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A study of the relationship between adverse weather conditions and flight delay

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Abstract—Previous studies have indicated the possibility of a relationship between adverse weather conditions and flight delays. Various methods had been employed to determine the effect of adverse weather conditions on flight delays, such as the directed acyclic graph and Autoregressive Integrated Moving Average (ARIMA) model [4], [5]. In this case study for Singapore, linear and square root regression methods were used as a preliminary step to determine and understand this relationship which had not been done before. The SAAM software from EUROCONTROL was also used to illustrate the effect of weather on flights. By comparing the R squared values obtained, it was determined that the square root model was better for representing the relationship between adverse weather conditions and flight delays. The models and results from this case study could be applied to modeling and optimization studies of airports and airspace on a macroscopic level in Singapore or the other nations in Southeast Asia with similar climate and other areas such as forecasting and sectorization. Future research could also be done using more advanced methodologies or models.

I. INTRODUCTION

A study by [1] revealed that weather conditions account for 75% of flight system delays. According to ICAO, adverse weather conditions could reduce the efficiency of radar systems, thus reducing the Area Control Centers' capability in tracking aircraft in their respective FIRs [2]. Prior research had also shown that 29% of air accidents were associated with weather conditions [3].

Studies have shown that flight delays can be costly. [4] concluded in their study that unexpected flight delays could result in a larger amount of fuel burnt. Another study showed that airlines tend to increase airfare in order to cover the extra cost of fuel, manpower and other resources [5]. The study indicated a significant reduction in cost for the airlines if flight delay could be reduced [6].

[7] proposed several new models to characterize and predict flight delays. These models employed methods such as regression, the Random Forest and ANOVA test.

[8] proposed an optimization model, using various aircraft movements as inputs, to identify the cause of flight delay as well as to provide a means to measuring air traffic management performance.

Cheng used the ARIMA model to determine the relationship between several factors and the average flight delay. In this model, the data points used were given weights depending on the holiday seasons, climate and flight schedules, in order to reflect the effects of weather, holiday and time schedule more accurately [9].

[10] devised a model in the form of a directed acyclic

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graph consisting of nodes and arcs in order to determine the effect of adverse weather conditions on the extent of flight delays. The nodes represented different scheduled events, e.g. flight departures and arrivals, start and end of crew duty, while the arcs represented scheduled activities between these events, such as aircraft taxiing and aircraft maintenance. With this graphical representation, the shortest path algorithm is applied to determine the shortest time at which different events could occur, i.e. the extent of delay in flight schedule due to adverse weather conditions.

Regression techniques have been widely used in various fields of study, such as research in traffic accidents [11] and studies related to education [12]. Regression is also applied in the field of ATM and aviation. One example would be the Multivariate Adaptive Regression Spline (MARS) model adapted by Chang for analysis of air traffic in terms of air passenger flow [13]. [14] studied the impact of the privatization of airports and developed a regression-based model for passenger demands for the routes of such airports. [15] explored the use of various regression methods, such as the linear regression method and multilevel regression method and, to analyze passenger processing times at the airport.

This case study is a preliminary step to establish a model for the relationship between adverse weather conditions and flight delay in Singapore, as there has been little research done previously to explore this relationship. Regression methods will be used in this study to start at a simpler level.

II. METHODOLOGY

A. Data Collection

Daily weather data from 1th June 2015 to 31th August 2015 were collected from the Meteorological Service Singapore (MSS) website (www.weather.gov.sg), consisting of rainfall amount and duration, and duration of thunderstorms. The rainfall data chosen for this project were those recorded by the measuring devices located in Changi, while the thunderstorm data were taken throughout Singapore.

The flight data used in this project were obtained from Flight Stats (www.flightstats.com), which provides departure and arrival information for flights under most airline companies, as well as detailed updates in every flight schedule. The scheduled and actual departure times for Singapore Arline (SQ) flights in Changi Airport were collected from 1st June 2015 to 31st August 2015 for the following:

- Flights towards Kuala Lumpur International Airport (Airport Code KUL) and Suvarnabhumi International Airport in Bangkok (Airport Code BKK) respectively.
- Flights towards Australia, China, Japan and Korea from 12 a.m. to 6:00 a.m. and 9 p.m. to 12:00 a.m. respectively.

The delay in departure time for every flight was then obtained by the time difference between the actual departure time and the scheduled departure time, i.e. actual departure time minus scheduled departure time. The average departure delay per flight was then obtained from all flights in each day.

III. REGRESSION MODEL

Multiple variable regression was employed to model the relationship between the duration of rainfall, the duration of thunderstorms, and the average departure delay per flight. In this model, the duration of rainfall is represented by the variable x_r, the duration of thunderstorm by x_{th}, and the average departure delay per flight by y. All three variables take on the unit of minutes.

There are many variations of regression models, but only two of these variations of regression models were considered for the data collected, namely linear model and square root model.

The linear model can be represented as follows:

$$y = c_0 + c_r x_r + c_{th} x_{th}$$

In the model above, c_0 represents the intercept of the regression curve, which accounts for errors due to other factors. c_r represents the coefficient related to the duration of rain, while c_{th} represents the coefficient related to the duration of thunderstorm. In the linear model, c_0 takes on the unit of minutes while c_r and c_{th} are dimensionless.

For the square root model, the variables x_r and x_{th} undergo a square root transformation as shown:

$$y = c_0 + c_r \sqrt{x_r} + c_{th} \sqrt{x_{th}}$$

In the square root model, c_0, c_r and c_{th} have the same meaning as that in the linear model, i.e. as the error due to other factors and coefficients related to rain and thunderstorm respectively, but c_r and c_{th} take on the unit of $\sqrt{min}$ for the whole model to be physically consistent.

The data collated in Microsoft Excel were imported into MATLAB and converted into a matrix form, which is a common data format used in MATLAB. The Curve Fitting Tool, by using this data matrix as a basis, performed

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iterations to determine the regression model.

A. Usage of SAAM for Simulation and Modeling

The System for traffic Assignment and Analysis at a Macroscopic level (SAAM) software from EUROCONTROL was used to model a case of adverse weather condition in the vicinity of Changi Airport, in order to simulate a possible scenario and gain some insight of how the weather could affect flights.

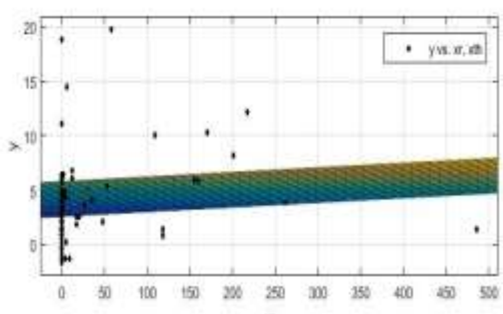
IV. RESULTS AND DISCUSSION

A. Regression Models

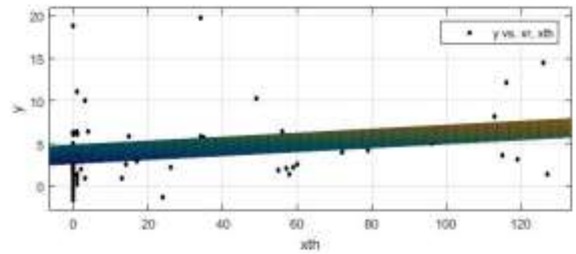
Using the Least Absolute Residual (LAR) fitting method in the Curve Fitting Tool, the value of the coefficients c_0, c_r and c_{th} obtained for the linear model were 2.711, 0.004228 and 0.02322 respectively, representing the linear model in the equation form, $y = 2.711 + 0.004228x_r + 0.02322x_{th}$. Figures 1(a) and 1(b) are the graphical representations of the linear model obtained in x_r - y view and x_{th} - y view respectively.

Similarly, by using the LAR fitting method, the coefficients c_0, c_r and c_{th} obtained for the square root model were 2.463, 0.06916 and 0.2571 respectively, representing the model in the equation form, $y = 2.463 + 0.06916\sqrt{x_r} + 0.2571\sqrt{x_{th}}$. Figures 2(a) and 2(b) are the graphical representations of the square root model obtained in x_r - y view and x_{th} - y view respectively.

The R squared value for the linear model was 0.9195 while the R squared value for the square root model was 0.9215. Therefore, the square root model is more reflective of the relationship between adverse weather conditions and flight delay.

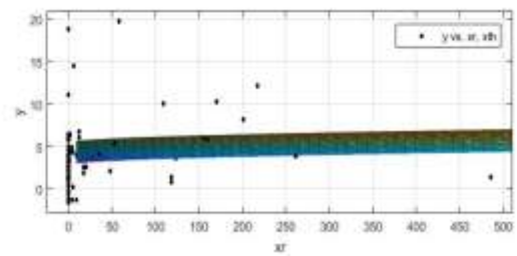


(a)

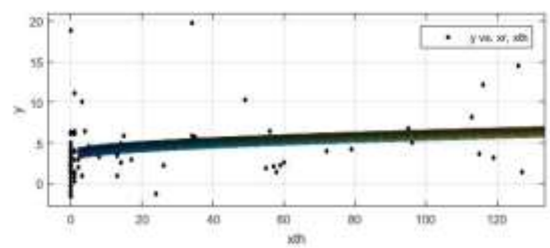


(b)

Fig. 1. (a & b) Graphical representations of the linear model in x_r-y view and x_th-y view



(a)



(b)

Fig. 2. (a & b) Graphical representations of the square root model in x_r-y view and x_th-y view

B. SAAM Diagrams

Figure 3 is a visual representation of flights departing from Changi Airport (WSSS) and heading towards Philippines, Japan and South Korea during normal operations. The thickness of each segment is proportional to the number of flights on that particular segment. Figure 4 shows the flights heading towards the same destinations when there is a thunderstorm, represented as the grey area in the figure, near Changi Airport.

Figures 3 and 4 illustrate a scenario where flights along the path with the thunderstorm have to be either rerouted or delayed for safety reasons. The eastbound flights from Changi Airport shown in Figure 3 do not appear in Figure 4, indicating that these flights are either held in the airport or redirected to another route during the thunderstorm. The northbound route in Figure 4 appears to be thicker than that in Figure 3, suggesting that some of the flights on the eastbound route are redirected to the northbound route during the thunderstorm.

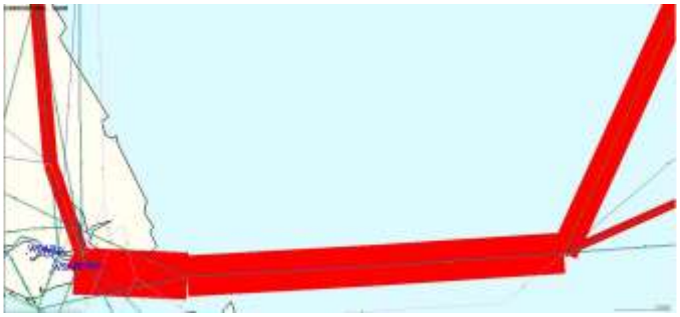


Fig. 3. Visual representation of flights departing from Changi Airport during normal operations

Fig. 4. Visual representation of flights departing from Changi Airport during a thunderstorm

V. CONCLUSION

Both the linear model and square root model showed an increase in average flight delay with increased durations of rainfall and thunderstorm, but since the R squared value was higher for the square root model, it seems that the square root model is more accurate at determining the relationship between adverse weather conditions and flight delay.

The models and results in this case study could be incorporated in other studies related to modelling and optimization of airports and airspace at a macroscopic level due to the simplicity of the models, in order to justify the need for studies at a microscopic level. The studies which use these models and results could be specific to Singapore or even the other Southeast Asian nations which have similar climate to Singapore.

The methodology and/or results could also be applied to other areas of interest, such as forecasting and sectorization. Future study could include the use of more advanced models or methodologies to provide more detailed studies of the relationship between adverse weather conditions and flight delay.

SAAM was used to illustrate the effect of adverse weather conditions on flight delays. There is a possibility of using SAAM further or using other related software to do simulation and modeling in future study.

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— This article does not have any appendix. —