Impact of the Mt.Baekdu explosion to South Korea's Air Transportation with hypothetical scenario

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***Abstract*— This research focuses on the hypothetical case of the possible eruption of Mount Baekdu and the assessment of the level of disruption to South Korea. The focus of the analysis is on the nine routes that are connected with major airports in South Korea. This study analyzes the effects of volcanic ash to air traffic flow at national and worldwide levels.**

Keywords Volcanic ash; Air Traffic Flow; Mt. Baekdu;

I. INTRODUCTION

A. Background

The ash cloud from the Eyjafjallajokull volcano in Iceland caused a significant impact on the aviation industry on April 14, 2010. [1] Airspaces across Europe closed, with at least 17,000 flights a day being cancelled for over a week. Overall 100,000 flights were cancelled and 10 million passengers were unable to board their flights. South Korea was also affected, with a total of 55 cargo flights (total 4,060 tons) and 88 commercial flights (about 29,000 people) cancelled during the volcanic activity between April 16 and April 20.

Volcanic ash clouds make aircrafts impossible to fly due to the ash comprised of minerals of extremely small and hard rock particles. These particles have a blasting effect on the aircraft's cockpit window when an aircraft meets the ash at high speeds. The hard ash also damages all the engine components and the blades and blisks are worn down very rapidly. In the early 1980s, several commercial aircrafts were damaged after flying through volcanic ash clouds; eruption of Mount St. Helens, U.S.A. in 1980; Galuggung Volcano, Indonesia in 1982, Redoubt Volcano, Alaska, U.S.A., in 1989; Mount Pinatubo Volcano, Philippines in 1991; Mount Propocatepelt, Mexico in 1997 and 1998. These volcanic eruptions all caused significant damages to the aircrafts, including engine failure, and severely disrupted regional air operations.

B. Literature Review

There have been many studies trying to address economic impacts of Volcanic Ash. Jiang (2013) investigates the damages of volcanic ash and analyzes the case study of the social and economic impacts of volcanic ash eruptions in the world. This study helps to estimate the potential volcanic ash impacts in South Korea when Mt. Baekdu volcano erupts in the future [2]. Lee (2012) attempts to address the clarification of the characteristics of dispersion of volcanic tephra emitted from Mount Baekdu with various eruption environment from Weather Research and Forecast (WRF) and FLEXPART. Synoptic conditions, on October 12, 2010, was adopted because the volcanic ash of Mount Baekdu could potentially reach the Korean peninsula and its dispersion pattern was compared with different Volcanic Explosivity Index (VEI) and particle. The Figure 1 shows the distribution of particles emitted from the Mt. Baekdu under different VEI at 24 and 48 hours after release [3].

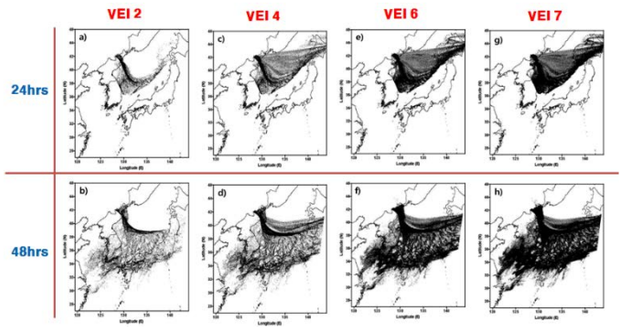

Figure 1. Distribution of particles emitted from the Mt. Baekdu under different VEI at 24 and 48 hours after release (3)

Casadevall (1994) analyzed the eruption of Redoubt volcano and its effect on the commercial and military air operation in Alaska. These effects were due to the direct impact of volcanic ash on jet aircraft, as well as the rerouting and cancellations of flights operations resulting from the eruption. This study described the damage to the aircraft involved in encounters with Redoubt ash clouds and identified some of the strengths and weaknesses of the system to warn of an impending eruption or notification of an eruption progress [4]. Webley and Mastin (2009) summarized how an interdisciplinary working group on eruption source parameters has been instigating research to improve upon the understanding of volcanic ash cloud characterization and predictions [5]. Scaini (2014) analyzed the impacts of volcanic ash dispersal with GIS-based tool. It combined ash dispersal model and air traffic data to estimate the potential impacts on air traffic of an eruption from Katla volcano, subsuming a "worst-case" meteorological scenario [6].

C. Research Objective

Volcanic risk assessment has typically focused on loss of the economy and physical damage. This research analyzes the effect of volcanic ash to air traffic flow at national and worldwide levels, in the hypothetical case of Mount Baekdu eruption by assessing the level of disruption to the Korea and nearby countries. We combined hypothetical ash dispersal model and air traffic data to assess the potential impacts on air transportation of an eruption from Mount Baekdu. We analyze the impact through the air-traffic route based on eruption scenarios.

II. CURRENT STATE OF KOREA'S AIR TRANSPORTATION

A. Airport Overview

South Korea have 15 airports, of which are eight international and seven domestic airports. Major airports are Incheon (ICN), Gimpo (GMP), Gimhae (PUS), and Jeju (CJU) international airport. Approximately, 30,000 international flights depart and arrive in South Korea. They carry more than 5 million passengers a month (**TABLE I**).

B. *Major Airports & Route*

South Korea's routes are composed of 12 international and 26 domestic routes. These routes are controlled in one Flight Information Region (FIR) which is the Incheon FIR. (Figure 2, Yellow line). These airports cover about 98% of the total number for international flights and for passengers of which 87% are domestic flights carrying 90% domestic passengers.

TABLE I. TOTAL NUMBER OF FLIGHTS, PASSENGERS AND RATE PER MONTH

	International		Domestic	
	Flights	Passengers	Flights	Passengers
All airports	30,745	5,154,906	28,872	4,348,489
Major airports	30,126	5,071,736	25,105	3,915,285
Ratio	97.99%	98.39%	86.95%	90.04%

These 4 major airports are connected to 9 different routes such as B467-①, G597-②, G585-③, A582-④, A586-⑤, G203-⑥, Y711&Y722-⑦, Y644-⑧ and A595-⑨ (Figure 2)

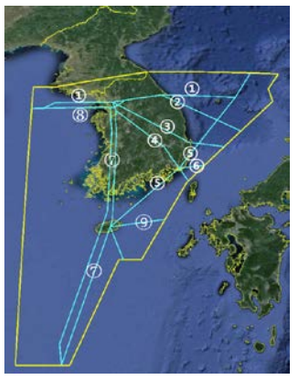

Figure 2. Route for Major airports (Google earth)

III. DATA DESCRIPTION

Traffic volume of each route is the confidential data. However, the flight information from Korea Airports Corporation (KAC), Incheon International Airport Corporation (IIAC), and Airportal site provide the flight schedules (Departure, Arrival), which were used to assign route for each flight in order to find Origin & Destination (OD). We collected the weekly flight schedule and then follow these steps to refine the data before the analysis.

A. *Find Origin & Destination (OD)*

The airline, flight number, schedule time, origin and destination of flight which could be found from information offered by KAC, IIAC and Airportal web page. The flight schedule included information on code sharing so it should be classified as one flight service, even if multiple airlines are served.

B. *Assign the route Assign the route*

When we find the OD, the route will be assigned using the flight tracking data, aeronautical chart and flight tracking site (www.flightaware.com).

C. *Calculating the number of flights (each route & airport)*

After assigning the route, we can calculate the number of flights each route. Some of the routes are divided into two routes which are Right/Left side and Up/Down side based on airport. We can also calculate the number of flights for each major airport (Table II).

TABLE II. NUMBER OF FLIGHTS EACH ROUTE (TOTAL OF MAJOR AIRPORTS)

Route	Mon	Tue	Wed	Thu	Fri	Sat	Sun
G597_B467	6	9	6	6	10	8	8
G597_R	96	88	98	89	93	97	101
A586_R	12	16	12	14	12	16	12
A586_L	50	42	48	51	48	44	50
G585	90	85	85	85	88	88	91
A582_D	14	14	12	14	13	15	14
A582_U	55	51	57	51	66	60	62
G203	16	16	16	16	16	16	16
Y711	156	136	150	157	153	166	166
Y722	150	147	137	151	161	158	159
A595	6	5	7	4	8	4	8
G597_L	89	88	89	87	91	91	92
Y644	86	85	93	86	88	87	94
Total	826	782	810	811	847	850	873

IV. SCENARIO

Two different kinds of scenarios were assumed to observe the impact of the Mt. Baekdu explosion to South Korea's air traffic flow. Assumption is based on the period of 7 days[1] using four major airports in South Korea. These airports are connected to the nine different routes and we assumed the hypothetical ash dispersal model[2] refer to the Figure 1. Volcanic Explosivity Index (VEI) is VEI 4 which is the same with the eruption of Eyjafjallajökull in Iceland. After that, we analyze the impact of eruption of route and airport serviceability.

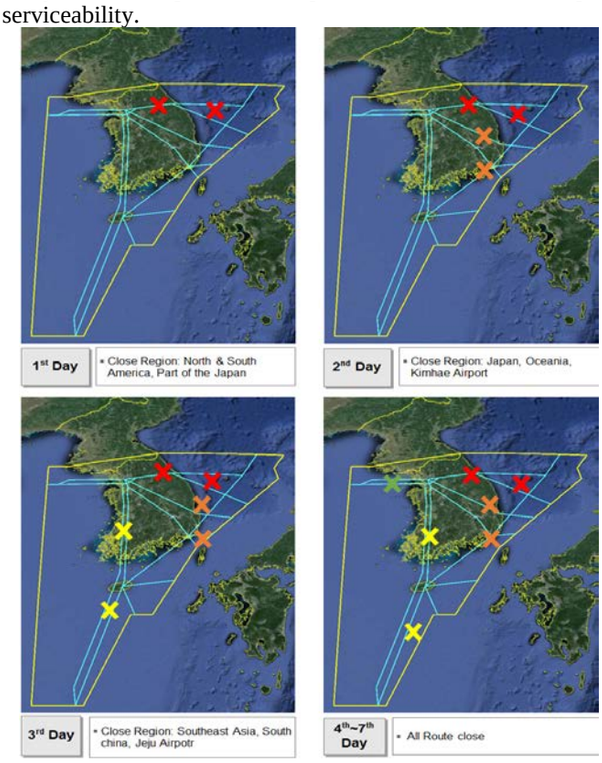

Figure 3. Hypothetical scenario

A. *Scenario A (No recovery)*

On the 1st day, the right direction of G597-B476, G597_R and A586_R will close. The aircrafts cannot fly to North and South America and part of Japan. On the 2nd day, route of the G585, A582, A586_L, G203 and PUS will be closed. Flying to Japan and Oceania will not be possible. On the 3rd day, route of the Y711, Y722, and CJU will be closed. Accordingly, the aircraft cannot fly in the direction of Southeast Asia and Southern China. On the 4th ~ 7th day, G597 will close in both direction, as well as Y644 along with GMP and ICN.

B. *Scenario B (Gradually recovery from 5th, 6th and 7th day)*

This case will be similar to Scenario A but the routes are considered to start recovering again starting on the 5th day, 6th day, and 7th day in opposite direction. As in "Eruption of

[1] A bilateral air transport agreement (also sometimes called a bilateral air service agreement or BASA) is an agreement which two nations sign to allow international commercial air transport services between their territories. BASA cover the basic framework under which airlines are granted bilateral rights to fly two countries. They also decided the capacity and frequency based on a week.

[2] South Korea, including all its island, lies between latitudes 33° and 39°N, and longitudes 124° and 130°E. So, South Korea has four distinct seasons: Spring, summer, autumn and winter. Mount Baekdu located on the border between North Korea and China. When the wind blow from north if Mount Baekdu explode that will be impact to South Korea.

Eyjafjallajokull case", it also shows a gradual recovery after the 6th day of eruption. The wind direction is from the northwest in our scenario. So, we assumed that west part of our nation would be the first to recover due to seasonal wind.

V. ANALYSIS

A. Route

1) Result of the scenario A

The results are shown in **TABLE III**. **TABLE III** represents the number of cancellations of scheduled flights due to Scenario A. Total of 4,480 flights (if Mount Baekdu explode on Tuesday) will be cancelled during one week. Only 22.7% of total number of flights can be served for the passengers.

TABLE III. THE NUMBER OF CANCELLED FLIGHTS (SCENARIO A)

Starting day for eruption	Cancelled flights	Serviceability (week)
Mon	4,443	23.4%
Tue	4,480	22.7%
Wed	4,440	23.4%
Thu	4,417	23.8%
Fri	4,374	24.6%
Sat	4,376	24.5%
Sun	4,387	24.3%

(Red: worst case), **(5,799 FLIGHTS/ WEEK)**

Figure 4 shows the serviceability of Scenario A. The red bar represents the serviceability of each day and the blue line represents the serviceability of the cumulative average. In the following scenario A, from the 4th day there would be no service at all.

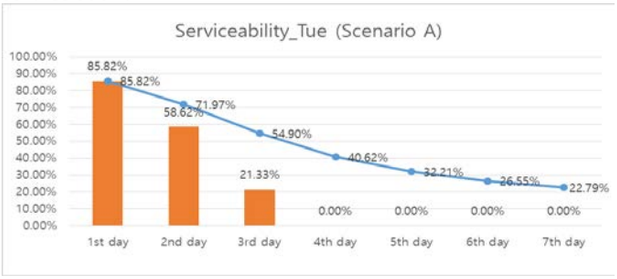

Figure 4. Serviceability of Scenario A

2) Result of the scenario B

Table IV represents the number of cancelled flights during a week with the scenario B. It has different starting day for eruption of worst case depending on when the volcanic ash begins to dissipate. So, except for the case of the recovery starting on 5th day, when eruption start on Tuesday, the impact of eruption would be the largest.

TABLE IV. THE NUMBER OF CANCELLED FLIGHTS (SCENARIO B)

Starting day for eruption	Recovery starting on 5th day		Recovery starting on 6th day		Recovery starting on 7th day	
	F[a]	S[b]	F	S	F	S
Mon	3,007	48.1%	3,747	35.4%	4,257	26.6%
Tue	3,072	47.0%	3,807	34.3%	4,305	25.7%
Wed	3,098	46.6%	3,804	34.4%	4,267	26.4%
Thu	3,087	46.8%	3,768	35.0%	4,235	26.9%
Fri	3,023	47.9%	3,707	36.1%	4,201	27.5%
Sat	2,977	48.7%	3,702	36.2%	4,197	27.6%
Sun	2,984	48.5%	3,702	36.2%	4,209	27.4%

a. F: number of cancelled flights b. S: Serviceability, **(5,799 FLIGHTS/ WEEK)**

In Figure 5, serviceability of Scenario B that is shown in the blue line. This serviceability is the cumulative average. The highest serviceability was less than half of the overall even when the volcanic ashes recover from 5th day. It means that less than 50% of flights could only fly for a week. However, serviceability of 5th recovery is more than twice the serviceability of scenario A (No-recovery).

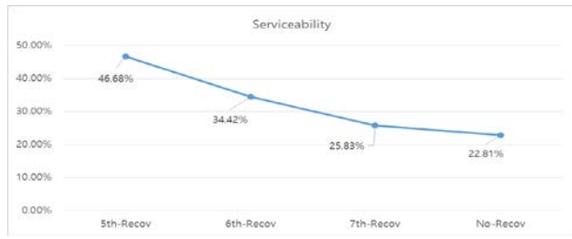

Figure 5. Serviceability of Scenario B

B. Airport

1) Result of the scenario A

The results are shown in Table V and Figure 6. Table V represents the weekly serviceability of scheduled flights of major airports due to Scenario A.

TABLE V. SERVICEABILITY OF SCENARIO A WITH EACH MAJOR AIRPORTS

Starting day for eruption	Serviceability (week)			
	ICN	GMP	PUS	CJU
Mon	25.54%	16.5%	12.75%	28.21%
Tue	25.16%		11.53%	22.56%
Wed	25.70%		12.48%	27.18%
Thu	25.87%		12.75%	33.85%
Fri	27.00%		12.89%	29.74%
Sat	27.24%		12.08%	26.15%
Sun	26.61%		12.75%	32.31%

The pattern of closures for airport is shown in Figure 6. It also shows daily serviceability of the major airport with scenario A. In the Scenario A, PUS could only fly the 1st day of eruption and CJU also could fly the 1st and 2nd day due to the type of the connection routes.

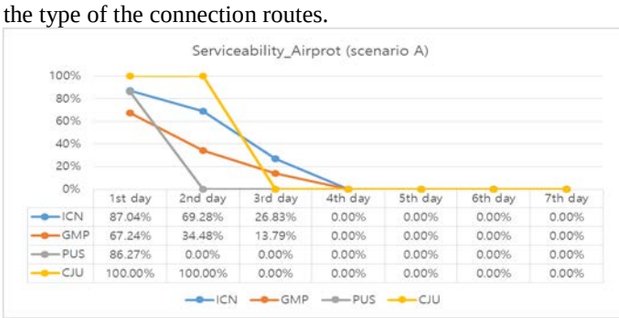

Figure 6. Serviceability of Scenario A (Airport)

2) Result of the scenario B

Figure 7, it represents the serviceability of each major with Scenario A and B. ICN and GMP can re-open the same day with starting on recovery day. CJU re-open a day later after starting on recovery day and PUS re-open two days later.

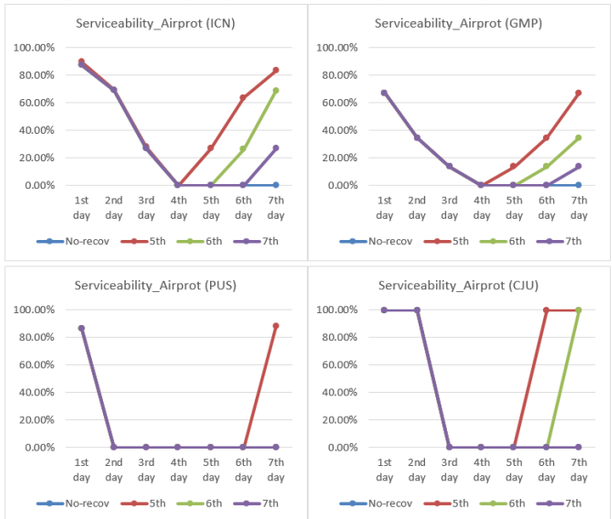

Figure 7. Serviceability of each major airports

C. *Proportion of the Impact of the region*

1) Result of the scenario A

Figure 8 provides ratio of serviceable flights by region with scenario A. America (7.51%) and Oceania (12.77%) were the most affected; by contrast, Africa and Europe of ratio of serviceable flights are high. Those regions can operate more than one third. Figure 9 shows the serviceability of regions by total number of serviceable flights. 86.6% (1131 by 1318 flights) of total number of serviceable flights is Asia region despite the Asia region's serviceability is 23.49% (1131 by 4858 flights).

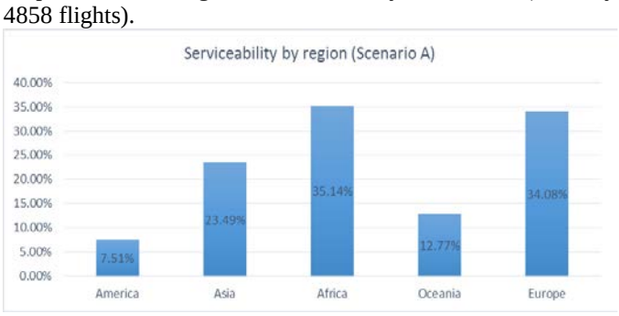

Figure 8. Impact of each region with Scenario A

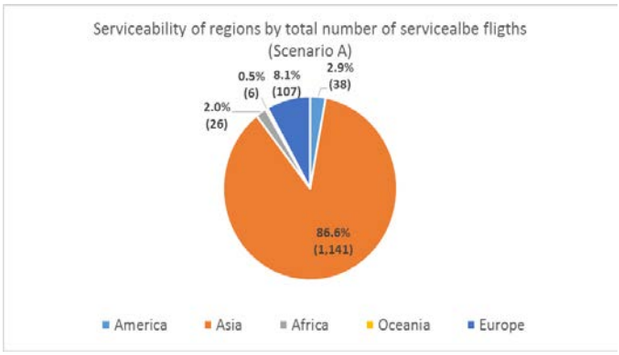

Figure 9. Serviceability of regions by total number of serviceable flights (Scenario A)

2) Result of the scenario B

Figure 10 shows the proportion and number of serviceable flights by region with scenario B. It also represents geographical characteristic of South Korea.

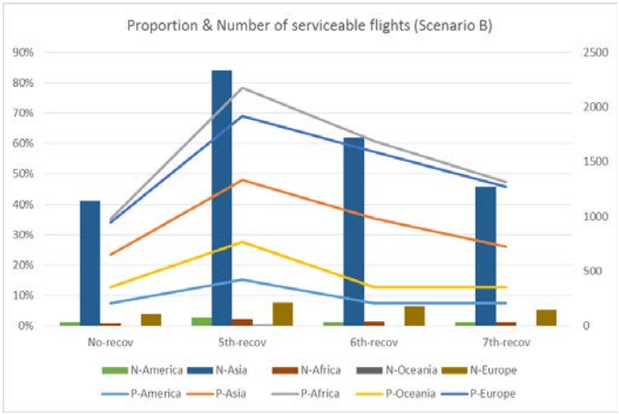

Figure 10. Proportion & Number of serviceable flights

VI. CONCLUSION & FUTURE RESEARCH

A. *Conclusion*

In this research, the main purpose is to estimate the impact of an eruption of Mt. Baekdu. We have analyzed the impacts on air transportation serviceability from hypothetical volcanic ash dispersal scenario. Less than a quarter of total number of international flights could be served during one week with scenario A (No recovery). The highest serviceability of Scenario B was less than 50% of total number of flights even the volcanic ashes gradually dissipated from 5th day of eruption. Airlines and government should develop their emergency response plan in case of eruption of Mt. Baekdu.

B. *Limitation*

This research was of the very first attempt to analyze the impact of Mt. Baekdu eruption from the perspective of air transportation with hypothetical scenario. It still has a long way to develop and mature into a concrete study. First this research only considered the cancelled international commercial flights from and to South Korea's four major airports with an exception of 3,879[3] flights that fly over South Korea because we have a very limited information on the fly-overs. In addition, the seasonally adjusted wind direction based on happened in Oct 2010 following the Figure 2. Because, it is possible that the volcanic ashes can reach South Korea after eruption of Mount Baekdu at that season. Finally, we did not calculate the impact of the number of passengers due to the lack of the information.

C. *Future study*

We should consider to extend the scope of the research not only for South Korea but also Japan and China. We only focused on the major airports in South Korea. Secondly, we also need to extend our analysis to different seasons. We expect that Japan is more severely affected than Korean peninsula in winter, while we assume an eruption would affect China and Russia more severely. Third, we could consider the re-routing probability in the future study. This research could not decide the re-routing with general flight information. Lastly, we can develop a scenario to the smaller time segment as shown in Figure 11 (4 segments; 23~05, 05~11, 11~17, 17~23).

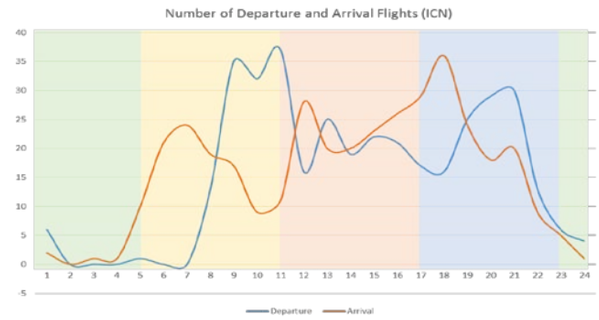

Figure 11. Number of Departure and Arrival flights (ICN), (APR 2015)

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[3] Oct.2015. The number is a 12% increase from 2014. The number of daily average of fly over flights are 125.