Analyzing Impacts of Baekdu Volcano Eruption Disasters to Air Transportation of South Korea¹

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Abstract

Volcanic eruption disasters are one of the natural disaster types that result in catastrophic aviation disasters. Impacts of a volcanic eruption event occurred in a country are global over the borderline of the affected country in this global era. Air transportation closures in Europe caused by the eruption of the Iceland Eyjafjallajökull volcano from April 14 2010 significantly led to the disruption of European economy.

South Korea has not considered the volcanic eruption disaster as the major disaster type because the occurrence of volcanic eruption disasters is not frequent. Significant eruption events of South Korean volcanoes such as Mount Baekdu or Mount Halla have not been observed since the Korea Meteorological Administration began with its weather forecasting service with modern observatories and technologies. However, Mount Baekdu is not the extinct volcano according to the previous historical records. Mount Baekdu erupted fifteen times during the period of twelve hundred years. The twelve years of Mount Baekdu monitoring provides new evidence for magmatic unrest of the volcano between 2002 and 2006 by observing volcanic seismicity, ground deformation, and volcanic gas geochemistry from volcanic earthquakes and other activities.

The objectives of this research are to identify the causes of volcanic eruption disasters to aviation transportation systems, and to introduce an event-impact evaluation procedure for investigating effects of volcanic eruption disasters to aviation transportation systems with cases of major volcanic eruption events specially focused on the aviation transportation damage.

Keywords: Baekdu volcano, volcano eruption disaster, Eyjafjallajökull volcano, air transportation, event-impact evaluation procedure

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1. Introduction

Volcanic eruption disasters are one of the natural disaster types caused by the movement of plate tectonics of the Earth. Volcanic eruptions are the phenomena that active volcanoes interact with other earth materials at plate boundaries to produce magma (molten rocks), and dissolved gas of water vapor and carbon dioxide. When volcano magma erupts onto the surface of the Earth, the openings of magma is transferred to lava. A volcanic eruption event occurred in a country can significantly affect in terms of air traffic, agriculture, public health, industries and climate change over the borderline of the affected country. Air transportation closures in Europe caused by the eruption of the Iceland Eyjafjallajökull volcano from April 14 2010 is a good example for the air traffic disruption of about 100,000 flights and 10 million passenger journeys (EUROCONTROL, 2010).

South Korea has not considered the volcanic eruption disaster as the major disaster type because the occurrence of volcanic eruption disasters is not frequent. Significant eruption events of South Korean volcanoes such as Maout Baekdu or Mount Halla have not been observed since the Korea Meteorological Administration began with its weather forecasting service with modern observatories and technologies. Thus, the Korean government has not specified the volcanic eruption disaster as one of the Korean major natural disasters in the National Disaster and Safety Management Base Act and Natural Disaster Management Act. The national disaster management system of the South Korean government for the volcanic eruption disaster is in the beginning stage in terms of national legislations, policies, planning, and practices of four disaster management steps including mitigation, preparedness, response and recovery.

However, Mount Baekdu is not the extinct volcano according to the previous historical records. Mount Baekdu erupted fifteen times with the years of 946, 947, 1014 ~ 1019, 1122, 1176, 1199 ~ 1201, 1217, 1373, 1401 ~ 1406, 1597, 1668, 1702, 1724, 1900, 1903 during the period of twelve hundred years. It is over once a 100-year time period(Lee, 2012). The estimated eruption of year 946 is close to VEI (Volcanic Explosivity Index) 7.4 that is the estimated eruption volume of $83 \sim 117 \text{ km}^3$. The twelve years of Mount Baekdu monitoring provides new evidence for magmatic unrest of the volcano between 2002 and 2006 by observing volcanic seismicity, ground deformation, and volcanic gas geochemistry from volcanic earthquakes and other activities. Seismic activities of Mount Baekdu were the highest frequency of 243 earthquakes in terms of monthly earthquake frequency in November, 2003. The most significant 4.4 magnitude earthquake of Mount Baekdu in December 2003 during the period of the last twelve years opened the issue of Mount Baekdu eruption risk(Yun, 2012).

The objectives of this research are to identify the causes of volcanic eruption disasters to aviation transportation systems, and to introduce an event-impact evaluation procedure for investigating effects of volcanic eruption disasters to aviation transportation systems with cases of major volcanic eruption events specially focused on the aviation transportation damage.

2. Literature Review of Aviation Safety

There is no such thing as absolute safety in air transportation. Risk of aviation accidents is two-dimensional. Evaluation of the acceptability of a given risk associated with a specific hazard such as accident type must take into account both the likelihood of occurrence of the hazard and the severity of potential consequences (ICAO, 2006). Since the first fatal air crash occurred in 1908, many causes of aviation accidents have been identified. Intentional accidents
are generally related to criminal activities or terrorism. Unintentional aviation accidents can be divided into mechanical failure (technical malfunction), human error (pilot or air traffic controller), health-related incident with the pilot, or limiting conditions like bad weather (Levinson and Granot, 2002). As skies have become more crowded and aircraft have become larger, the risk of aircraft accidents has increased.

The Annex 13 of International Civil Aviation Organization (ICAO) defines aircraft accident as an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which entails: a) a fatality or serious injury, b) substantial damage to the aircraft involving structural failure or requiring major repair, or c) the aircraft is missing or is completely inaccessible. ICAO Annex 13 also explains aircraft incident as an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation. An incident may be thought of as an undesired event that under different circumstances could result in harm to people or damage to property that would be understood as an accident (ICAO, 2006).

Hohenemser et al. (1983) identify a number of characteristics of human-caused disasters, including a causal sequence of events and a basic distinction among human-caused disasters. They classify aviation accidents as 'rare catastrophe' events. According to them, most human-caused disasters in the 'rare catastrophes' category stem from failures in the following three areas of human activity where public safety, rather than public health, is important: 1) large-scale structure such as public buildings, bridges, or dams, 2) road, air, marine, and rail transportation systems, and 3) industry including manufacturing, power production, storage, and hazardous material transport. Transportation system risk is defined as the probability of death or injury per kilometer travelled (Smith, 1991).

The National Transportation Safety Board (NTSB) of the U.S. government developed a more complex classification system for aircraft accidents under 14 CFR 121 since March 20, 1997. Aircraft accidents are divided into 1) major accidents in which aircraft is destroyed, or multiple fatalities are involved, or there is one fatality and a aircraft is substantially damaged, 2) serious accidents in which there is one fatality without substantial damage to an aircraft, or there is at least one serious injury and a aircraft is substantially damaged, 3) injury accidents with at least one serious injury and without substantial damage to a aircraft, and 4) damage accident in which no person is killed or seriously injured, but in which any aircraft is substantially damaged.

3. Case Studies of Volcanic Eruption Impacts to Aviation System
3.1 Selecting Case Studies

This research investigated and collected volcanic eruption information of the total number of two hundred and twenty five volcanic events from the Center for Research on the Epidemiology of Disaster (CRED) during the period of 1900 to 2012. This research first selected and analyzed twelve volcanic eruption events among the 225 cases with the selection process of volcanic eruption magnitude, occurrence year, impacts of volcanic events in terms of aviation transportsations. The first selected case is the 1973 Asame volcano eruption in Japan that resulted in windshield damage of DC-9 airplane. The most recent case is the 2010 eruption of Mount Merapi in Indonesia. The four cases including the 1980 St. Helen volcano eruption of Washington State, the 1989 Mt. Redoubt case of Alaska State, the 1991 Pinatubo eruption of
Philippine, and the Eyjafjallajökull volcano of Iceland are finally determined to more closely investigate volcano eruption impacts to aircraft and airport operation. The process of selecting case studies of volcano eruption impacts to aviation systems is shown with the case study selection criteria in figure 1.

3.2 Volcanic Ash Impacts to Aviation System

Volcanic ash impacts from the twelve selected cases to aviation systems can be categorized into two parts: aircraft impacts and airport impacts. Aircrafts in flight frequently experienced engine failures or engine flameout from ash intake. Volcanic ashes create low visibility problems for pilots. Aircrafts flying through volcanic ash clouds experience damage in aircraft mechanical systems including windshield, blade tip, oil filter systems, leading edge, compressor blade, or mid span shroud. Grounded aircrafts are observed abrasion or intake of ash from runway. Electronic systems of aircrafts are vulnerable to volcanic ash intake or electric shocks. Aircraft damage cases by volcanic ashes are presented in figure 2.

Airports are also affected by volcanic ashes. Airport runways observe loss of traction. Airport infrastructure is damaged by roof collapse or HBAC (heating, ventilation & cooling) system malfunction. Consequently, closed airspace results in disruption and reduction of passenger and air-cargo transportation.

Fig. 1 The case study selection process for volcano eruption impact to aviation system
3.3 Eyjafjallajökull Volcano Eruption Case

The Eyjafjallajökull volcano eruption affected the European airspace closure started on 14 April 2010 with an estimated 250 million cubic metres (330,000,000 cu yd) (¼ km3) of ejected tephra. The ash plume of the Eyjafjallajökull volcano eruption reached a height of approximately 9 kilometers which rates the explosive power of the eruption as the 4 Volcanic Explosivity Index. The main period of the airspace closure in European countries was from April 15th to 22nd of 2010, peaking at eighty percent decrease on 18th April. The air traffic crisis by the Eyjafjallajökull volcano eruption is shown in figure 4.
The spread of Eyjafjallajökull volcanic ashes to European countries during the period of April 14th to 19th is presented in figure 5. Iceland air traffic was affected for 13 days rather than 8 days seen elsewhere. Aside from Iceland, three countries presented a ninety percent reduction in air traffic in April over five consecutive days: Finland, Ireland and the United Kingdom. Helsinki, Dublin, Manchester and Edinburgh were most affected airports corresponding to the most affected countries. 104,000 flights were cancelled during the April Airspace crisis in Europe. That is 48 percent of expected traffic over eight days, implying approximately 10 million passengers unable to board their flights (Eurocontrol, 2010). The air traffic decrease effect by state or region in terms of percent difference from week before is shown in figure 6.
Fig. 5 Eyjafjallajökull volcanic ash spread during the period of April 14th to 19th
Source: United Kingdom Weather Service
Fig. 6 Air Traffic Decrease Effect (percent difference from week before) by State or Region

Source: EUROCONTROL (2010)

4.1 Event-Impact Evaluation Procedure

This research develops a heuristic, stepwise event-impact evaluation procedure for identifying air traffic demand reduction impacts of Baekdu volcanic eruption to the South Korean aviation system. This procedure is composed of four modules: a seasonal adjustment module, a trend adjustment module, a air traffic reduction computation module, and an economic impact analysis module (Kim and Moore, 2008). Figure 7 describes the conceptual framework of event-impact evaluation procedure in this research.

The method of identifying seasonal and trend variations in air traffic data is complex. The seasonal adjustment module identifies a cyclical pattern that regularly recurs over a 12-month period. The trend can be a linear, an exponential, a negative exponential, or a more complicated nonlinear form.

![Conceptual framework of event-impact evaluation procedure](image)

Econometricians including Wonnacott and Wonnacott (1979), Pindyck and Rubinfeld (1991) and Ramanathan (1993) introduce relevant methods for deseasonalizing and detrending regularly cyclical data sets. This research applies the decomposition method. The decomposition method is the ad hoc method based on the approach that the variations of a time series entry data set can be represented as the product of the following four components (Kim, 1997):
\[ yt = L \times S \times C \times I \tag{1} \]

where
- \( yt \) = directed time series entry data,
- \( L \) = value of the long-term secular trend in series,
- \( S \) = value of seasonal component,
- \( C \) = (long-term) cyclical component, and
- \( I \) = irregular component.

An \textit{ad hoc} smooth approach is used to remove the combined seasonal and irregular components \( S \times I \) from the original series \( yt \). The smooth approach including applicable models is demonstrated in figure 8.

Fig. 8 The \textit{ad hoc} smooth approach for deseasonalizing and detrending air service data

The air traffic reduction computation module computes the difference between observed data and the deseasonalized and detrended data. Residuals between the observed and the estimated data sets during the period of study event are regarded as the air traffic change caused by the event. The estimation methods of economic impacts can be estimated by input-output models.

Monthly data sets of air service are suspected to have the seasonality. Z scores of the combined seasonal and irregular components \( S \times I \) are computed from the original data divided by the 12-month average value (\( yt \sim \)) of each year:
The average values of monthly Z scores represent the average seasonal factors computed from Z scores of each month.

4.2 Air traffic data of South Korea

This research collected all of domestic/foreign airlines departing from and arriving to international airports of South Korea. Air traffic data sets obtained in this study are flights, passenger numbers and tons of air cargo. Air traffic examples of the two South Korean international airlines including Korea Airline (KAL) and Asiana Airline are shown in figure 9, 10, and 11.

![Fig. 9 Annual number of South Korean international airline flights (departure/arrival)](image)

![Fig. 10 Annual number of South Korean international air passengers(person) (departure/arrival)](image)
5. Conclusion

This research developed the event-impact evaluation procedure with four modules for estimating aviation impacts in case of Baekdu volcano eruption. The average values of monthly Z scores for entry and exit data sets can be computed to perform seasonal adjustments from the original data sets. Further studies are recommended to computing seasonal and long-term trend factors of air traffic data sets for factor generalization, identifying the duration and magnitude of Baekdu volcano effects with different volcano eruption scenarios. Other case studies for transportation security are recommended to evaluate the applicability of this event-impact evaluation procedure.

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