washington National Airport (DCA) were used as a case study. The presented recommendations and conclusions are particular to the airports under MWAA, but may be generalized to correspond to other airport authorities and airports.

II. SYSTEM DESCRIPTION

A. System Overview

REMSAT will serve as a system that will jointly monitor both noise and emissions levels at airports and surrounding areas. Air quality data from REMSAT, with each monitored emission measured in parts per million (ppm), will determine whether emissions levels at the airport and areas surrounding it are conforming to those defined by the NAAQS. Noise level data, with sounds measured in A-weighted decibels (dBA), will determine whether sounds generated by airport traffic are within the Day-Night Average Sound Level (DNL) community noise exposure metric, which are determined by the Federal Aviation Administration (FAA) through their Federal Aviation Regulation (FAR) part 150 analyses done

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at each airport [2] [3]. Meteorological conditions during the emissions and noise level observation periods will also be recorded via each airport's meteorological observation stations, called Automated Surface Observing Stations (ASOS). ASOS records and reports on an hourly basis meteorological information such as ambient temperature, wind speed and direction, ambient air pressure, precipitation accumulation and type, and visibility [4]. Data recorded through the system will also be of use for studying any correlation that might exist between the quantities of noise and emissions present at and near airports. The existence of such a monitoring station will be of importance to direct stakeholders as well as indirect stakeholders. REMSAT's direct stakeholders are airport operators such as MWAA, the local and state governments with jurisdiction over the surrounding communities, federal agencies such as the FAA and EPA, community members, and institutions conducting research on emissions, noise, and its long-term effects on humans. Indirect stakeholders would include entities such as the airlines and aircraft manufacturers.

B. Major Assumptions

The following assumptions were made for this system design. The REMSAT prototype design will only comprise of a network of co-located noise and emissions sensors for the passive monitoring of noise level and air quality around DCA, IAD, and the communities surrounding both airports. This area to be monitored encompasses the states of Maryland, Virginia, and the District of Columbia. REMSAT will not be designed to identify the specific sources of the emissions and noise pollution, as the technology for the exact tracing of pollution sources is currently non-existent. REMSAT will not design the sensors, but will use off-the-shelf technology that is readily available and made to detect the pollutants identified by the national standards.

Sensors will be limited to areas within a 12-nautical mile (nm) radius of each airport (see Figure 1), as most flights either arriving or departing both airports fly at 3000 feet above ground level (AGL) or lower within that radius. Flights operating above 3000 feet AGL have been found to contribute only negligible amounts of pollution at ground level, and are not considered to cause harm to public health [5]. Carbon dioxide, though identified as a greenhouse gas, will not be included in the system design as a pollutant to monitor, as it is not identified as a criteria pollutant in the NAAQS [6]. REMSAT will be designed with the assumption that the only airports in operation in the area are IAD and DCA. Nearby airports such as Andrews Air Force Base, Manassas Regional Airport, and Leesburg Executive Airport, are assumed to be non-contributing to the pollution and are not included in the monitoring network. However, if the system goes beyond this case study and is implemented, all airports within the region must be taken into consideration as they all contribute to the area's noise and emissions levels. Such an implementation will require each of those nearby airports to undergo the same procedures for having a monitoring network set up as described in the DCA and IAD case study.

Since majority of the flights operating out of IAD and DCA are commercial flights operating under FAR part 121 and use Jet-A fuel for propulsion, it is assumed that all emissions are the direct result of the combustion of Jet-A fuel. Any aircraft using 100 Low Lead fuel is considered to contribute negligible amounts of emissions and it is assumed these aircraft are not within the scope. Military air traffic, rotary wing aircraft, and general aviation (non-commercial) operations are assumed to contribute negligible amounts of emissions compared to commercial operations [7][8].

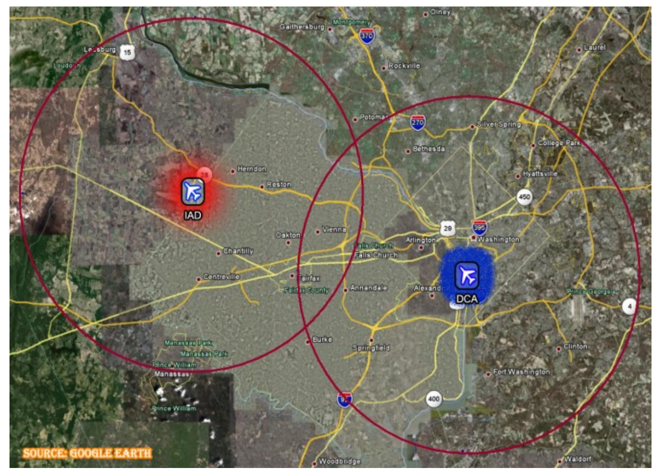

Figure 1:12 Nautical Mile radii of DCA and IAD

C. External Systems

The main function of REMSAT will be to allow stakeholders to access noise and emission data using a computer system that will both display and analyze the collected information. Power supply for the sensors, external storage for the recorded pollution data at a remote server site, and data transmission connection between the sensors and the central monitoring station are considered as part of the external system and will not be included in the design of REMSAT. Electrical power supply will be tapped from existing infrastructure. Data will be transmitted through existing telecommunications networks. For providing data, the main function interacts with three external functions that collect data, store data, and allow stakeholders to request data. To ensure that the noise and emission sensors or functioning properly, the function that collects data is maintained by an external system that produces a failure report when there is a sensor malfunction. Refer to Figure 2.1 & 2.2 for the External Systems Diagram.

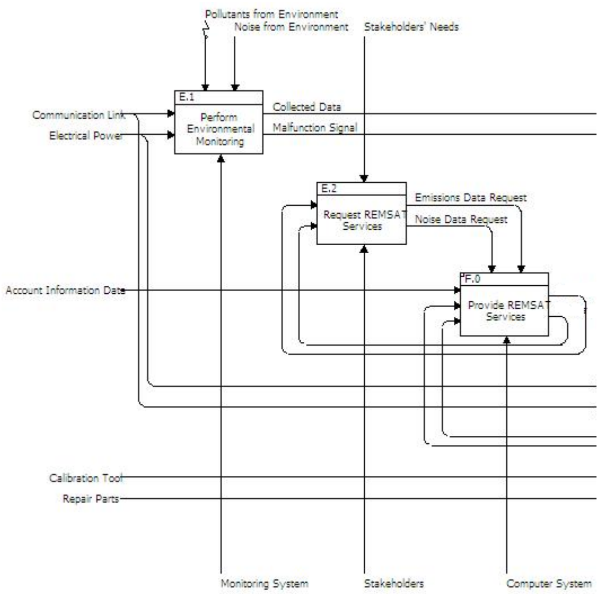

Figure 2.1: External Systems Diagram

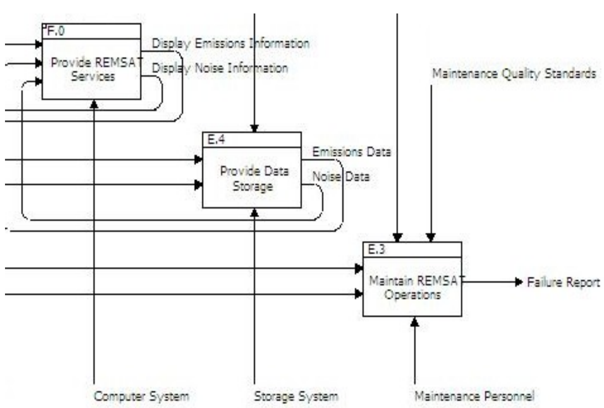

Figure 2.2: External Systems Diagram

D. Functional Architecture

The main function that provides REMSAT services has two sub-functions (Fig. 3). The first sub-function processes the noise and emission data, as well as the stakeholder's account information. If the account information is correct, a second sub-function provides an interface that allows stakeholders to view the processed data.

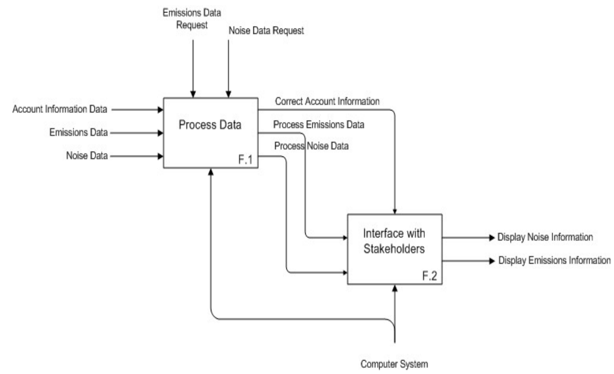

Figure 3: Functional Architecture

III. System Design

A. Design Alternatives

Three design alternatives are proposed for REMSAT. All design alternatives have co-located noise and emissions sensors at each monitoring station, and serve the same function of receiving environmental information and relaying the data to the central monitoring station. These alternatives were compared in a tradeoff analysis after monitoring station locations have been identified. The best alternative was selected based on the tradeoff analysis results. The alternatives are the following:

1) **Ground-Fixed:** All sensors are placed in fixed sensor locations on the ground. Sensors are automated and will not require human interaction during monitoring operations

2) **Ground-Mobile:** All sensors are placed on ground vehicles that are moved to different pre-designated locations depending on the time of day and wind pattern. A crew comprised of MWAA staff members will be required to operate the sensors during monitoring operations.

3) **Combination Ground-Fixed-Mobile:** A combination of several sensors fixed to certain locations with mobile sensors placed on ground vehicles.

B. Value Hierarchy

A value hierarchy was developed to identify what the stakeholders' values were for the different aspects of REMSAT. To elicit the weights from the stakeholders, a survey was deployed to experts on the subject matter, who will represent the system stakeholders for the purposes of this prototype development. REMSAT's top-level values are Data Quality and Sensor Location. Data Quality represents the performance at which the noise and emissions sensors will capture useful data. The sub-values under Data Quality are derived from the EPA's data emissions monitoring quality assurance handbook that are applicable to the noise sensors [9]. Sensor Location represents the values placed on the factors that affect where the sensors are located for monitoring with sub-values representing both environmental and socio-political factors. Cost is omitted from the value hierarchy as it will only be used for analyzing the initial installation and eventual operational budget for REMSAT as well as for utility versus cost comparison purposes. Figure 4 below is the value hierarchy for REMSAT.

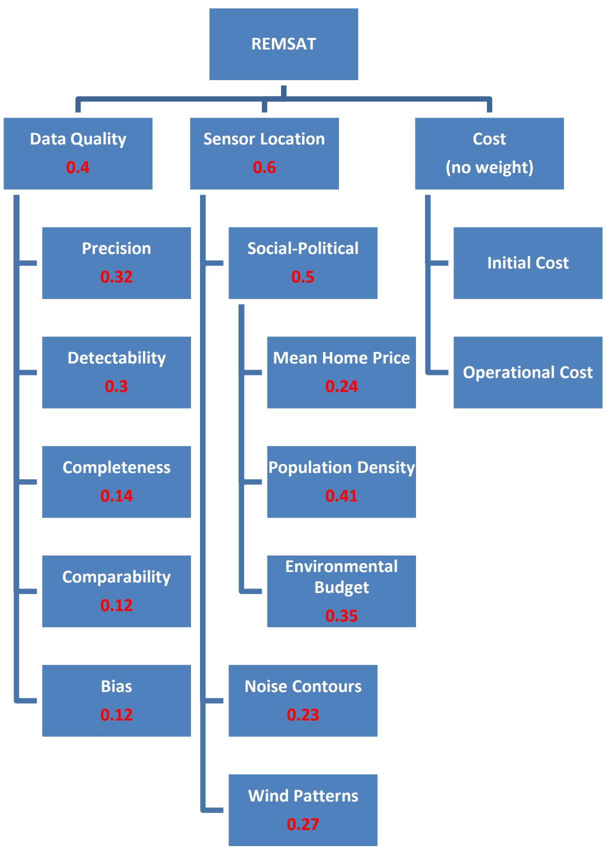

Figure 4: REMSAT Value Hierarchy

C. Utility Functions

Utility functions are formed based on the values assigned by stakeholders and are used in the analysis portion of this project to recommend a robust, cost effective design alternative. Below are the utility functions that are derived from the value hierarchy (Equation 1):

Equation 1: Top Level Utility Function

$$U_{REMSAT} = (W_1 * U_{Data\ Quality}) + (W_2 * U_{Sensor\ Location})$$

Where the sub-values are represented by the following utility functions (Equations 2 & 3):

Equation 2: Data Quality Utility Function

$$U_{Data\ Quality} = (W_3 * U_{Precision}) + (W_4 * U_{Detectability}) + (W_5 * U_{Completeness}) + (W_6 * U_{Comparability}) + (W_7 * U_{Bias})$$

Equation 3: Sensor Location Utility Function

$$U_{Sensor\ Location} = (W_8 * U_{Sociol\ Political}) + (W_9 * U_{Noise\ Contours}) + (W_{10} * U_{Wind\ Pattern})$$

IV. System Model and Analysis

A. Monitoring Station Location Selection

In order to establish an effective combined noise and emissions monitoring network, physical locations for each monitoring unit must first be established. Only upon identifying the locations can a tradeoff analysis be conducted to determine whether a network of fixed monitoring units, a fleet of mobile monitoring units, or a combination of both types of units is sufficient for capturing data at each location.

Monitoring unit locations will be limited to areas within the designated 12-nautical mile (nm) radius of each airport. Areas within this radius are then divided according to ZIP code. Each ZIP code is then scored on a scale of 1 to 6, with 1 being lowest possibility of getting a monitoring site and 6 being highest possibility of getting a site, on the following factors: population density, mean home price, state environmental budget, location relative to prevailing wind patterns, and location relative to airport noise level contours.

The demographic information is obtained from the most recent statistics and bins for the different possibility categories are created by taking the mean of each demographic and having bins representing the three standard deviations above and below it, yielding 6 bins for the 6 possibility locations. The population density, measured in people per square mile, represents the social impact level with areas having a higher population density assigned a higher possibility score. Mean home prices, in dollars, reflect the economic level with areas having a higher mean assigned a higher possibility score. Environmental budget, in dollars per person, reflect the level of political priority in environmental protection, and is calculated by taking the state's environmental budget and dividing it by its population. Areas with a higher annual budget per person are given a higher possibility score. Prevailing wind patterns are based on the wind rose for each airport, with areas downwind of the airport considered as having higher emissions exposure levels and given a higher possibility score. Noise level contours are those determined by MWAA's FAR part 150 studies for each airport, with areas designated as highest noise exposure areas given the highest possibility score.

The scores for each ZIP code are then summed and, based on the mean score and six standard deviations above and below; bins will be created for the total scores to categorize the areas by overall possibility score as a monitoring station location. Refer to Figure 5 for sensor location criteria.

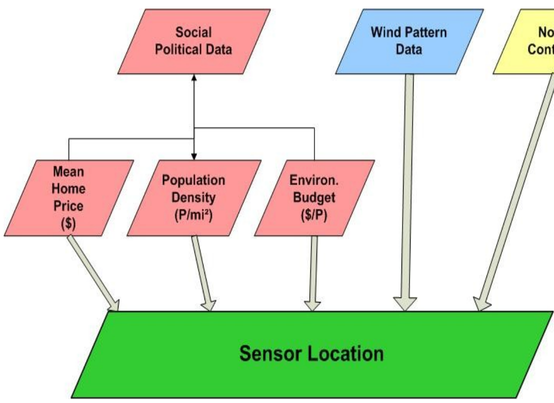

Figure 5: Sensor Placement Criteria Model

B. *Tradeoff Analysis for Design Alternatives*

A tradeoff analysis has been conducted on the three design alternatives to determine the best system for covering the ZIP codes identified as priority locations as previously mentioned in the section. Aside from stakeholders' values, other factors such as operational cost, manpower needed for operation, and other advantages and disadvantages for each design alternative will be used to develop a utility versus cost Pareto analysis to identify a robust, cost effective alternative. A product capability matrix was developed to compare the different sensors with the stakeholders' values. Sensitivity analysis was conducted to determine the cost or benefit of adding each additional monitoring station. A cost analysis was done to determine the initial installation budget as well as the operational and disposal budget for the various alternatives.

CONCLUSION

REMSAT can provide a way for monitoring emissions and noise pollution levels at and surrounding airports, and if implemented, it can provide a way for system stakeholders to know if the pollution levels are below the levels defined in federal environmental standards or exceeding them. Preliminary modeling of the system has identified that candidate locations for monitoring stations are those ZIP codes with higher population densities and situated adjacent to as well as within a 5-nautical mile radius of IAD and DCA respectively. Population density proved to be the biggest driving factor for those ZIP codes due to high numbers of residential properties. Population density was also given a heavier weight in the value hierarchy compared to other social-political factors, as well as noise contour and wind pattern.

Fixed sensors were found to be the best alternative for a sensor network connecting all the high-priority ZIP codes for both airports. Operation of fixed sensors requires minimal human intervention compared to a mobile or a mixed system, resulting in reduced operational costs and risks due to factors such as traffic congestion and human interaction.

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REFERENCES

[1] National Ambient Air Quality Standards, Environmental Protection Agency, [Web Page]. Available: http://www.epa.gov/air/criteria.html

[2] FAR Part 150 Noise Compatibility Program, Washington Dulles International Airport, Metropolitan Washington Airport Authority. March 1993.

[3] FAR Part 150 Noise Exposure Maps and Noise Compatibility Program, Ronald Reagan Washington National Airport, Metropolitan Washington Airport Authority, November 2004.

[4] Automated Surface Observing System (ASOS), National Oceanic and Atmospheric Administration. [Online]. Available: http://www.weather.gov/ost/asostech.html

[5] R. L. Wayson, G. G. Fleming. "Consideration of Air Quality Impacts By Airplane Operations at or Above 3000 feet AGL". Federal Aviation Administration. September 2000.

[6] Aviation and Emissions: A Primer, Federal Aviation Administration, [Online]. Available: http%3a//www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/aeprimer.pdf

[7] Washington Dulles International Airport (IAD) Air Traffic Statistics, Metropolitan Washington Airports Authority. [Online]. Available: http://www.metwashairports.com/dulles/about_dulles_international_2/air_traffic_statistics

[8] Ronald Reagan Washington National Airport (DCA) Air Traffic Statistics, Metropolitan Washington Airports Authority. [Online]. Available: http://www.metwashairports.com/reagan/about_reagan_national/air_traffic_statistics_2

[9] Quality Assurance Handbook for Air Pollution Measurement Systems (Volume II) Ambient Air Quality Monitoring Program,

Environmental Protection Agency, [Web Page]. Available:
http://www.epa.gov/ttn/amtic/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf