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A Study on Developing Airport Risk Assessment Algorithm by FOQA Data Analysis and SMS

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ABSTRACT

According to various researches, one of main causes of flight accidents is human factors. It is important to collect and analyze event data in advance to minimize and prevent human errors by developing safety checklist. As a result, international aviation industry developed FOQA(Flight Operations Quality Assurance) for commercial airliners, and, upon its proven effectiveness, it is now highly recommended to adopt for all operations of aircraft. Therefore, this thesis studied fundamental Airport Risk factors identification Algorithm based on ICAO(International Civil Aviation Organization), SMS(Safety Management Systems) and Matrix. Airport Risk factors identification algorithm has been applied for methodology of this research and categorized by level of safety based on two factors: Probability and Severity. In addition, altitude, traffic volume, and actual Flight Operation history for various airports, runway, aircraft model with different time and weather condition were used as variable values. This study conducted regression analysis of 'A' organization's flight event frequency and applied ICAO SMS Matrix to categorize the severity of the events according to international standards. Based on the analysis, derived from fundamental Airport Risk Identification Algorithm, which can be a proactive measure for safe operation. As a consequence, this study assessed the Airport safety level of each airport and drew a conclusion with countermeasures based on the problem found.

KEYWORDS: Flight data record, Flight operation quality assurance, International civil aviation organization, Safety management system, Airport risk identification algorithm

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1. Introduction

Airplane accidents occur because of combination of various risk factors rather than just one according to various researches, one of main causes of flight accidents is human factors.

It is important to collect and analyze event ata in advance to minimize and prevent human errors by developing safety checklist. As a result, international aviation industry developed FOQA(Flight Operations Quality Assurance) for commercial airliners, and, upon its proven effectiveness, it is now highly recommended to adopt for all operations of aircraft.

Therefore, this thesis studied fundamental Airport Risk factors identification Algorithm based on ICAO(International Civil Aviation Organization) SMS(Safety Management Systems) and Matrix. Airport Risk factors identification algorithm has been applied for methodology of this research and categorized by level of safety based on two factors: Probability and Severity. In addition, altitude, traffic volume, and actual Flight Operation history for various airports, runway, aircraft model with different time and weather condition were used As variable values.

This study conducted regression analysis of 'A' organization's flight event frequency and applied ICAO SMS Matrix to categorize the severity of the events according to international standards. Based on the analysis, derived from fundamental Airport Risk Identification Algorithm, which can be a proactive measure for safe operation.

As a consequence, this study assessed the Airport safety level of each airport and drew a conclusion with countermeasures based on the problem found.

In this study, Utilizing FOQA Data, the study estimated the frequency of occurrence through actual Weather Databse, airport location, the altitude, posture, etcetera and finally the derived results by completing the application of SMS Matrix according to the severity and the frequency of occurrence through the mathematical operation.

Finally, the study confirmed the significant value, validating data with accident data of the actual airport.

2. Research Background Safety Management System

SMS is defined as a series of systems that include all safety management programs encompassing precautionary actions, activities, performance of studies and it sets explicit goals and establishes safety management organization, policies based on the system integration [4].

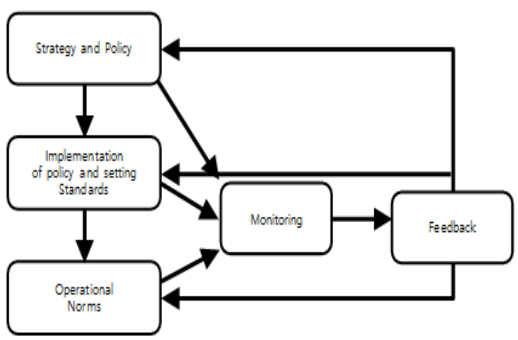

Figure-1. Safety Management System[1]
(International Civil Aviation Organization, 2015)

In other words, through data collection, the goal of SMS is to set safety culture in organizations by classification of hazards in advance and distinguishing level of risk, assessing and managing severity of risk[2].

Hazard is the cause of every loss of lives and property damages and it consists of ex-post, precaution and prediction aspects[3].

In aviation industry, ex-post aspect of hazards includes reporting of accidents, serious incidents and aviation safety hindrance reporting system[4]. Precautionary aspect of hazard involves safety investigation and assessment. prediction aspect of hazard involves flight data monitoring, flight quality assessment[5]. Risk is calculated by the level of severity and probability from hazard which was measured by the potential impact as Formula

$$Risk = \mathrm{Pr}obability \times Severity$$

(Formula 1)

To appraise the severity of hazards, the formula should determine the methodology of risk mitigation, considering the total expense and time to remove or mitigate the hazards. Through instituting corrective action, it should be also able to confirm if the severity of risk is reduced to acceptable standards. It also needs to be reexamined the probability of failure, needs to discern possibility of acceptance, additional risk and to perform additional assessment. It is also necessary to monitor and confirm if the risk mitigation and control is effective[6].

2.1 Flight Operations Quality Assurance

Using Flight Data Acquisition Unit attached to flight, FOQA is defined as the system that makes possible for one to collect and analyze various flight data, for example, velocity of flight, altitude, posture and performance[7]..

The flight data analysis began when the FDR(Flight Data Recorder) was invented for accident investigation in 1958. Later, QAR(Quick Access Recorder) was devised to record aircraft flight operation other than accident investigation.

However, as it is recognizable in the recent report of ICAO, with the technology development, increased demands for aircraft, which resulted in increased number of flight as well as enlarged size of airplanes in aviation industry, which led to increased numbers of airplane accidents[8].

Thus, international community has made great effort to reduce the damage of human lives and property caused by airplane accidents through various activities as well as investigations.

However, pilots were the ones who made the final decision and the actions for flight safety and most flight accidents resulted from human error. In this light, a system, such as, FOQA was invented and introduced to analyze and collect any possible situations that can happen during flight such as equipment failures, flight operation and human error in real time basis. It gathers all data generated during flight in real time basis, and it builds database and saves in storage device. After analyzing data once saved in the storage device, FOQA collects any possible risk factors except for normal flight condition. In this aspect, any potential risk factors that were collected will be classified into every environment and situations. FOQA makes accidents to be able to establish any proactive measures preventing flight accidents.

3. Research Methodology Airport Risk Identification Algorithm

For Risk prevention, SMS, FOQA systems are put into practice. They, however, cannot guarantee the airplane safety when there is combination of unusual condition resulted from each airport environment and flight condition[9].

Thus, this study investigated algorithms that can classify the severity of risks to each airport. In order to do this, first of all, airports were selected.

This study collected 448,020 times of flight data of accidents, incidents for recent 5 years. Based on the collected data, the study applied CCPD(Complementary Cumulative Probability Distribution) to five different models(Loss of Control, Controlled Flight into Flight, Runway Excursion, Undershoots, In-Flight Damage), multiplying data including CCPD by frequency of accidents to calculate CCPD.

After multiplication, to model probability of accident, the study used regression analysis estimation and calibration of risk frequency. Through mathematical techniques, the study conducted multivariate analysis. Finally the study implemented regression analysis to several reasons about statistical process.

Regression analysis estimation used model that adopted dichotomous result according to the occurrence of accidents. It included various variable factors including limitation of classified by class and comprehensive result.

logical formula of basic model is as follows. X is independent variable, bi is coefficient of regression, e is natural constant.

$$P\{\text{Accident Contribution}\} = \frac{1}{1+e^{b_0+b_1+x_1}+b_2X_2+b_3X_{3\ldots\ldots}}$$

(Formula 2)

3.1 Generation of Independent Variables Using Polynomial Regression

Accident probability modeling was the calibration of the frequency model about accident type, using the regression analysis estimation based on the accidents of recent 5 years and incident data of the airport, analyzes statistical process about accident and incident, and classified as Human, Machine, Environment, and factor in accordance with the Accident Prevention Manual of ICAO[7].

Accident probability modeling used model that also adopted dichotomous result according to the occurrence of accidents.

The model included each parameters to be considered and were able to reconstruct the variables associated with the various incidents according to the logistic regression analysis.

Then, the initial value which had high correlation between the independent variables and modified value was removed in order to eliminate the negative factors of multicollinearity[10].

In the case of the variables that remarkably affected low on the correlation of each accident, it is determined that the contribution rate of displacement on probability of accidents is low[11]. The specific examples of the calculated independent variables are shown in Table 1 ~ Table 3.

Table 1. Calculated Independent Variable Values (Machine)

Variable	Take off	Clime	Descent	Approach	Landing
Adjusted Constant	-13.065	-12.378	-13.088	-14.293	-15.612
User Class F	-1.2075	1.393	-1.2721-	1.366	1.601-
User Class G	1.339	1.488	1.282	-1.372	2.094
User Class T/C	-0.498	0.017	-	-	-
Aircraft Class A/B	-1.013	-0.778	-0.770	-1.150	-0.852
Aircraft Class C/D/E	0.935	0.138	-0.252	-2.108	-0.091

Table 2. Calculated Independent Variable Values (Environment)

Variable	Take off	Clime	Descent	Approach	Landing
Ceiling 1000ft to 2500ft	-0.345	-0.721	-0.889-	-0.971	1.3
Visibility less than 2 SM	2.881	3.096	2.143	1.364	2.042
Tailwind more than 12 kt	0.786	-	0.98	-	-
Temp less than 5C	0.043	0.197	0.558	0.269	0.988
Rain	-	0.991	-0.126	0.355	-1.541
Snow	0.449	-0.25	0.548	0.721	0.963
Gusts	-	0.041	-0.036	0.006	-
Hub/Non, Hub airport	1.334	-	-	-	-0.692

Table 3. Calculated Independent Variable Values(Human)

Variable	Take off	Clime	Descent	Approach	Landing
Physical Trouble	1.021	1.046	1.078	1.12	1.201
Procedure	0.641	0.541	0.601	0.722	0.891
In Experience	0.021	-	0.031	0.038	0.041
Cross Check	0.013	0.01	0.018	0.024	0.061
Fatigue	0.028	0.031	0.041	0.064	0.071
CRM	0.487	-0.02	0.601	0.714	1.02
Un Procedure	-	0.041	-	0.006	-
Different View	-	-	-	-	-0.692

3.2 Modified Algorithm

By applying the calculated independent variables in modeling for each event, a formula was derived. By using the basic regression equation of formula 2, the study defined the model as follows.

After the step above, the calculated values can be calculated position of vertical and horizontal According to the formula of accident occurrence probability

$$
\begin{aligned}
b = &-13.065 - 1.2075(User\ Classf) + 1.339(User\ ClassG) \\
&-0.48(User\ Class\ T/C) - 1.013(Aircraft\ ClassA/B) + \\
&0.935(Aircraft\ ClassC/D/E) - 0.701(Ceilinglessthan200ft) - \\
&0.345(Ceilinglessthan200ftto1000ft) - \\
&0.223(Ceilinglessthan1000ftto2500ft) + \\
&2.05(Visibilitylessthan2SM) + 2.881(Visibilityfrom2to4SM) + \\
&3.142(Visibilityfrom4to8SM) - 1.012(Xwindfrom2to5kt) - \\
&0.713(Xwindfrom5to12kt) - 1.221(Xwindmorethan12kt) + \\
&0.786(Tailwindmorethan12kt) + 0.043(Templessthan5^{\circ}C) - \\
&0.023(Tempfrom5^{\circ}Cto15^{\circ}C) - 0.067(Tempmorethan25^{\circ}C) + \\
&2.014(IcingCondition) + 0.437(Snow) + 0.445(Fog) + 0.449(Hail) - \\
&1.344(Thunderstorm) + 0.929(FOD) + 1.334(Hub/NonhubAirport) + \\
&1.021(PhysicalTrouble) - 0.641(Procedure) + 0.0217(\varepsilon Experience) + \\
&0.013(Cross) + 0.028(Fatigue) + 8.937(LogCriticalityFactor)
\end{aligned}
$$

(Formula 3)

Severity is classified as 5 levels such as Catastrophic, Hazardous, Major, Minor, and Negligible based on the severity of the anticipated accidents. For example, the Catastrophic, which is the highest level, is defined as anticipated accidents with total destruction of equipment, lots of deaths. The Negligible, which is the lowest level, means the small mistake that can be neglected[9].

Table 4. Location Model.

Type of Data	Model	(%)
X	$Pd > x = e^{-0.00431x^{0.983632}}$	99.1
Y	$Pd > y = e^{0.21683y^{0.46621}}$	95.7
Z	$Pd > z = e^{-0.01682x^{0.766497}}$	98.3

3.3 Comparison Analysis

The selected P airport was rated as CAT-I international airport and is installed with two parallel runways and the sized of them are 3200m 60m and 2,743m 45m. ILS(Instrument Landing System) is also installed in the airport. Due to the seasonal effects and Obstacle of north side airport, it is designated a special airport by the Ministry of Land and Transportation that performed Circling Approach, Non-Precision Approach (Ministry of Land and Transportation, 2016).

The P airport is also remarked as an airport at high risk where there was a catastrophic flight accident of Air China flight B767 in April, 2002. This study selected P airport because of the convenience in comparison analysis of actual flight records and accident statistics with the derived algorithm simulation results.

Table 5. P Airport Risk Identification Results

Risk Identification	Average Probability	Average Severity
Take Off	1	D
Clime	2	D
Descent	4	C
Approach	5	B
Landing	5	C
Total	**4 (2.3E-06)**	**C**

Likelihood	Severity				
	Minimal E	Minor D	Major C	Hazardous B	Catastrophic A
Frequent 5	5E	5D	5C	5B	5A
Probable 4	4E	4D	4C ✈	4B	4A
Remote 3	3E	3D	3C	3B	3A
Extremely Remote 2	2E	2D	2C	2B	2A
Extremely Improbable 1	1E	1D	1C	1B	1A

For the estimation of risk frequency, this study analyzed the actual flight number based on the FOQA data of the airport's recent 5 year records and applied the number of the occurrence of abnormal situations. The degree of limited value in abnormal situations used standard operating procedures and the criterion of aircraft manufacturers. The total 12,463 annual weather data measured every hour in a year using KAMA(Korea Aviation Meteorological Agency) Metar data was put into the Weather Database. The calculated value using algorithm is as follows.

The analyzed results showed the average of 2.3E-06, which was one accident per 434,782 departures and it also demonstrated that the probability of accidents was 1.3E-06 higher than the recommended safety level of ICAO.

The frequency of risk exposure in this airport was 17 times, and the occurrence rating severe accident was level C and comprehensive risk rating of the airport was 4C.

Finally, the comparison and verification were conducted by using the calculated value through algorithm with the actual accident statistics of P international airport.

From April, 2002 to October, 2011, there was one accident among 437,761 flights in P airport, and that frequency represents probability of 2.3E-06. After October, 2011 to present date, the number of flight still remains the same level from the derived value (Korea Airport Cooperation 2016) (Ministry of Land and Transportation, 2016)

4. Conclusions Research Summary

The demand for air transport constantly increases every year. As the air transport got modernized, detailed, and automated, the probability of accident occurrence by the human errors caused by flight crews did not diminish while accident frequency due to the technical errors caused by defects of its own aircraft reduced.

To this effect, it is indispensable to remove safety hazards through proactive, predictive management to minimize the human errors of flight crews.

Most of the accidents caused by human errors, as the result of this study shows, are generated by the multiple actions of Machine, Human, and Environment.

In this study, the necessity for effective and predictable risk assessment of each airport was highlighted, so the study analyzed the accident data, classified the types of accidents, and derived the contributing factors using regression analysis in this study. Then, Using Polynomial Regression analysis, independent variable were generated and the severity was derived by applying the types of accident.

Utilizing FOQA Data, the study estimated the frequency of occurrence through actual Weather Database, airport location, the altitude, posture, etc and finally the derived results by completing the application of SMS Matrix according to the severity and the frequency of occurrence through the mathematical operation.

Finally, the study confirmed the significant value, validating data with accident data of the actual airport.

Even though the study confirmed the adjacent actual figures of P international airport data based on the verification through statistics, it should not be regarded as exactly correct because it is the probability-based figures.

Therefore, derived airport risk identification algorithm will be utilized in not only the existing standard operating procedures but also the debriefing and the education for flight quality promotion in advance for safe navigation. Also it has to be applied according to the mission criteria and characteristics of each operating agencies.

As the improvement of operational procedures and the minimization of human errors for the aircraft accident rate decrease, it is expected to reduce the economic costs, improve the long-term safety, and advance the aircraft operation ratio by analyzing the causes of accident threats.

Airport risk identification algorithm was derived from the study is in its experimental stage, thus there are points to be improved.

The result of regression analysis needs to be continuously modified because of the error existed in the use of statistical data. Severity estimation has also predictable aspect, so there exists the infinite number of cases.

Thus, the study suggested the need of the classification into types of accidents, incidents and abnormal conditions through analysis of their data.

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FOQA 이벤트 분석 및 SMS를 활용한 공항 위험도 평가 알고리즘 개발 연구

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요 약

다양한 연구에 따르면, 비행사고의 주요 원인 중 하나는 인적 요인이다. 안전 점검표를 개발하여 사람의 실수를 최소화하고 사고 예방을 위해 이벤트 데이터를 사전에 수집・분석하는 것이 중요하다. 그 결과, 국제 항공 산업은 상업용 여객기에 대한 비행 운영 품질 보증시스템(FOQA)을 개발하였고, 그 효과가 입증됨에 따라, 이제는 항공기의 모든 운항에 대해 채택하는 것을 적극 권장 하고 있다. 본 논문에서는 ICAO (국제민간항공기구), SMS(안전관리시스템) 및 매트릭스에 기초한 공항 위험요인 식별 알고리즘의 기본을 연구하였다. 공항 위험 요인 식별 알고리즘은 본 연구의 방법론에 적용되었으며 확률과 심각도라는 두 가지 요인에 기초하여 안전 수준별로 분류하였다. 또한 시간과 기상 조건이 다른 다양한 공항, 활주로, 항공기 모델에 대한 고도, 교통량, 실제 비행 운항 데이터가 가변값으로 사용되었다. 본 연구는 'A' 항공사의 비행 이벤트 빈도수에 대한 회귀 분석을 실시하고 ICAO SMS 매트릭스를 적용하여 국제 표준에 따라 심각도를 분류하였다. 이 분석에 기초하여, 사전 예방적 조치가 될 수 있는 기본적인 공항 위험 식별 알고리즘에서 도출하였다 본 연구의 회귀 분석 결과는 통계 데이터 사용에 오류가 존재하기 때문에 지속적으로 업데이트 해야 할 필요가 있으며 사고, 이상 상황의 유형을 분류할 필요가 있다고 제언한다. 향후 본 연구를 활용한 항공기 사고율에 대한 운용절차 개선과 인적오류 최소화, 사고위협 원인분석을 통해 항공운송산업의 비용 절감, 장기적 안전성 향상, 항공기 운항비율 고도화를 기대하는 바이다.

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