A Study on Shelter Airport Selection during Large-scale Volcanic Disasters using CARATS Open Dataset

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Air transport supports economic growth and prosperity through movement of passengers and goods. As air transport network grow larger and more complex, more vulnerable of the network's performance to an event such as weather conditions and natural disaster, e.g., volcanic eruption will become. Recently, European countries' air transport industry and economy had encountered disruption significantly from a volcanic eruption. Japan is also considered these disruptions as the threat of a national air transport network. The study focuses on solving the air transport network's problem during volcanic eruption by using the historical data of volcanic eruption in Japan which sited in its airspace and close to airports hub. Genetic algorithm (GA) is applied with historical flight and airports information provided by the Ministry of Land, Infrastructure, and Transport as constraints to find the satisfaction algorithm to provide the optimal alternative itineraries and the most suitable airport for airborne aircraft evacuation.

Key words: *genetic algorithm, large-scale volcanic disasters, shelter airport selection*

1. INTRODUCTION

Air transport supports economic growth and prosperity through movement of passengers and goods. With low fare of low-cost carrier airlines (LCC) and stronger economies resulted in worldwide air passenger numbers exceeding four billion in 2017 [1] for the first time and continuously grow. As air transport network grow larger and more complex, more vulnerable of the network's performance to an event such as weather conditions and natural disaster e.g. volcanic eruption will become. Recently airline industry had encountered the uncertainty situations of volcanic eruption and its ash cloud. In 2010, the Eyjafefjallajökull and Merpi Volcano eruption had significantly disrupted air transport and economic in Europe [2]–[4].

In Japan, the world fifth largest airline industry and one of the busiest airspace in the world according to IATA annual report June 2019. The country has also encountered many natural disasters included earthquakes and volcanic eruptions. they have considered as threat of national air transport network. One of the most concerning is how to reduce the vulnerability [5] and secure the network, rerouting and evacuate on-ground and airborne aircrafts from the disrupted airspace and airport [6], [7]. In shelter airport selection, there are many major criteria that should be considered such as uncertainty of occurrence, flight's itineraries, airport capacity, aircraft type and level of volcanic ash cloud. From the previous studies, optimizations model and algorithms for flight rerouting and rescheduling on air traffic management have not covered a perspective for uncertainties of volcanic events, aircraft evacuation with real-world flight and airport data. Therefore, we aim to develop new shelter airport selection system for the event of volcanic eruption which consider as a problem in this study.

The study focuses on solving air transport network problem during volcanic eruption using the historical data, together with CARATS open dataset of flight traffic coordination and airports information (AIS) provided by Japan's Ministry of Land, Infrastructure and Transport [8]–[10] as aircraft and airport constraints to find the satisfaction resilience algorithm to the disrupted event. Genetic algorithm (GA) is applied to provide the optimal path and select the most suitable airport for both on-ground and airborne aircraft evacuation.

The remainder of this paper is organized as follows: Section 2 presents a review of related literature. Section 3 shows methodology of research and proposed mathematical model. The case study of mt. Hakone is presented in section 4 with computational result in section5. Finally, the conclusion of the study and future research suggestion in section 6.

2. LITERATURE REVIEWS

The vulnerability and resilience of transport network systems have been trends of great interest because of there are strategic economic sectors of every country. There are many studies of transport network systems on wide range of modes including air transport [12], [13] and developing models for inter-modal resilient operations [14].

Mattsson and Jenelius [15] had described two main approaches to measure vulnerability of transport networks: topological vulnerability, system-based vulnerability and mixed approach in 2015. In the topological vulnerability approach, the network was represented as an abstract graph and the researcher measures system damage as a result of changes in network topology after a disruption affects one or more nodes or links. This type of approach typically uses only supply data on available infrastructure and service frequencies. Many researchers [16]–[21] had studied on applying airport constraints to identify the most satisfaction airports for aircraft evacuation and rerouting, which are generally those with; I highest degree centrality (i.e., largest number of destinations), ii closeness (i.e. shortest average distance to all other airports), iii betweenness centrality (i.e., lying in the largest number of shortest paths between airport and iv. airport clusters classification by using airport size, air traffic volume, intra-inter connection network between hub and their spoke, infrastructure. which can be divided to 4 clusters: small national spokes, large national spokes and small national hubs, large international hubs and super hubs.

On the other hand, the system-based vulnerability approach's network graph was modelled with complemented of real-world dataset or predicted traffic flows and interaction between supply and demand under disruptions (e.g. irregular airline operations, with particular focus on the recovery of aircraft, crews, and passengers in an optimal cost-minimizing). The studies of system-based vulnerability approach can be found in [22], [23], where road and rail network vulnerability under variety of disruptive events was measured according to the total delays experienced by the users, who needed to alter their original itineraries as well as the amount of unsatisfied demand [24].

In mixed approached, the topological approach with network topology of nodes and link on air transport supply side was considered alongside with real-world dataset or predicted traffic flows and interaction of demand side which represent a whole air transport network system interact under disruptions situations. Many researchers had studied the vulnerability of European air transport network of major airport closure scenario from the perspective of the delays imposed to disrupted airline passengers using real-world dataset on passenger itineraries. The studies based on the 25 busiest European airports closure simulation one by one to measuring the effect on the network then relocated them in order the minimum-delay itineraries [25]. The study had found that the airport capacity had significant impact of aircraft and passenger relocation in the event of disruptions [13], [26]–[29]. Many computational algorithms had been used to solve these air transport optimizations. By managing air traffic on both aerodrome; the terminal and near airport area and airspace side; the airspace area beyond aerodrome between origin and destination airport, including rescheduling, rerouting and evacuation from original itinerary to avoid bad weather and natural disaster condition for the safety of aircraft and its cargos both passenger and goods.

Since 1999, Menon had developed the systematic method for multiple-aircraft conflict routing in of air traffic management from free-flight protocol by ICAO using genetic algorithm (GA) [30]. with consideration in aircraft constraint e.g. model, load factor and fuel consumption. In order to optimize air traffic and avoid air routing conflict within specific airspace. In 2004, Hansen had applied the real-time air traffic control data of arrival aircraft to enhance the accuracy of the algorithm [31]. Since then, the complexity of real-time air traffic control of the arrival scheduling and sequencing (ASS) at the busy airport had been studied further and had considered size of aircraft according to leading and following aircraft to prevent turbulence caused by leading aircraft, and also length of runway to optimal assignments landing sequence to aircraft [32], [33].

Genetic algorithm has been used to solve the problem of flight scheduling and rerouting in situation of man-made disruption, bed weather conditions and air traffic congestion. One of the most critical problem of air traffic and routing management was how to find the proper route for those aircraft those situations, especially in disrupted conditions which considered as obstacle to aircraft on airspace between origin and destination airports. Several studies have shown that using GA without obstacle mapping had led to local minimum path finding and with unenclosed obstacle environment

GA could give varies and not truly optimized results [34], [35]. Therefore, an enclosed obstacle area must be considered when using GA to find global minimum with truly optimized to disrupted area avoidance e.g. are of bad weather and volcanic ash cloud.

According to exiting literature in air transport routing ans scheduling optimization, there is no research consider shelter airport for aircraft in the event of volcanic eruption under aircraft type, airport capacity and volcanic enclosed aread by using genetic algorithm so far. As problems mentioned, this study aims to present an airport selection for both on-ground and airborne aircraft evacuation in situation of volcanic eruption considering airport capacity, aircraft type and enclosed area avoidance of volcanic ash cloud. The proposed genetic algorithm was constructed for air evacuation and airport selection by minimizing evacuation distance to shelter airport and avoid ash cloud disrupted area.

3. METHODOLOGY

This section discusses a conceptual model and genetic algorithm for shelter airport selection during volcanic eruption. The conceptual model, mathematical model, and solution technique are described as follows:

3.1 Conceptual model and assumption

The method of optimization in which this section considers quantitative measurement. The models were created as the alternative suggestion for shelter airport selection for aircrafts in the event of volcanic eruption. Firstly, the data of the study has been collected and analyzed such as volcano and its ash cloud behavior, impact area, affected airports and aircrafts which in this study was considered both on-ground and airborne aircrafts, aircraft type and its ability constraint, location of alternative shelter airports; aircraft handling infrastructure and capacity, the distance from and during the selected study period. Secondly, the mathematical models will be formulated according problem's objective and constraint. Thirdly, the mathematical models were coded and run as computational optimization solver by using Genetic Algorithms or GAs. Finally, the result of proposed model will be analyzed and presented in detail for further determining the appropriate evacuation plan. For detail of study methodology, it will be described in the next section of "the Genetic Algorithm: formulation". Before the mathematical model is considered, the study makes the following assumptions on the problem:

1. According to effect of volcanic ash on aircraft engine's performance by ICAO, all aircraft must avoid contact with volcanic ash particle and rocks by flying into the volcanic eruption areas and ash cloud airspace in any density level. Therefore, it can be assumed that once volcanic eruption warning in any level has been delivered, all airports and aircrafts must be 100% avoid those area and evacuation to safe airport and airspace with all causes.
2. Since volcanic ash particle can be caused of severe damage to aircraft's engine, no shelter airport can be located within the affected area is allowed.
3. Each shelter airport has limited capacity to accommodate the evacuation demand; number of aircraft; type and size of aircraft, and length of runway.

3.2 The Genetic Algorithm: formulation

Genetic Algorithms (GAs) is a type of artificial intelligence, it is an optimization method based on concepts of natural selection and genetics; Darwin's theory of evolution. They work with population of individuals, each evolve by adapt itself to the environment, repeating crossover, mutation, and selection a possible solution to a given environment's conditions or problem. The appropriate solution can be found within a short time by using the series of numerical computation. GAs typically work by iteratively generating and evaluating individuals using and evaluation function. The basic algorithm of GAs can be described as follow:

a. Initialize population of individuals
b. Evaluate each individual using evaluation function
c. Repeat until a criterion is satisfied
    i. Select parents from population
    ii. Perform crossover on parents to create new generation of population
    iii. Perform mutation of new generation population
    iv. Evaluate each individual of new population

In evacuation models measure the efficiency of evacuation by total travel cost in terms of response distance or time [36]. According to volcanic eruption, it can be predictable and typically known for several hours to days before eruption. But once it has occurred, the impact from fallen rock and ash cloud can be spread over nearby area and in airborne from a few to hundreds of kilometers away from the eruption site within an hour depends on the strength of wind current before has an impact on nearby airports and aircrafts. The authorities will have sufficient time to evacuate the affected to the safe area. Thus, the first objective function aims to focus in travel distance criterion. Base on assumption of the conceptual model, no shelter airport can be located in the volcanic rock and ash risk area.

Restrictions and constraints to solve the aircraft assignment and shelter airport selection for volcanic eruption evacuation. The constraints involved: airport capacity, runway capacity and restriction, aircraft constraints.

1. Airport capacity: number of aircraft which airport can accommodate.
2. Runway capacity: runway length; restrict for specific size of aircraft
3. Aircraft: a. aircraft type and size; the restriction for suitable for landing and departing, airport selection for evacuation, and b. aircraft's itinerary; the identify of which aircraft could be counted as affected inbound aircraft needed to be evacuated for the optimization calculation

3.3 Proposed Model

The Computational algorithm is proposed for shelter airport selection and evacuation planning. The objective of the model is to minimize flight distance between affected airports and airspace to the shelter airports calculated by airports and aircraft positioning using geo-coordination (Latitude and Longitude) in **Fig.1**.

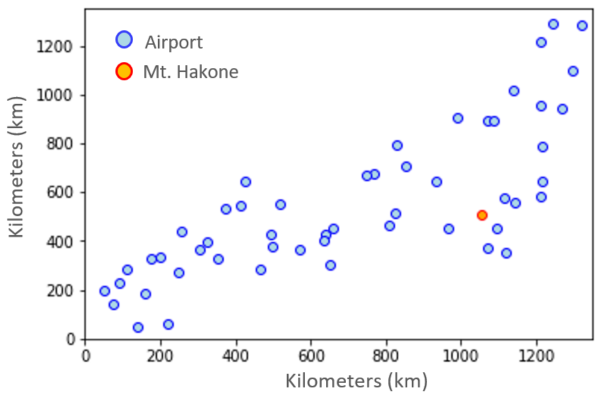

Fig. 1 Airports and Mt. Hakone: coordination map

This algorithm aims to propose alternative selection of shelter airport in the perspective of decision makers or local government. Therefore, a computational algorithm has been developed for this study which considers the assignment of affected aircrafts both airborne and on-ground aircraft to candidate shelter airports outside the affected area with particular distance and flight time, limited accommodate capacity of each shelter airport, and limited number of shelter airport. The indices, parameters, decision variables, objective function, and constraints are presented as follows:

Index sets

I Set of affected airports; $i \in I$

J Set of candidates shelter airports; $j \in J$

Parameters

MC_j Maximum aircraft accommodation limitation of selected airport $j \in J$

P_i Population of aircraft in affected airport $i \in I$

p_i Proportion of population in affected airport $i \in I$ need to be evacuated; constant number 0.25, 0.5, 0.75, 1.0

F_{ij} Indicator of candidate airport $j \in J$ if the candidate airport is located inside affected airport $i \in I$

D_{ij} Distance (km) from affected airport $i \in I$ to shelter airport's candidate $j \in J$

c_j Proportion of empty evacuation slot of evacuation of the candidate airport $j \in J$; constant number 0.25, 0.5, 0.75, 1.0

h_{ij} Penalty value assigned to candidate shelter airport $j \in J$ as its capacity constraint to control GA from exceed possible capacity of assigned aircraft.

Decision variables

X_j 1 if candidate airport $j \in J$ is selected, 0 otherwise

TP_i Total population of affected airport $i \in I$

T_{ij} Flight time of each aircraft to shelter airport $i \in I$

E_{ij} 1 if aircraft of affected airport $i \in I$ is assigned to candidate shelter airport $j \in J$ during period of evacuation, 0 otherwise

Z_{ij} Number of assigned aircraft from affected airport $i \in I$ to candidate shelter airport $j \in J$

Objective function

$$\text{Min} \sum_i \sum_j T_{ij} * E_{ij} \qquad (1)$$

Subjective to

Evacuate to the airport in the safe zone: selected shelter airport must not in the affected area or the affected airport $i \in I$

$$X_j \notin F_{ij} \qquad \forall j \qquad (2)$$

Candidate shelter airport capacity limitation: this equation states that total number of assigned evacuating aircraft to candidate airport must not exceed the maximum capacity of the airport of the proportion of empty evacuation slot of shelter airport $j \in J$

$$\sum_{j \in J} E_{ij} \leq c_j * MC_j \qquad \forall j \qquad (3)$$

Penalty method: Since GAs are unconstrained optimization methods, therefore GAs' application with constrained needed to apply penalty method in order to set up the barrier for the optimization. In this study, penalty method has been used to penalize infeasible solution by disadvantage to its individual's fitness to force the algorithm to avoid constraint violation. By giving an additional flight time to each violation solution depended on degree of constraint violation (number of maximum airport capacity violation) in order to control the number of assigned aircraft to shelter airport not to exceed its maximum capacity. This can be done by assigning constant value h_{ij} to its flight time in order to give disadvantage to its fitness according to the degree of constraint violation. Thus, the degree of constraint violation can be calculated from the different number between number of assigned aircraft $\sum_{j \in J} E_{ij}$ at shelter airport $j \in J$ and maximum capacity of shelter airport $j \in J$ multiply by constant a where $a \geq 1$ according to the minimum duration 65 mins of an aircraft taken; 35 mins of unload and reload its passenger, goods and minimum engine cooling down time, 25 mins of taxi and turnaround time, and 5 mins of taking off time.

$$h_{ij} = a * \{\sum_{j \in J} E_{ij} - c_j * (MC_j)\}^2 \qquad a \geq 1 \quad (4)$$

4. CASE STUDY

This section presents a case study; in which apply the mentioned approach to a real situation of mt. Hakone in Kanto peninsula, Kanakawa, Japan, one of the Japan's most active volcano [11] which sited in the middle of the most busy airspace and near airports hub of Japan (e.g. Haneda and Narita airport).

From the ashfall observation on Mt. Sakurajima, Central of Japan and mt.Asamayama, South of Japan during the year 2009 to 2015 had discovered the pattern of ashfall during the period of eruption, typical plume height of explosion was between 2-5km the total accumulated ashfall at the end of the active period, 50% was deposited within the first 4.2km from the vent, while 99% was deposited within the first 23.3 km but the trace of ashfall could be found away from the vent up to hundreds of kilometer. The observations had also found that the ashfall direction and distribution was highly non-uniform, it was influenced by seasonal winds [37]. The direction of ash cloud and ash fall from the eruption is depend of the local wind direction at the time period of eruption. In this study, time frame of CARATS flight dataset of March 13rd, 2016 with one-hour time span. Only inbound airborne aircrafts which have possible destination to the affected airports and flying distance within one hour. During the selected time period of the study on march, wind's direction in Kanto peninsula move toward East across this area but the possible direction of the wind profile can be varied toward North-east and South-east to Pacific ocean with vary windspeed during day-time and night-time from 9.3km/hr. to 30km/hr. [38]. The Hakone volcano's ash fall hazard map was simulated based on these observations. The number of affected airports and aircrafts increase related to direction and coverage area/airspace of airborne ash cloud.

This kind of disaster is unlike other natural disaster such as landslide, flood or earthquakes. The volcanic eruption typically is known many hours to days before the eruption has occurred. Government and related authorities will be able determine the impact area of the eruption and setting the evacuation plan needed. In case of aircraft evacuation, air traffic control agency and related authorities can have several hours to give suggestion to airlines and airports to avoid affected flight route and evacuation to the safe airports with sufficient capacities, outside impact area within flight range ability of each aircraft.

(1) The site of volcano

In **Fig.2** shows the volcanic ash cloud spreading distance of mt. Hakone and the number of affected airports and aircrafts both on-ground and airborne, based on the classification of impact level by the possible distance of volcanic ash-cloud spread from the observations of 2 active volcanos; mt.Sakurayama and mt.Asamayama. In this study, affected area was simulated by using geocoordinate (Latitude and Longitude) with starting point at Mt. Hakone volcano (35°14'00" N, 139°01'15" E) cover the possible area and airspace with distance of 500km from the volcano. The direction was varied toward North-east and South-east to Pacific Ocean from 45°NE to 45°SE according to seasonal wind's profile in Spring of Kanto peninsula at the study period.

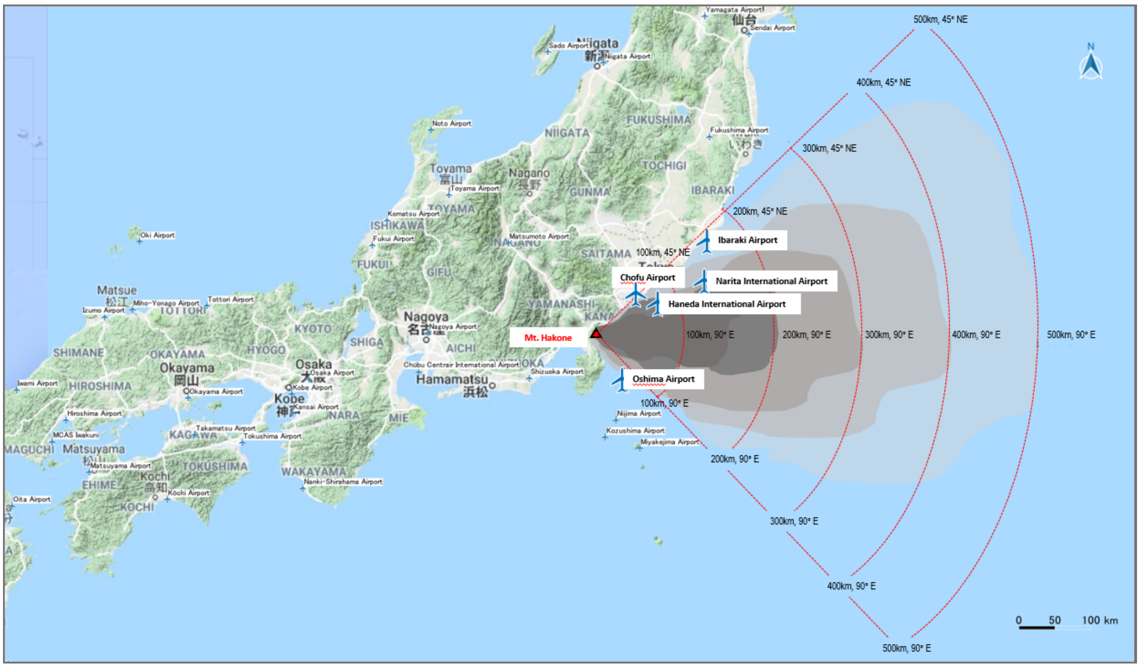

Fig.2 Map of possible affected area and airports, Japan Civil Aviation Bureau (JCAB), Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

(2) The affected airports and airspace

The airport geo-coordinates by Aviation Information Services agency of Japan [refer AIS] and airspace were mapped on the terrain map of Kanto and nearby region to determine which airports and airspace will be affected from the ash cloud within range of 100-500km in the study time period as shown in **Fig.2** and **Table 1**.

Table 1 Affected Airports Simulation: Case study mt. Hakone Eruption

Airport Name	Geo-coordination (Latitude, Longitude)	Direction from mt. Hakone	Distance from mt. Hakone (km)
Oshima Airport	34°46′55″N 139°21′37″E	NE	58.036
Chofu Airport	35°40′18″N 139°31′41″E	NE	66.602
Haneda International Airport	35°33′12″N 139°46′52″E	NE	77.239
Narita International Airport	35°45′53″N 140°23′11″E	NE	136.85
Ibaraki Airport	36°10′54″N 140°24′53″E	SE	164.031

(3) The number of affected aircrafts

According to **Table 2** and **Fig.2**, total number of affected airports from 100-500km range from volcano is 5 airports; Haneda international airport, Narita international airport, Oshima airport, Chofu airport and Ibaraki airport with the possible maximum on-ground aircraft 586 aircrafts (maximum number of aircraft handle by each airport). For airborne aircraft, we assumed that at the moment of volcanic eruption, all on-ground aircrafts which their itinerary pass the affected areas or even have destination at the affected airports will forced to reschedule or change their flight itinerary to other routes and destinations to avoid the impact from volcanic eruption. Therefore, the study airborne aircraft will consider only aircrafts which have already in the air with the possible inbound to the affected airports. From the Japan airspace observation within the latest time period of March 13th,2016, CARAT open data provided by MLIT, total number of airborne aircrafts are 586 aircrafts which can categorized into 2 groups by their location; within 500km radius from mt. Hakone and outside 500km radium. Most the airborne aircraft from these 2 groups ,479 out of 586 were outbound aircrafts with safe itineraries, only 107 of them were inbound to the affected airspace and airports which need to be the evacuated. Total number of affected aircraft from both airborne and on-ground are 693 aircrafts.

(4) The sheltering airports: selection and criteria

The shelter airport need specific capability for accommodating for aircraft evacuation since each airport has limited aircraft handle capability depends on its infrastructure included maximum number of handling aircraft, type and size of aircraft, number and length of runway which can accommodate the specific size of aircraft.

Table 2 Number of aircraft in the observed aerodrome and airspace in study time frame, CARATS

Flight Status	Location	**Possible Itinerary**	**Number Aircrafts**	**Total**
On-ground: at affected airports	Oshima Airport	n/a	13	**586**
	Chofu Airport	n/a	24	
	Haneda International Airport	n/a	228	
	Narita International Airport	n/a	240	
	Ibaraki Airport	n/a	81	
Airborne	Within 500km radius from mt. Hakone	Outbound from Affected Airports	17	**255**
		Inbound to Affected Airports	107	
		Safe Itinerary	131	
	Not in 500km radius from mt. Hakone	Outbound from Affected Airports	14	**331**
		Safe Itinerary	317	
Grand Total				**1,172**

The high-lighted cells above are the total number of affected aircraft used in this study.

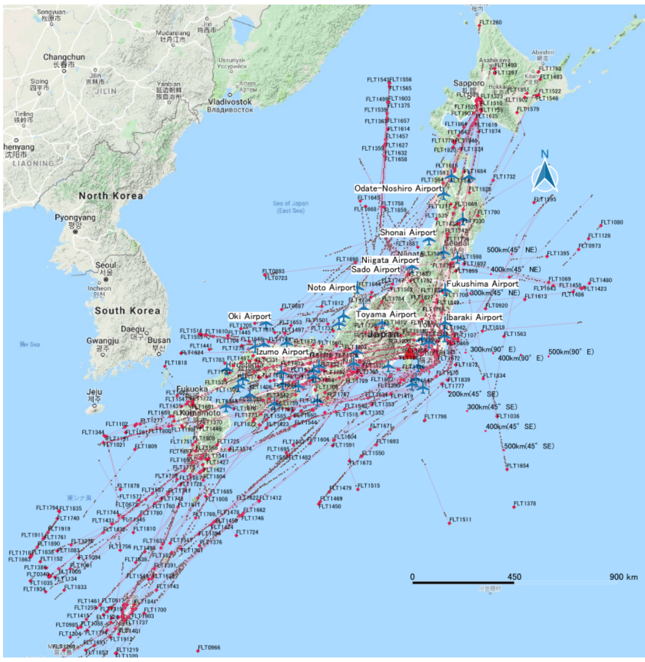

Fig.2 Aircrafts in the observed aerodrome and airspace in study time frame, CARATS

Therefore, sheltering airport selection's criteria is respectively relate to the evacuating aircraft. According to Japan Civil Aviation Bureau (JCAB, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), there are 98 airports operated by government, private sector and Japanese Self Defense unit. In this study is focused on sheltering airport selection by I: location of the sheltering airport: the airport must be located outside the affected area of volcanic eruption within the same 100-500km radius of the possible affected area of the eruption for aircrafts and airports, thus the possible selected airport can be located near the original destination (the affected airports), airborne aircrafts which their destination is at the affected airports may need no additional fuel for the evacuation. This will also reduce too much tension on other airports and their regular air traffic and flight management. II: The selected sheltering airport must have sufficient length of runway for the aircraft in order to perform landing and take-off during the evacuation and recovering from the event respectively. According to aerodrome reference code in Annex 14 – volume 1 by ICAO [39] as shown in **Table 3 (Appendix A)**, each aircraft has been categized into 6 groups related to their wingspan and ability of taking off and landing at specific field (runway) length. From the previous observation on air traffic data of 107 airborne aircrafts with inbound itinerary to the affected airspace and airports , we had discovered that 54.21% of aircraft were in code group C with wingspan 24 m up to but less than 36 m, needed more 1,200 m up to but less than 1,800 of field length. Followed by group E and D with 28.97% and 14.02% of overall observed aircraft with field length of more than 1,800m up to 3,200m needed which are also as the same ratio with the 589 aircrafts of the overall observed Japan airspace in same study time frame as shown in **Fig.3**.

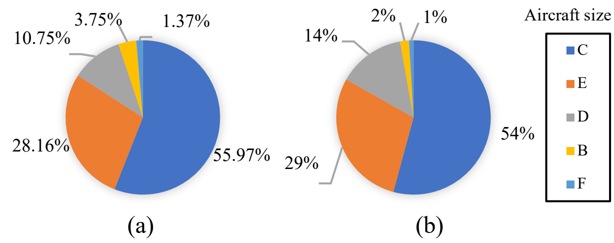

Fig.3 Aircrafts size classification ration by wingspan of 586 overall observed Japan airspace (a) and 107 inbound aircraft to the affected airspace and airports (b)

From finding, 98.13% of 107 the inbound airborne aircrafts needed field length of 1,200 m up to more than 3,000 m to perform landing and taking off and it can also be assumed that 586 aircrafts at on-ground at the affected airports are also at the same ratio. According to Japan's airports information provided by AIS, 82 from 94 airports or 88.3% of all Japan' airports can accommodate aircraft with code letter from C - F (medium - larger size of aircraft) with capability to handle up to 1,877 aircrafts, calculated from maximum capacity of each airport. Therefore, Japan's available airports could have enough capability and capacity to accommodate aircrafts in case of emerged evacuation from volcanic eruption as mentioned in this study. Beside of considering number of available airports, their capacity and capability to sheltering the specific size of evacuating aircrafts, the capability of transferring affected crews, and passengers need to be counted in choosing airport as shelter airport connectivity function. For example, the capability of transferring affected crews, and passengers to accommodation facilities or transferring them to nearby airports for new connecting flight itinerary or even change transport mode to reach the final destinations. Therefore, this study is specifically chosen 42 airports on mainland of Japan out of 94 airports in order to maintain connectivity of selected shelter airport if such function is required with 5 affected airports excluded.

5. COMPUTATIONAL RESULT

5.1 The Nearest Neighbor Search

The assignment of the affected aircrafts to shelter airports can be solved by the nearest neighbor search before the numerical calculation by genetic algorithms (GAs). In this nearest neighbor search, the affected aircrafts will be assigned to the nearest shelter airport available by using distance from the current position of each affected aircrafts as shown in **Fig.4**. However, since the nearest neighbor search did not consider on the shelter airport's capacity, therefore the assigned aircrafts at each shelter airport was biased and number of assigned aircraft could be exceeded the maximum capacity of the shelter airport as the results in **Table 4 (Appendix A)**. The shelter airport with its location close to the position of affected aircraft will granted priority to be selected. Since 84% of affected aircrafts were on-ground aircrafts at 5 affected airports, the nearest shelter airport of those affected will be assigned as the shelter airports with on capacity concerned in the nearest neighbor search as mentioned. Therefore, many of those nearest shelter airports will handle large amount of aircraft which exceeded their capacities and with only 26 of 42 shelter airports have been selected, 90.3% of affected aircraft has been assigned to: Fukushima Airport 46.4%, Shizuoka Airport 35.7%, Matsumoto Airport 4.8%, Noto Airport 2.6%, Fukui Airport 0.9%, and other 9.7% as shown in **Fig.5** and **Fig.6**.

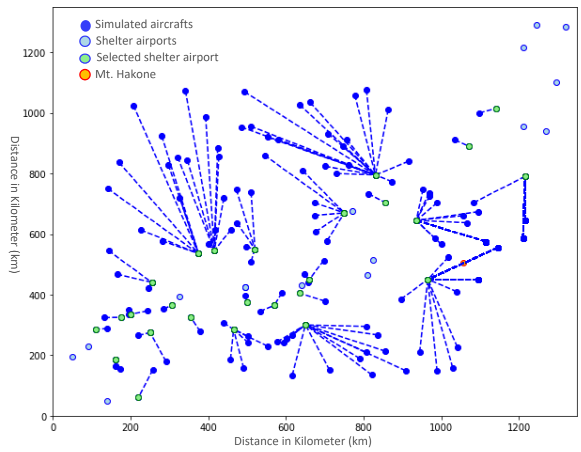

Fig.4 Mapping of assigned aircrafts to shelter airport by using the nearest neighbor search

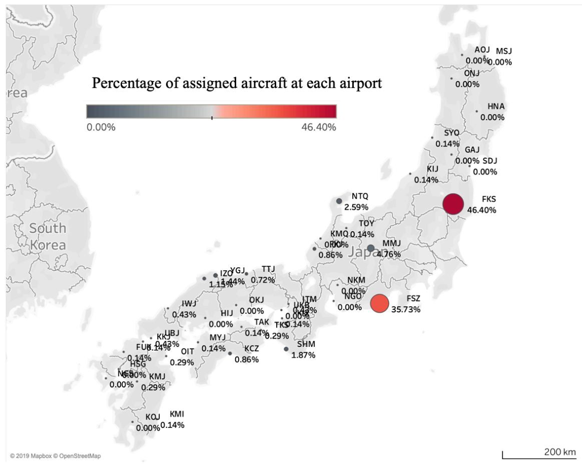

Fig.5 Mapping of assigned aircrafts to shelter airport by using the nearest neighbor search

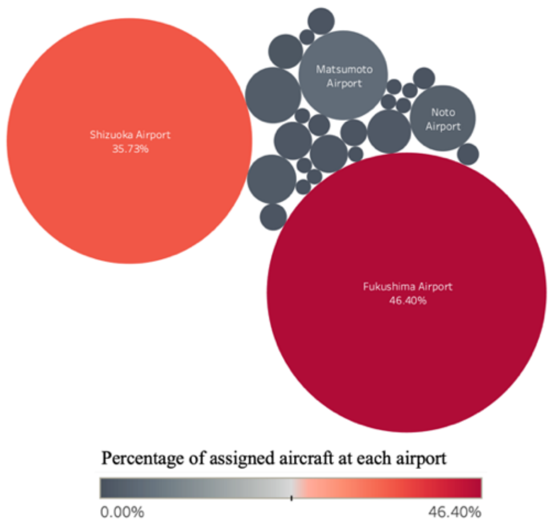

Fig.6 Assigned aircraft distribution: Nearest Neighbor Search

5.2 The Genetic Algorithms Search

According to the methodology of this research, the result from genetic algorithms (GAs) is presented with graphical models and sensitivity analysis with various constants assigned with shelter airport capacity's constraint to the GAs in order the determine the possible results in case of changing of study environments.

In GAs, the affected aircrafts will be assigned to the nearest available shelter airport the same as in nearest neighbor search. However, genetic algorithms were also considered the shelter airport's capacity into the calculations. From the beginning of process, 300 individuals for the objective's solution was randomly generated then evaluate its fitness against problem's objective in equation (1) and subjective in equation (2)(3) along with penalty function as equation (4) to force algorithm not to violate those subjective before selected as a parent for next generation's offspring in genetic algorithms through gene crossover and mutation to produce new alternative offspring which preserve and alternate possible of solution before gone through the fitness test's evaluation as the best solution for the objective's problem. The aircraft assignment to shelter airports appeared to be more distribution related to their size of maximum capacity compare to the nearest neighbor search method, 42 shelter airports have been selected with 1.0% to 4.0% of total affected aircrafts have been assigned to each airport as shown in **Table 4, Fig.8** and **Fig.9**.

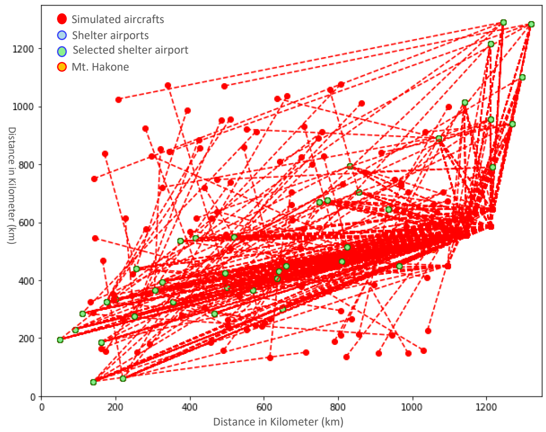

Fig.7 Mapping of assigned aircrafts to shelter airport by using Genetic algorithms

The study also presented sensitivity analysis in various numbers of shelter airport's capacity and affected aircrafts that shown in **Fig.7** and **Table 5**. In **Table 5**, we first run the model with various number of shelter airport's capacity by using constant number of shelter capacity (r) from 1.0 to 0.0 with decrement of 0.25 to present the different objective functions and assignments. From the model simulation's results, the system needs at least 36 shelter airports with minimum 107 available parking slot for accommodating the possible maximum number of affected aircrafts at the proportion of population at affected airport $i \in I$; $p_i = 0.0$ and the proportions of available shelter airport; $c_j = 0.5$. The result has pointed to the reversed proportion between flight time to shelter airport and available capacity when the numbers of the available capacity has been reduced, the total flight time to the shelter will be exponentially increased. In the study, GAs with the decreasing of constant number of shelter capacity (c_j) from 0.0 to 1.0 with increment of 0.25, the total number of available parking slot of those 42 shelter airports will dropped from 1,009 to 252 slots with increasing of total flight time from 851.9 to 3,972 hours (calculated from maximum possible 693 affected aircraft both on-ground at affected airports and airborne aircraft), selected shelter airports will be at the greater distance from the current position of affected aircraft since the nearest airports could not accommodate all of the demands as shown in **Table 5**.

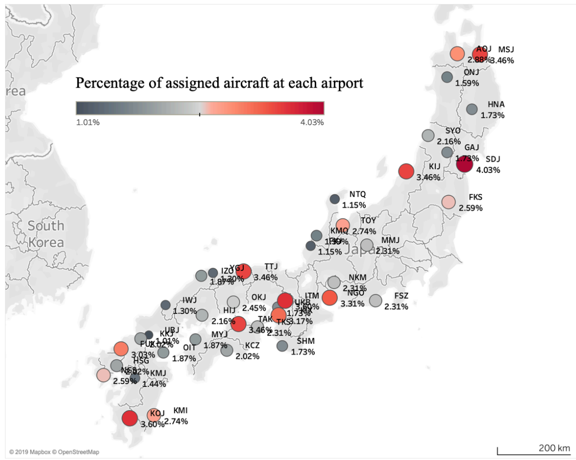

Fig.8 Mapping of assigned aircrafts to shelter airport by using Genetic algorithms

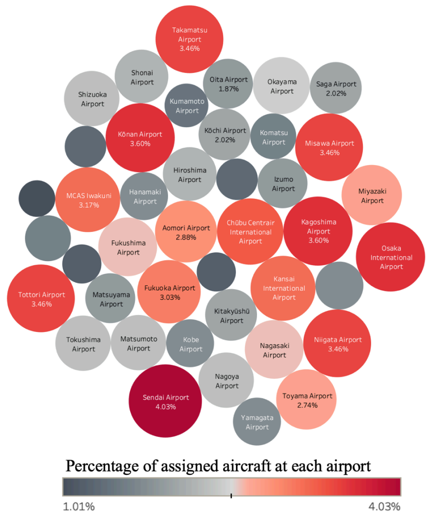

Fig.9 Assigned aircraft distribution: Genetic Algorithms

Table 5 the sensitivity analysis for number of available shelter airport's capacity and affected on-ground aircraft, using constant values 0.0 – 1.0, 0.25 increment.

The proportion of population (p_i) at affected airport $i \in I$	Total number of affected aircrafts	The proportions of available aircraft stand at shelter airport (c_j)	0.00	0.25	0.50	0.75	1.00
		Available aircraft stand at shelter airport $j \in J$	0	252	505	757	1009
0.00	107	Total flight time (hrs)	46.3	45.7	46.2	44.6	45.1
		Number of selected airports	37	37	36	39	36
0.25	254	Total flight time (hrs)	166.3	158.3	160.1	158.3	150.9
		Number of selected airports	42	42	41	42	42
0.50	400	Total flight time (hrs)	328.0	320.2	305.9	314.7	286.5
		Number of selected airports	42	42	42	42	42
0.75	547	Total flight time (hrs)	1443.0	1516.6	766.0	621.9	464.0
		Number of selected airports	42	42	42	42	42
1.00	693	Total flight time (hrs)	3972.0	3151.1	2361.9	1417.1	851.9
		Number of selected airports	42	42	42	42	42

* Total flight time (hrs) is used as individual fitness evaluation in GAs, calculated from distances between aircraft and selected shelter airports, and average speed of aircraft at 880km/hr.

6. CONCLUSIONS

This study proposes a conceptual algorithm for shelter airport selection for aircraft evacuation in the event of volcanic eruption by considering evacuation flight time and maximum shelter airport capacity. The algorithm has been tested with a case study of volcanic eruption at mt. Hakone in the central (Kanto region) of Japan with selected air traffic data in the period of March 13th 2016, the latest CARAT open-data provided by MLIT in order to simulate the affected aircraft during the event. The 693 affected aircrafts of both airborne and on-ground has been examined to select the appropriate shelter for evacuation. 42 out of 94 airports on mainland of Japan with 1,009 possible maximum aircraft parking slots available have been chosen as shelter airports by criterions of location on mainland of Japan for maintain connectivity with other modes of transportations and sufficient runway's length for accommodating affected aircraft.

The nearest neighbor search and genetic algorithms have been used to find the appropriate solutions of shelter airport selection. In the nearest neighbour search, affected aircrafts have been assigned to the nearest shelter airport by using the nearest distance pairing between the current position of each affected aircraft to the shelter airport by using geo-coordination (latitude and longitude). The result of nearest neighbour search has selected the nearest shelter airport by distance and shortest flight time for each aircraft but since the calculation did not consider the restriction of maximum capacity of each shelter airport can accommodate, the nearest neighbor search has given the large exceeded number of assigned aircraft to shelter airport with most of the aircrafts have been assigned to a few shelter airports.

In contrast of genetic algorithms, the constraint of shelter airport maximum capacity has been considered along with nearest neighbor search which enable algorithm to perform the nearest airport searching but avoid exceeding number of aircraft assigned to each shelter airport. During the process of each individual crossover and mutation to produce new alternative offspring which preserve and alternate possible of solution before gone through the fitness test's evaluation as the best solution for the objective's problem. Therefore, the result from GAs have shown the different in shelter selection, number of assigned aircraft to each airport and shelter airport selection distribution. The algorithm was also revealed the critical shelter airports for aircrafts evacuation during the volcanic eruption event, the shelter airport with large aircraft accommodation capacity will be critical shelter airport during the event. The alternative adjustment of the proportion of available aircraft parking slots at shelter airports, along with the proportion of affected aircrafts give flexibility to the algorithms' output, it could give suggestion in which shelter airports could accommodate with reasonable number of aircraft according to their capacities.

The study could help as the suggestion for the authorities in the emergency airport and aircraft evacuation planning. Although the genetic algorithms in this study could give a conceptual and shelter airport selection solution for aircrafts evacuation in the volcanic eruption event by using the nearest distances and airport's capacity constraint, it still has limitation in complexity of airport, airline and air traffic management as mentioned earlier. The further applications on airport selection may need set up on more objectives, and constraints in order to make an effective shelter airport selection algorithm gives more realistic selection from the beginning of evacuation until recovering.

APPENDIX A

Table 3 Aerodrome Design and Operations, Aerodrome reference code in Annex 14 - volume 1: by ICAO

Runway		Aero plane		
Code Name	Aeroplane reference field length	Code Letter	Wingspan	Outer main gear wheel span
1	Less than 800 m	A	< 15 m	< 4.5 m
2	800 m up to but not including 1200 m	B	15 m but < 24 m	4.5 m but < 6 m
3	1200 m up to but not including 1800 m	C	24 m but < 36 m	6 m but < 9 m
4	1800 m and over	D	36 m but < 52 m	9 m but < 14 m
		E	52 m but < 65 m	9 m but < 14 m
		F	65 m but < 80 m	14 m but < 16 m

Table 4 Number of assigned aircraft by Nearest neighbor search and Genetic algorithm VS. maximum capacity of shelter airport

Shelter airport	Maximum capacity	Nearest neighbor search		Genetic Algorithm	
		Number of assigned aircrafts	Delta Capacity	Number of assigned aircrafts	Delta Capacity
Fukushima Airport	14	322	-308	18	-4
Shizuoka Airport	17	248	-231	16	1
Matsumoto Airport	14	33	-19	16	-2
Noto Airport	4	18	-14	8	-4
Fukui Airport	1	6	-5	8	-7
Miho-Yonago Airport	5	10	-5	9	-4
Nanki-Shirahama Airport	9	13	-4	12	-3
Iwami Airport	3	3	0	9	-6
Izumo Airport	10	8	2	13	-3
Yamaguchi Ube Airport	6	3	3	7	-1
Yamagata Airport	5	0	5	12	-7
Kumamoto Airport	8	2	6	10	-2
Komatsu Airport	8	0	8	11	-3
Odate-Noshiro Airport	8	0	8	11	-3
Oita Airport	11	2	9	13	-2
Hanamaki Airport	10	0	10	12	-2
Kitakyūshū Airport	11	1	10	14	-3
Kobe Airport	10	0	10	12	-2
Saga Airport	10	0	10	14	-4
Shonai Airport	11	1	10	15	-4
Hiroshima Airport	12	0	12	15	-3
Kōchi Airport	18	6	12	14	4
Tokushima Airport	14	2	12	16	-2
Okayama Airport	13	0	13	17	-4
Miyazaki Airport	16	1	15	19	-3
Tottori Airport	21	5	16	24	-3
Toyama Airport	18	1	17	19	-1
Aomori Airport	19	0	19	20	-1
Nagasaki Airport	19	0	19	18	1
Matsuyama Airport	23	1	22	13	10
Niigata Airport	24	1	23	24	0
Misawa Airport	24	0	24	24	0
Takamatsu Airport	25	1	24	24	1
Kagoshima Airport	35	0	35	25	10
Sendai Airport	47	0	47	28	19
Osaka International Airport	60	3	57	25	35
Kōnan Airport	64	0	64	25	39
Fukuoka Airport	67	1	66	21	46
Kansai International Airport	67	1	66	22	45
MCAS Iwakuni	76	1	75	22	54
Chūbu Centrair International Airport	80	0	80	23	57

Shelter airport	Maximum capacity	Nearest neighbor search		Genetic Algorithm	
		Number of assigned aircrafts	Delta Capacity	Number of assigned aircrafts	Delta Capacity
Nagoya Airport	92	0	92	16	76

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