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# An Application of the Risk Assessment Model for Runway End Safety Areas to a Specific Airport in Korea

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## *Abstract*

*Over the last decade there has been an obvious reduction in the number of non-fatal and fatal accidents involving the worldwide commercial jet airplane fleet. While most runway excursions are relatively minor with no serious injuries or airplane damage occurring, they have the potential to pose a serious risk to public safety and infrastructure. Preventive risk controls are the most important way to reduce the frequency and consequences of runway excursions. This research was based on a comprehensive database of Runway Safety Areas-related accidents. It was matched by a representative sample of normal operation data, such that the exposure to a range of flight-operational and meteorological risk factors between accidents and normal flights could be compared. This study focused on the risk frequency about a case airport which does not meet the 'Runway end safety area' requirement of ICAO Standards and Recommended Practices and Korean standards and used 'RSA risk model' for estimating the risk frequency. As results of this study, risk frequency of the runway end safety areas in the case airport is higher than that of 'Runway end safety area' requirement of ICAO SARPs and Korean standards. It means that alternatives for risk frequency mitigation to a level as low as reasonably practicable is required in the case airport.*

***Keywords****: Runway Excursion, Risk Assessment Model, Risk safety areas, Overruns, Veer offs, Runway End Safety Area*

## 1. Introduction

Landing-Takeoff Overruns and Veer-offs account for most of the accidents that occur on or in the immediate vicinity of the runway. Accident statistics show that, from 1959 to 2014, 61% of the world's jet fatal aircraft accidents occurred during landing and takeoff phase of the flight and accounted for 48% of all onboard fatalities (Boeing 2015). Although the causal factors involve some type of human error in many cases, the conditions at the airport may contribute significantly to the frequency and consequence of the accidents.

Runway excursion accidents, which include aircraft running off the end of the runway (overruns) and off the side of the runway (veer-offs), account for a significant proportion of all Approach and Landing accidents (ALAs). The International Federation of Airline Pilots Association (IFALPA) reports that almost 24 % of all incidents and accidents in air transport operations are runway excursions (IFALPA, 2008). There is a danger that decisions made to manage overrun risk in the absence of an understanding of the risk will lead to inefficient allocation of resources and mitigation measures which do not alter the risk, in addition to a false sense of safety (S.B. Hong, T. Dilshod, D. Kim, 2016).

This is supported by analysis of worldwide accidents by the International Air Transport Association (IATA), which in the 45th edition of the IATA Safety Review found that 25

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per cent of all accidents in 2008 were runway excursions (IATA, 2009). In Europe, a 2007 report by the European Aviation Safety Agency (EASA) found that runway excursions were the third most common type of accident involving large commercial air transport aircraft in EASA member states between 1998 and 2007. They were only surpassed in number by aircraft system and engine malfunctions, and abnormal ground contact accidents. The report also found that while controlled flight into terrain (CFIT) accidents, which have traditionally been one of 'aviation's historic killers' (ATSB, 2007), are declining overall, runway excursions showed an upward trend (EASA, 2008).

Runway excursion has become a significant accident issue despite advances made in aviation technologies. Over the past 25 years, 33 % of fatal accidents have been related to runway excursions. Between 1991 and 2013, eight fatal accidents have resulted from unstabilized approaches in the Republic of Korea, accounting for approximately 50 % of total runway excursions (ICAO, 2013).

ICAO Runway End Safety Area (RESA) specifications all begin at the limit of the 'Runway Strip' not at the limit of the Runway/Stop way surface. RESA SARPs were revised in 1999 when the then Recommended Practice of a 90 meter RESA was converted into a Standard (ICAO, 2015). The current requirement is that Code 3 and 4 runways have a RESA which extends a minimum of 90 meters beyond the runway strip and be a minimum of twice the width of the defined runway width. The additional Recommended Practice for these runway codes is that the RESA length is 240 meters or as near to this length as is practicable at a width equal to that of the graded strip. For Code 1 and 2 Runways, the Recommended Practice is for a RESA length of 120 meters with a width equal to the graded strip (ICAO, 2015).

The location models were integrated into the analysis methodology and software with the capability of assessing Runway Safety Areas (RSA) lateral areas, the areas contiguous to the longitudinal sides of the runway. The analysis was validated and took into consideration the RSA boundaries and existing obstacles within the existing or proposed RSA (Transportation Research Board; TRB, 2014).

## 2. Developments in Methodology

The RSA risk analysis requires three models that consider probability, location and consequences (Refer Figure 1). The output of the analysis is the risk of accident during runway excursions and undershoots. Various numerical techniques were evaluated to conduct the multivariate analysis, and logistic regression was the preferred statistical procedure for a number of reasons (TRB, 2008 www.TRB.org). This technique is suited to models with a dichotomous outcome (accident and non-accident) with multiple predictor variables that include a mixture of continuous and categorical parameters.

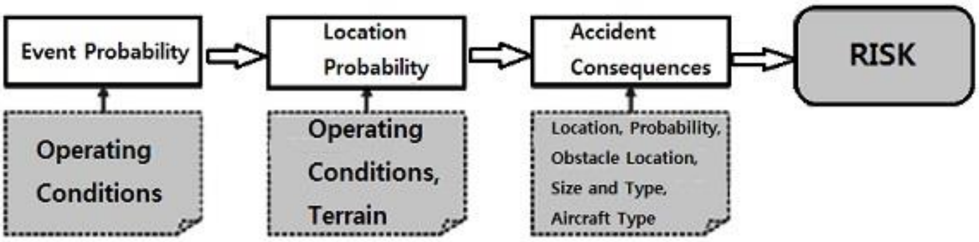


**Figure 1. Modeling Approach**

### 2.1. Event Probability Model

To avoid the negative effects of multi-co-linearity on the model, correlations between independent variables were first tested to eliminate highly correlated variables, particularly if they did not significantly contribute to explaining the variation of the probability of an accident. (TRB, 2011 www.TRB.org).

The basic model structure selected is a logistic equation, as follows:

$$P\{Accident\_Occurence\} = \frac{1}{1+e^{b_0+b_1X_1+b_2X_2+b_3X_3+\dots}} \quad (1)$$

where

P {Accident Occurrence} = the probability (0–100%) of an accident type occurring given certain operational conditions;

Xi =independent variables (*e.g.*, ceiling, visibility, crosswind, precipitation, aircraft type, criticality factor); and bi =regression coefficients.

Using the adjusted intercepts, the final frequency models are the following, shown on Table 1.

**Table 1. Independent Variables Used for Frequency Models**

| Variable | LDOR | LDVO | TOOR | TOVO |
|---|---|---|---|---|
| Adjusted Constant | -13.065 | -13.088 | -14.293 | -15.612 |
| User Class F | | | 1.266 | |
| User Class G | 1.539 | 1.682 | | 2.094 |
| User Class T/C | -0.498 | | | |
| Aircraft Class A/B | -1.013 | -0.770 | -1.150 | -0.852 |
| Aircraft Class D/E/F | 0.935 | -0.252 | -2.108 | -0.091 |
| Ceiling less then 200ft | -0.019 | | 0.792 | |
| Ceiling 200 to 1000ft | -0.772 | | -0.114 | |
| Ceiling 1000 to 2500ft | -0.345 | | | |
| Visibility less then 2 SM | 2.881 | 2.143 | 1.364 | 2.042 |
| Visibility from 2to 4 SM | 1.532 | | -0.334 | 0.808 |
| Visibility 4 to 8 SM | 0.200 | | 0.652 | -1.500 |
| Xwind from 5 to 12 kt | -0.913 | 0.653 | -0.695 | 0.102 |
| Xwi from 2 to 5 kt | -1.342 | -0.091 | -1.045 | |
| Xwind more than 12 kt | -0.921 | 2.192 | 0.219 | 0.706 |
| Tailwind from 5 to 12kt | | 0.066 | | |
| Tailwind more than 12 kt | 0.786 | 0.98 | | |
| Temp less than 5 C | 0.043 | 0.558 | 0.269 | 0.988 |
| Temp from 5 to 15 C | -0.019 | -0.453 | -0.544 | -0.42 |
| Temp more than 25 C | -1.067 | 0.291 | 0.315 | -0.921 |
| Icing Conditions | 2.007 | 2.67 | 3.324 | |
| Rain | | -0.126 | 0.355 | -1.541 |
| Snow | 0.449 | 0.548 | 0.721 | 0.963 |
| Frozen Precipitation | | -0.103 | | |

### 2.2. Location Model

The origin of the coordinate system is where the runway centerline intersects the runway threshold for landing accidents and the start-of-roll threshold for take-off accidents. Positive x is the distance from the threshold towards the end of the runway and negative X is the distance before the runway threshold. Y measures the distance from the runway centerline (Figure 2). The measurement system is similar to those used by most risk assessment studies in the area, such as the British National Air Traffic Services (NATS) and FAA's crash location studies (Cowell *et al*. 1997, David 1990).

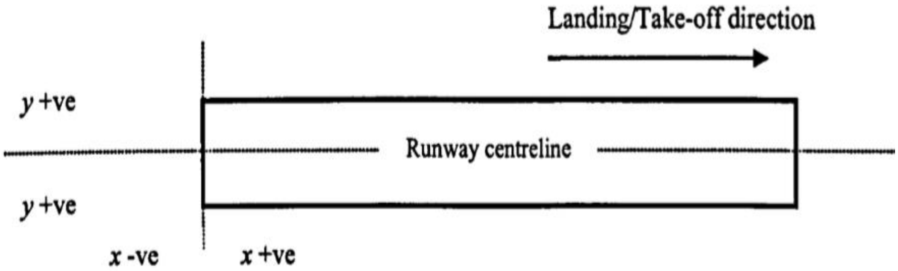


Figure 2. Location Coordinate System

The current analysis considered a total of four possible scenarios under which the longitudinal length of RSAs (x and y distance) could be challenged. These are explained in turn. Below are Figures 3 and Figure 4.

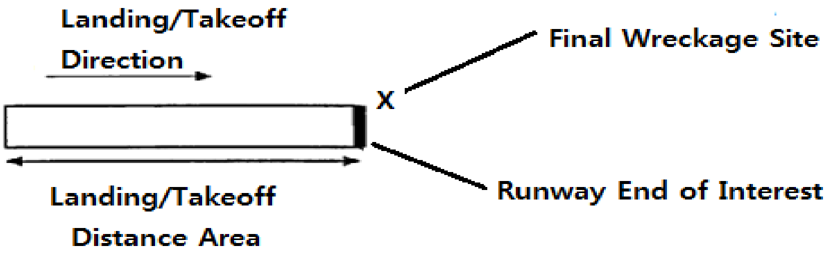


Figure 3. Overrun Landing/Takeoff LCS

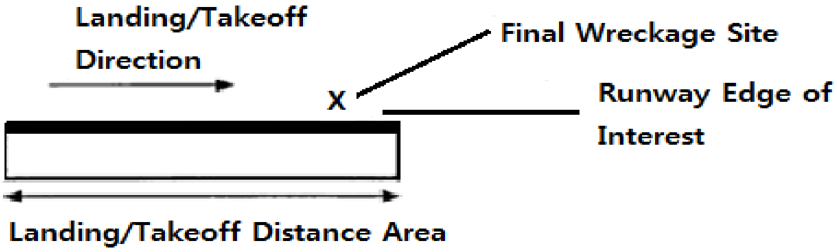


Figure 4. Veer-off Landing/Takeoff LCS

The model can be represented by the following equation:

$$P\{Lovation > y\} = e^{-by^{m}} \qquad (2)$$

where

P{Location>y} = the probability the overrun/undershoot distance from the runway border (veer-offs) or centerline (overruns and undershoots) is greater than y;

y = a given location or distance from the extended runway centerline or runway border;

b, m = regression coefficients.

A typical transverse location distribution is presented, and the model parameters are presented in Table 2. (TRB, 2011)

**Table 2. Summary of Location Models**

| Type | Model | $R^2$ |
|---|---|---|
| LDOR | $P(d > x) = e^{-0.00321x^{0.984941}}$ | 99.8% |
| | $P(d > y) = e^{-0.20938y^{0.4862}}$ | 93.9% |
| LDVO | $P(d > y) = e^{-0.02568y^{0.803946}}$ | 99.5% |
| TOOR | $P(d > x) = e^{-0.00109xx^{1.06764}}$ | 99.2% |
| | $P(d > y) = e^{-0.04282y^{0.659566}}$ | 98.7% |
| TOVO | $P(d > y) = e^{-0.01639y^{0.863462}}$ | 94.2% |

A polynomial curve was fit to the cumulative probability points. A high degree polynomial was used to obtain the models representing the probabilities for each subarea with the highest accuracy possible. The models are represented by the following equations. An $R^2$ of 99.99% was achieved ($R^2$ is a statistical measure of fit; $R^2$= 100% signifies a perfect fit) (TRB, 2014).

Integrated Model for TOVOs and LDVOs is as the follow;

$$CP = -12.1793D^6 + 36.7712D^5 - 38.3658D^4 + 13.9251D^3 + 0.4265D^2 + 0.4225D$$

$(R^2 = 99.9\%)$

Model for LDVO;

$$CP = -20.4465D^6 + 63.2398D^5 - 69.4061D^4 + 29.2621D^3 - 1.8031D^2 + 0.1538D$$

$(R^2 = 99.9\%)$

Model for TOVO;

$$CP = -13.1509D^6 - 43.3722D^5 + 54.6310D^4 - 32.0242D^3 + 7.4079D^2 + 1.2068D$$

where:

D is the normalized longitudinal distance from the beginning of the runway and

CP is the cumulative probability that a veer-off will occur within D.

The lateral deviation models were developed using the following form:

$$PL > L_1 = e^{aL^b} \qquad (3)$$

where

P{$L > L_1$} is the probability that the lateral deviation $L$exceeds a given distance $L_1$and

a, b are model coefficients.

The last column in Table 3 shows the models' $R^2$, which represent the excellent accuracy achieved.

**Table 3. Lateral Deviation Models for Normalization Using RSA**

| | L Range | a | b | $R^2$ |
|---|---|---|---|---|
| 1 | 0-0.1 | -0.03399 | 0.8407 | 97.4% |
| 2 | 0.1-0.2 | -0.00690 | 1.1339 | 99.3% |
| 3 | 0.2-0.3 | -0.01306 | 1.0032 | 99.4% |
| 4 | 0.3-0.4 | -0.00644 | 1.1576 | 99.5% |
| 5 | 0.4-0.5 | -0.01354 | 0.9881 | 99.1% |
| 6 | 0.5-0.6 | -0.00906 | 1.0482 | 98.3% |
| 7 | 0.6-0.7 | -0.00909 | 1.0014 | 99.0% |
| 8 | 0.7-0.8 | -0.01136 | 0.9206 | 99.2% |
| 9 | 0.8-0.9 | -0.01037 | 0.970348 | 98.9% |
| 10 | 0.9-1.0 | -0.00361 | 1.18109 | 99.1% |

## 3. Applying to Overrun and Veer-off Models

The length of RSA needed for runway end was considered in turn, taking into account its specific accident frequency risk exposure, runway use patterns as well as traffic levels. This section will explain Ulsan Airport runway and Airport RSA geometric layouts. The airport has a single runway, which the direction and dimension is 18/36 and 2,000m x 45m respectively. Its runway strip and RESA are not to meet the criteria of both ICAO SARPs and Korean regulation (Refer to Figure 5).

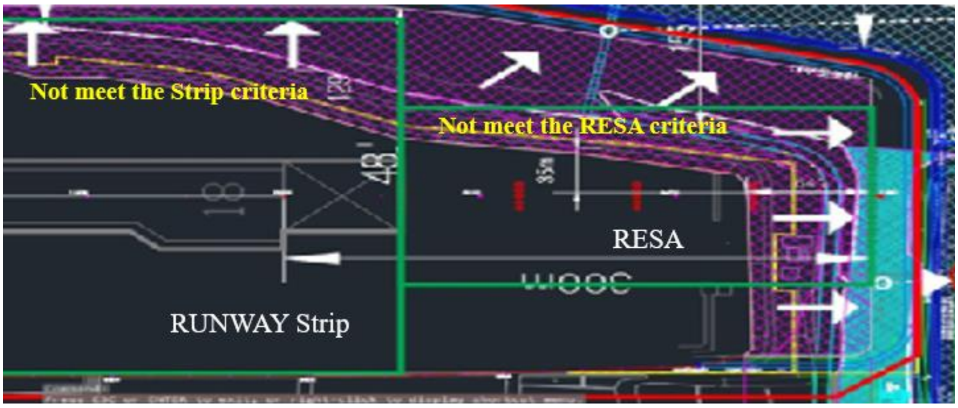


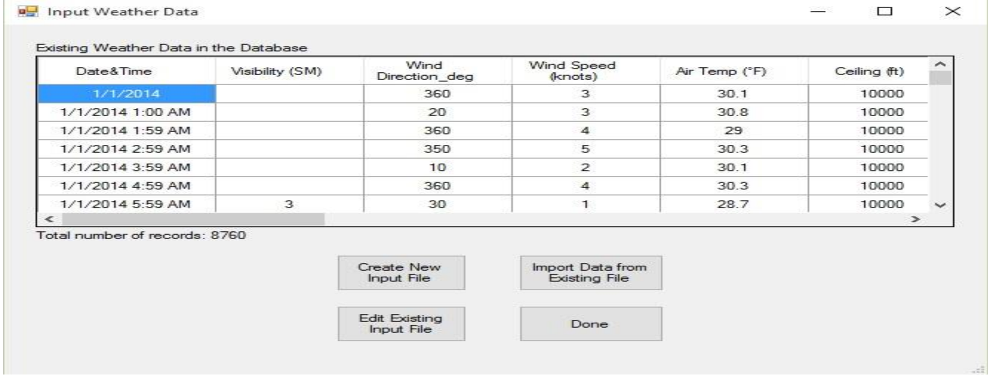
Figure 5. Layout of Ulsan Runway Strip and RESA

### 3.1. Applying Historical Operation Data

An alternative source of Historical Operation Data (HOD) was therefore sought through airport operators, especially in terms of aircraft landing weights. However, even though this airport does charge landing fees according to maximum landing weight, the actual weight of the aircraft at landing is seldom recorded. As such, airport data on landing weights is not precise enough for risk assessment purposes. Source of HOD was collected from Ulsan Airport authority. The number of flight operation is 5,184 for one year.

**Table 4. Summary of Aircraft Data**

| Item | B737-800/900 | A320 |
|---|---|---|
| Wingspan (ft) | 112.6 | 111.9 |
| Length | 123.3 | 129.5/138.2 |
| MTOW | 162,040 | 155,492/174,198 |
| Takeoff distance (ft) | 7.185 | 7,545.9 |
| Landing distance (ft) | 4,724.4 | 5,249.3/5,577.4 |
| V2 (kts) | 145 | 145/149 |
| Approach speed (kts) | 138 | 138 |



Existing Weather Data in the Database

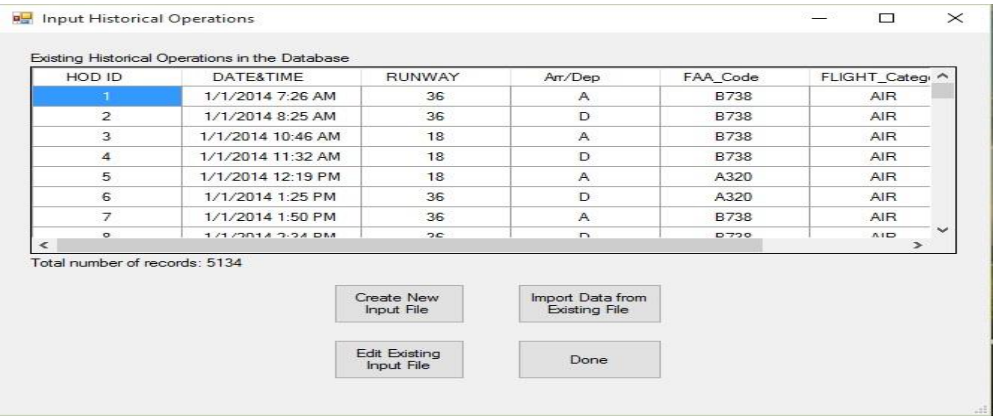
| Date&Time | Visibility (SM) | Wind Direction_deg | Wind Speed (knots) | Air Temp (°F) | Ceiling (ft) |
|---|---|---|---|---|---|
| 1/1/2014 | | 360 | 3 | 30.1 | 10000 |
| 1/1/2014 1:00 AM | | 20 | 3 | 30.8 | 10000 |
| 1/1/2014 1:59 AM | | 360 | 4 | 29 | 10000 |
| 1/1/2014 2:59 AM | | 350 | 5 | 30.3 | 10000 |
| 1/1/2014 3:59 AM | | 10 | 2 | 30.1 | 10000 |
| 1/1/2014 4:59 AM | | 360 | 4 | 30.3 | 10000 |
| 1/1/2014 5:59 AM | 3 | 30 | 1 | 28.7 | 10000 |

Total number of records: 8760

Figure 6. Input Data of Historical Flight Operation

### 3.2. Applying Historical Weather Data

This section describes the procedure to prepare historical weather data for the airport. The historical weather data provided are consolidated internally in the program with the historical operations information provided. The process is used to characterize the sample operations for the airport and weather conditions that these operations were subject. The period for weather data must match the same period for historical operations data. Having one year of data will help take into consideration seasonal weather and operational variations.



Existing Historical Operations in the Database

| HOD ID | DATE&TIME | RUNWAY | Arr/Dep | FAA_Code | FLIGHT_Categ |
|---|---|---|---|---|---|
| 1 | 1/1/2014 7:26 AM | 36 | A | B738 | AIR |
| 2 | 1/1/2014 8:25 AM | 36 | D | B738 | AIR |
| 3 | 1/1/2014 10:46 AM | 18 | A | B738 | AIR |
| 4 | 1/1/2014 11:32 AM | 18 | D | B738 | AIR |
| 5 | 1/1/2014 12:19 PM | 18 | A | A320 | AIR |
| 6 | 1/1/2014 1:25 PM | 36 | D | A320 | AIR |
| 7 | 1/1/2014 1:50 PM | 36 | A | B738 | AIR |

Total number of records: 5134

Figure 7. Input of Historical Weather Data

## 4. Overrun and Veer-off Risk Assessment Analysis

### 4.1. RSARA Analysis of Results

The table 5 is shown below, it contains in the second column the average probabilities for Landing-Takeoff Overrun and Veer-off. Landing Overrun Average probability is 7.8E-07 (per 10 million flights almost 7.8 accidents) and the Takeoff Overrun average probability is 2.5E-07 (per 10 million flights almost 2.5 accidents) almost type of event and the total average probability for the airport. Now, the average probabilities for Landing Veer-off is 4.3E-07 (per 10 million flights almost 4.2 accidents) and the one for Takeoff Veer-off is 2.2E-07 (per 100 million flights almost 2.5 accidents) almost type of event and the total average probability for the airport. In case of Takeoff procedures, Veer-off Risk probabilities are absolutely absent.

**Table 5. Overall Results of Overrun and Veer-off**

| Accident | Average Probability | Average # of Years to Critical Incident | % Ops Above TLS | Average # of Years to Critical Incident for TLS |
|---|---|---|---|---|
| **LDOR** | **7.9E-07** | **>100** | **16.0** | **>100** |
| **TOOR** | **2.5E-07** | **>100** | **0.8** | **>100** |
| **LDVO** | **4.3E-07** | **>100** | **4.9** | **>100** |
| **TOVO** | **2.2E-08** | **>100** | **0.0** | **>100** |

The average number of years between incidents or accidents, it shows average sum of less than 100 years to Critical Incident for all position. This number is estimated based on the event probability, the annual volume of operations challenging the RSA for the given event, and the expected growth rate. Please note that this number is not to predict how many years it will take for that accident to happen; rather, it is an indication on how frequently the event can take place if the same conditions of operations are kept for a very long period of activity at the airport.

The percentage of movements challenging the RSA that have a risk higher than the selected TLS (for LDORs, 16%, TOOR 0.8% and LDVO 4.9%, TOVO 0.0%, of the movements are under a risk higher than 1.0E-06, one in one million movements).

### 4.2. Sensitivity Analysis

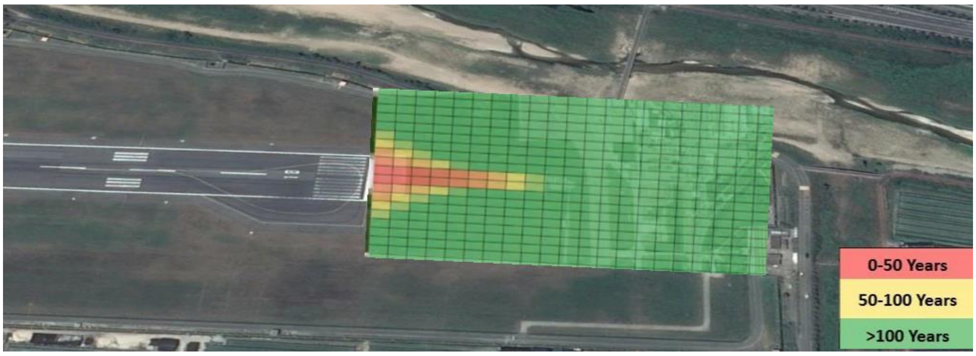


**Figure 8. Event Probability - Expected Return Time (years/event)**

The Expected return time of Event probability of the Lang or Takeoff overrun described, that, the occurring Accidents/ Incidents Average Probability by years. The red color area risk rate is between 0-50 years, and the yellow color area risk rate is 50-100 and the last green color area less than 100

The red color risk areas described higher probability of accident/incident risk probability of Landing or Takeoff Overrun, Yellow areas are Medium, the last one green area almost free of risk for landing or takeoff overrun (Figure 8).

### 4.3. Identification of Normal Operation Data (NOD) Risk Probabilities

The accident database before NOD was incorporated in later analyses. The analysis aims to give a basic description of the accidents in the database, provide a better understanding of their nature and background conditions and to allow comparisons to be made between the four accident types. Many previous studies have identified the causes and contributory factors of take-off and landing accidents.

This paper does not repeat that exercise but examines the prevalence of a number of key risk factors that are relevant to the core objectives of the research, i. e. quantifying the criticality of risk factors and building predictive accident frequency models. Numerous references report that poor weather conditions such as adverse wind conditions and low visibility are associated with take-off and landing accidents. Special emphasis was therefore placed on providing a comprehensive study of the pervasiveness of poor weather conditions in RSA-related aircraft mishaps.

Almost low visibility condition of weather improves most critical situation on landing and takeoff. When is wind direction of degree in parallel with runway direction and rainy and snowy days' runway condition will became most risky, it makes to aircraft most inconvenient situation. The using of the one-year flight data's, we may have defined Maximum and Minimum risk probabilities of both case of Study. First of all, we should have identified ICAO Standard procedure airport Maximum and Minimum Risk Probabilities.

**Table 6. ICAO Standard Procedure Airport Maximum and Minimum Risk Probabilities**

| ICAO SARPs | | | |
|---|---|---|---|
| **LDOR** | **LDVO** | **TOOR** | **TOVO** |
| **Highest** | **Highest** | **Highest** | **Highest** |
| **2.37E-05** | **2.17E-05** | **1.34E-06** | **1.61E-06** |
| **Lowest** | **Lowest** | **Lowest** | **Lowest** |
| **1.7E-08** | **2.69E-08** | **3.14E-08** | **7.68E-10** |

Our next step is to identify case study Maximum and minimum risk probability and their actual dates. Now we have to compare both of airport cases. Ulsan airport and ICAO standard procedure airport.

**Table 7. Case a Study Risk Probability of Overrun and Veer-off (A and B)**

| A) Runway ID | Actual Dates | Type Incident | Total probability of Ulsan Airport case study |
|---|---|---|---|
| **18** | **12/2/2014** | **LDOR** | **5.16E-05** |
| | **12/2/2014** | | **3.34E-05** |
| | **8/7/2014** | | **3.26E-05** |
| **18** | **12/2/2014** | **TOOR** | **2.38E-06** |

| | | | |
|---|---|---|---|
| | **10/2/2014** | | **1.65E-06** |
| | **10/2/2014** | | **1.65E-06** |
| | **10/2/2014** | | **1.65E-06** |
| **36** | **29/3/2014** | **LDOR** | **8.168E-06** |
| **36** | **29/3/2014** | **TOOR** | **6.01E-07** |
| **B) Runway ID** | **Actual Dates** | **Type Incident** | **Total probability of Ulsan Airport case study** |
| **18** | **22/10/2014** | **LDVO** | **2.22E-05** |
| | **28/4/2014** | | **2.20E-05** |
| | **29/3/2014** | | **2.19E-05** |
| | **28/4/2014** | | **1.81E-05** |
| | **12/2/2014** | | **1.89E-05** |
| | **28/5/2014** | | **8.68E-06** |
| | **28/5/2014** | | **8.49E-06** |
| | **28/5/2014** | | **6.94E-06** |
| **18** | **28/5/2014** | **TOVO** | **1.20E-07** |
| | **28/5/2014** | | **1.16E-07** |
| **36** | **22/10/2014** | **LDVO** | **2.22E-05** |
| | **28/4/2014** | | **2.20E-05** |
| | **12/2/2014** | | **2.19E-05** |
| **36** | **12/2/2014** | **TOVO** | **1.64E-06** |

Every act has level of safety, like our case. Our Normal safety level determined with ICAO standard procedure airport. If RSA risk probabilities are do not exceed between maximum and minimum, so airport RSA risk probability is normal. Otherwise RSA risk probability is considered abnormal.

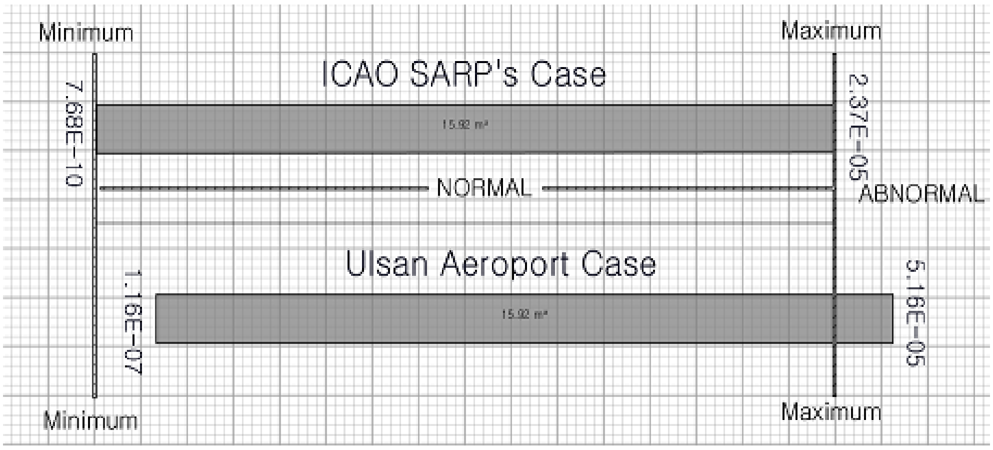


**Figure 9. Precisely Explaining our Case Study Case**

Above Figure 9 described RSA probabilities of risk for Ulsan airport, Korea. There two parts of RSA Probabilities of risk. One of them reports ICAO SARPs Airport's Risk probability. It is norm for all of airports. Second one is Ulsan Airport Real location and basis of RSA size. The shown two lines characterize extent rate. The first of line belonging to ICAO Standards and Recommended Practices for RSA. As well this risk probability measurement is norm for standard procedure. The next line also explains measurement of the risk probability, but that is reverse.

The Table 9 and Figure 9 give us clearly description on this case. At the few dates of Risk Probability are out of the norm. As a result, on that day's weather conditions were abnormal, and it made high risk of RSA probabilities on the runway surface and its end area. Decision of the research appearance, that, the weather phenomena's (heavy snow, strong rain, freezing conditions, and the fog *i.e.*), which are affect to the airport normal operation procedures.

Extremely, it makes confident to the rather on the weather phenomenal days, also it gives us to know before flight operation procedures and may prevent and mitigate risk of accidents and incidents probabilities on runway surface or its end area. After approval those phenomena's, Operations may reduce on the flight procedures. Finally, research gives us, that, it's reduce government finance for Airport Facilities and its surface construction. Even, it makes well safety procedures on airport zone and runway surface or its end area.

## 5. Conclusion

The accident frequency models form part of the overall risk assessment methodology developed by the present research, which features a number of improvements compared to traditional approaches to airport risk assessment. The risk assessment and its means for calculating a risk profile by the risk frequency and risk effect analysis under the given environment, and the risk management is the optimal according to the result of the proposed alternatives in a given environment, and evaluate assess of the risks and strengths and weaknesses of each alternativist means for selecting the alternatives.

## Acknowledgments

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