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A Research on the Advanced Risk Assessment of Runway Safety Areas with Enhanced Algorithm

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Abstract:Runway accidents are sensitively affected by the amount of precipitation. However, the current Runway Safety Area Risk Assessment algorithm does not take the amount of precipitation. Therefore, this study subdivided level of rainfall and snowfall and derived an advanced algorith which computes more accurate accident probablity data.

Keyword: RSARA, Runway Safety, Safety Management, Risk Analysis Algorithm

I. Introduction

Global Aviation Industry and Runway Accidents . Since the Wright brothers' first successful flight in 1903, global aviation industry is developing rapidly on account of capital intensive investments and academic research efforts. International Civil Aviation Organization (ICAO) Air Navigation Report 2014 edition claims, 3.1 billion passengers use the global air transport network for the needs of business and tourism purpose, and this figure is expected to reach over 6.4 billion by 2030, which represents approximately 5% of annual increment on aviation demand. [ⅰ] Furthermore, it is analyzed that a 20% increase of air traffic volume close vicinity to an aerodrome causes a 140% increase for runway accident rate. [ⅱ] According to a runway safety area research, 83% of runway accidents happened during the landing phase, and the causes of runway accidents were due to aircraft overrun (44%), veer-off (48%), and undershoot (8%). [ⅲ]

Runway Safety Areas

In order to minimize risk of runway accidents, ICAO and United States Federal Aviation Authority (FAA) defined Runway Safety Area (RSA) or Runway End Safety Area (RESA) as "the surface surrounding the runway prepared or suitable for reducing the risk of damage to airplanes in the event of an undershoot, overshoot, or excursion from the runway" and published RSA standards for global aviation industry. [ⅳ] Therefore, it is critical for airport operators to manage RSA to reduce the risk of overrun, veer-off, and undershoot cases because RSA is the last resort to minimize the catastrophic accident in real operation. However, it is difficult to implement RSA standards for those airports built before RSA standards came along and face with various constraints to secure enough safety area such as natural or manmade obstacles, and local community's opposition. Consequently, questions whether taking-off and landing over those airport runways are safe or not have been emerged among the global aviation community, and United States Transportation Research Board (TRB) decided to develop a program in concurrence with FAA, which can measure the level of runway safety based on empirical information, for example, weather data. This research collaboration, which is called Airport Cooperative Research Program (ACRP), developed and introduced Runway Safety Area Risk Analysis (RSARA) software as a risk assessment tool.

Research Question

Even though this software is widely used across international aviation community, this tool does not consider the actual quantity of rainfall or snowfall which obviously affects runway surface condition and coefficient of friction. These changes in condition also influence take-off and landing distance and performance in actual operation. Therefore, this study improves current RSARA algorithm by subdividing the amount of rainfall and snowfall into several classes in order to derive more accurate runway risk assessment model.

II. RSARA Methodology

Runway Safety Area Risk Analysis

Alongside growth of air traffic movements, runway accidents rate is also increasing. Hence, as a countermeasure, FAA established RSA standards to reduce runway accidents. As aeronautical science and technology advance, sizes, performance and limitations of aircrafts have become diverse, and this caused RSA standards to be redefined to accommodate various fleets. As a result, in 1999, FAA initiated a reform of RSA standards based on FAA Order 5200-8. [ⅴ] However, FAA realized that there is no accredited tool in aviation industry which can empirically measure the actual operation risk based on cumulative runway accident data. As the final outcome, FAA and TRB developed RSARA via ACRP in 2011 which empirically assesses the risk of runway accidents and provides safe runway margins, and this freeware have been widely contributed to secure the runway accidents for a number of airports.

RSARA Event Classifications

RSARA classifies various runway accidents into following five event categories; Take-Off Overruns (TOOR), Take-Off Veer Offs (TOVO), Landing Overruns (LDOR), Landing Undershoots (LDUS), and Landing Veer-Offs (LDVO). TOOR occurs when the aircraft fails to take-off before the end of the runway length, whereas LDOR characterized as an aircraft lands after the end of the runway. In addition, TOVO happens when an aircraft deviates respect to the axis of the runway when performing take-off, and LDVO corresponds to the same lateral deviation of the aircraft with the respect to the axis of runway centerline during landing phase. LDUS can be defined as an event which is set when an aircraft initiates landing before the planned landing spot of runway. [ⅵ] These events also categorized into three subsections: probability, location, and consequence. Probability considers aircraft performance, airport category, runway elevation and length, and weather condition. Location corresponds to runway dimension, geometric location, and instalment of Engineered Materials Arrestor System (EMAS). Finally, consequence reflects types, size, and shape of obstacles which threats aviation safety. [vii]

Existing RSARA Mathematical Algorithm

Existing RSARA applied following mathematical algorithm. [vii]

$$P\{Accident\_Occurenc\} = \frac{1}{1+e^{b_0+b_1X_1+b_2X_2+b_3X_3+\cdots\cdots}} \quad \text{(Equation 1)}$$

The value P{Accident _Occurrence} is the probability of a runway accident with given operational conditions, and Xi are the independent variables such as aircraft type, wind force, visibility, and rainfall. Also, bi are regression coefficients. [viii] Furthermore, Complementary Cumulative Probability Distribution (CCPD) applied for the 5 event categories: TOOR, TOVO, LDOR, LDUS, and LDVO.

$$P\{Location > X\} = e^{-ax^n} \quad \text{(Equation 2)}$$

Equation 2 shows longitudinal distribution where P{Location > X} is the chance of the undershoot or overrun. The location is the distance along the runway centerline longer than X, and X is a location over runway end where a is regression coefficient. [viii] The modeling concept for aircraft overruns can be schematized as Figure 1. Modelling Concept for Runway Overruns.

$$P\{Location > Y\} = e^{-hy^m} \quad \text{(Equation 3)}$$

The lateral distribution can be found from above Equation 3 where P{Location > Y} is the probability of the veer-off which is lateral deviation, and Y is a distance from the runway centerline where b is regression coefficient.

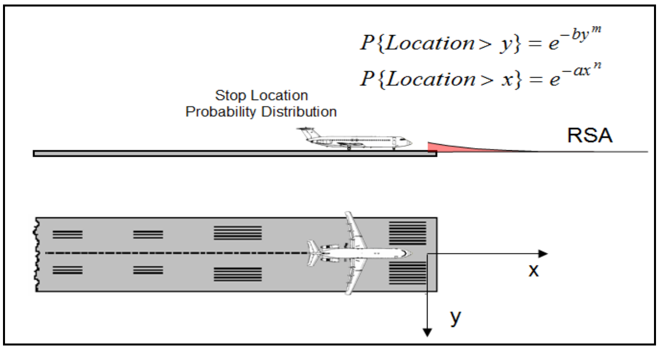

Figure 1. Modelling Concept for Runway Overruns

III. **Advanced RSARA Methodology**

Advanced Algorithm

Some airports especially in North East Asia which have distinct four seasons experience extreme weather anomalies such as torrential rainfall during rainy season or heavy snowfall in winter. However, the current RSARA algorithm does not take severity of precipitation into account mathematical model. Therefore, this research decided to reengineer the current mathematical model of the RSARA algorithm so that the advanced algorithm can reflect the quantity of such precipitation and derive more accurate risk assessment analysis. Thus, this study classified quantity of rain to Light (less than 2.5mm/h), Moderate (greater than 2.5mm/h but less than 10.0 mm/h), and Heavy (greater than 10.0mm/h). Likewise, the amount of snow classified as Light (less than 1.0mm/h), Moderate (greater than 1.0mm/h but less than 5.0 mm/h), and Heavy (greater than 5.0mm/h). After this process, this research set additional independent variables through polynomial regression analysis by using IMB SPSS 2.0. The calculated independent variable values is shown in following Table 1.

Table 1. Calculated Independent Variable Values

Variable	LDOR	LDUS	LDVO	TOOR	TOVO
Light Rain	-	0.982	-0.120	0.348	-1.531
Moderate Rain	-	0.986	-0.124	0.352	-1.537
Heavy Rain	-	0.991	-0.127	0.358	-1.542
Light Snow	0.437	-0.241	0.538	0.717	0.951
Moderate Snow	0.445	-0.248	0.543	0.719	0.958
Heavy Snow	0.449	-0.252	0.552	0.722	0.966

Modified Algorithm

With the calculated independent variables, this study applied the independent variables into the Equation 1 and derive advanced formula for regression coefficient value bi for each event categories. For example, bi formula for landing overrun can be defined as follows:

$$Landing\ Overrun \quad \text{(Equation 4)}$$

$$\begin{aligned} b = & -13.065+1.539(User\ Class\ G)-0.498(User\ Class\ T/C)-1.013(Aircraft\ Class\ A/B)\\ & +0.935(Aircraft\ C/D/E)-0.019(Ceiling\ less\ than\ 200ft)-0.772(Ceiling\ 200ft\ to\ 1000ft)\\ & -0.345(Ceiling\ 1000ft\ to\ 2500ft)+2.881(Visibility\ less\ than\ 2SM)+1.532(Visibility\ from\ 2\ to\ 4SM)\\ & +0.200(Visibility\ from\ 4\ to\ 8SM)-0.913(Xwind\ from\ 5\ to\ 12kt)-1.342(Xwind\ from\ 2\ to\ 5kt)\\ & -0.921(Xwind\ more\ than\ 12kt)+0.786(Tailwind\ more\ than\ 12kt)+0.043(Temp\ less\ than\ 5^{\circ}C)\\ & -0.019(Temp\ from\ 5\ to\ 15^{\circ}C)-1.067(Temp\ more\ than\ 25^{\circ}C)+2.007(Icing\ Conditions)\\ & +0.437(Snow\ Light)+0.445(Snow\ Moderate)+0.449(Snow\ Heavy)-1.344(Thunderstorm)\\ & +0.929(Foreign\ OD)+1.334(Hub/Non\ Hub\ Airport)+9.237(Log\ Criticality\ Factor) \end{aligned}$$

After this process, accident occurrence probability value applied to both longitudinal and lateral location formulas: Equation 2 and Equation 3. As a result, the advanced location model derived as Table 2 below.

Table 2. Advanced Location Model

Type of Accident	Type of Data	Model	R^2(%)
LDOR	X	$P\{d > x\} = e^{-0.00321x^{0.984932}}$	99.8
	Y	$P\{d > y\} = e^{-0.20983y^{0.48621}}$	94.2
LDUS	X	$P\{d > x\} = e^{-0.01481x^{0.749897}}$	98.6
	Y	$P\{d > y\} = e^{-0.02159y^{0.778789}}$	98.9
LDVO	Y	$P\{d > y\} = e^{-0.2568y^{0.808934}}$	99.4
TOOR	X	$P\{d > x\} = e^{-0.00109x^{1.06754}}$	98.9
	Y	$P\{d > y\} = e^{-0.04282y^{0.661898}}$	99.1
TOVO	Y	$P\{d > y\} = e^{-0.01639y^{0.874882}}$	94.3

IV. **Result Analysis**

Comparison Analysis

For the comparison analysis of the existing RSARA algorithm against advanced RSARA algorithm, this paper selected G International Airport as a sample airport which experienced runway accidents and have high traffic volume under typical Korean weather. Dimension of G International Airport is 1,199,267m^2, and this airport provides 3,600m*45m and 3,200*60m parallel runways. [ix] There are two runway accident histories since 1958: LDUS case in 19 November 1980 and LDOR case in 5 August 1998. [x] Empirical data used for the comparison analysis were 10 years of operation data including 121,622 air traffic data and 9,497 of Korea Aviation Methodological Agency's metar information.

Table 3. G International Airport RSARA Results

Accident	Average Probability	Average Number of Years to Accident
LDOR	3.3E-08	Over 100 years
TOOR	1.5E-07	54 years
LDUS	5.4E-08	92 years
LDVO	8.5E-09	Over 100 years
TOVO	1.6E-09	Over 100 years
Total	1.2E-07	89 years

G International Airport's RSARA result with the existing algorithm represents that average probability of accident is 1.2E-07 which mathematically means 1.2 number of accidents happen every ten million operations. This also means that the average number of years for an accident is 89 years as shown above Table 3. G International Airport RSARA Results.

Table 4. G International Airport Advanced RSARA Results

Accident	Average Probability	Average Number of Years to Accident
LDOR	2.9E-08	Over 100 years
TOOR	1.5E-07	53 years
LDUS	5.0E-08	91 years
LDVO	5.1E-09	Over 100 years
TOVO	1.1E-09	Over 100 years
Total	1.2E-07	88 years

Advanced RSARA mathematical algorithm computes above values in Table 4. G International Airport Advanced RSARA Results. According to the results, like current RSARA algorithm, the value for Average Probability was 1.2E-07. However, the value for average number of year to critical incident was slightly lower.

Table 5. Comparison Analysis for Real Accident Cases

Accident	Actual Statistics	Advanced Algorithm	Existing Algorithm
LDOR	Under 1.8E-0.7	2.9E-08	3.3E-08
LDUS	Under 1.8E-0.7	5.0E-08	5.4E-08
Airport Total	1.2E-0.7	1.2E-0.7	1.2E-07

If we compare these two RSARA results against real accident statistics of G International Airport, the advanced RSARA algorithm derived more close value to actual case for LDOR and LDUS accidents as shown Table 5. Comparison Analysis for Real Accident Cases. This means that the advanced algorithm derived more accurate result.

V. Conclusion

Research Summary

Standards for RSA have been improved by ICAO and FAA over decades to secure the safety of flight operation and minimize runway accidents. However, airports built before these standards introduced confronted difficulties to implement RSA due to various restrictions. For this reason, FAA and TRB launched ACRP to develop RSARA which can empirically assess and monitor runway safety. However, existing RSARA algorithm does not consider the amount of rainfall and snowfall, which affects runway surface conditions and coefficient of friction. Therefore, this study analyzed the existing RSARA's mathematical algorithm and enhanced its weather model by subdividing the precipitation level into 3 categories: Light, Moderate, and Heavy. As a result, this research computed additional independent variables thorough polynomial regression analysis by using SPSS 2.0, and applied the values into the probability equation in order to derive advanced regression coefficient values. To prove this advanced algorithm, G International Airport was chosen as a sample airport since this airport has high traffic density, typical Korean weather condition, and runway accident experiences. In conclusion, the comparison analysis for the G International Airport was conducted by two algorithms, and the results represent the Advanced RSARA algorithm was closer to actual accident statistics than existing RSARA algorithm.

Implications for Further Research

Even if the Advanced RSARA algorithm computes more accurate risk assessment than existing algorithm, the result gap between the actual statistics and data driven by the advanced algorithm was greater and not accurate enough than expected. Probably, it is because this research did not consider various human factors which also affect runway accident and related to majority of aviation accidents like weather conditions. Thus, further study could be developed by applying human factors into the risk assessment model. Moreover, more classified weather parameters such as density of fog, icing severity, sudden change of atmospheric pressure, etc. could be considered for more accurate risk assessment.

Acknowledgement

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