Disaster Response Operation Considering Road Network Disruptions: An Integrated Air-Land Transportation Model

道路網の寸断を考慮した災害応急対策：航空-陸上輸送統合モデル

SANSANO RODELIA LABITAN

ABSTRACT

Disaster happens everywhere and may come in many types. Communities are often disrupted and can cause harm to people, property, economy, as well as to the environment specially during large scale natural disasters. Therefore, finding ways to minimize damage caused by disaster is very important. During disaster, transportation plays an important role in disaster relief operations and evacuation. It also serves as a means to minimize and repair the damage caused by disasters particularly, land transportation.

The low cost and abundance of land vehicles permits land transportation to carry out humanitarian activities immediately following a disaster. This means of transportation often performs most of the trips but in situations where roads are disrupted, land transportation may not be able to meet all the necessary demands specially when there are isolated places and low accessibility places. In this situation, humanitarian response cannot simply depend on land transportation only since road disruptions can happen anywhere but needs assistance from other transportation modes such as air transportation. Specially, in large scale disasters, assistance from other places, whether locally or internationally often use air transportation to deliver their aid since it is faster. In these situations, airports play an important role as emergency hubs to cater disaster response operations. During this time, receiving the relief goods is not only the role of the airports but it also plays role in distribution since aircraft such as emergency helicopters are often used to reach some areas during disasters. At times like this, the use of land transportation decreases and an increase in air transportation takes place. In most cases, the increase in demand to use aircraft such as emergency helicopters are hard to meet since air transportation in general are expensive and availability is low. In addition, an increase in the use of aircraft also increase noise and air pollution since these aircraft use fuel and produce high noise when operating.

Currently, this air and land transportation combination is common and often used. When taken as a separate systems, several problems can be identified such as: (1) roads can be disrupted during disaster and can cause increase in travel time due to detouring and low accessibility; (2) land

transportation cannot be used to reach isolated places; (3) road disruption patterns are hard to identify before the disruption (4) conventional air transport is expensive; (5) there is low availably of air transport due to complexity in operation; (6) there is a significant increase in demand in air transport that cannot be met; (7) an increase in the use of air transportation will result to additional air, noise pollution and high cost.

To address these problems, this study proposed the use of a new air mobility called electric vertical take-off and landing (eVTOL) aircraft commonly known as air taxi or drone taxis. This new air mobility has a potential not only as a new form of transportation but also in logistics during disasters. Also, this new aircraft can address both the deficits of land and air transportation. These aircraft can help reach areas which are difficult to reach using land transportation because of disrupted roads especially isolated places. Also, since these are targeted to be a public mobility comparable to a regular land taxi, its availability will be higher compared to a emergency helicopters. Additionally, it also answers the problem in terms of cost and complex operation since studies shows it will be cheaper is less complex than its traditional air transportation counterpart. Moreover, since these are electric vehicles, it offers lesser noise and air pollution.

To effectively use this mobility, a suitable facility is needed to accommodate it. In this study, we propose the establishment of emergency ports that will serve as landing and takeoff as well as temporary holding area of goods for distribution but finding suitable location can be challenging since road disruption patterns are unknown before a disaster. To do so, a method of identifying these locations that considers road network disruption probability is necessary. Additionally, these locations must also consider the cost of transportation since one of the main considerations in disaster operation specifically in humanitarian logistics is budget. Also, since new technology contains a lot of uncertainties, a sensitivity analysis to address the variations in cost is also incorporated in the model.

Considering all the above factors, to highlight the importance of air and land transportation integration through the use of eVTOL aircraft in humanitarian logistics considering possibility of road disruptions caused by disasters, the following research objectives are presented: (1) to develop a method as to find the optimum locations of emergency ports that minimizes the transportation cost of relief goods to disaster shelters and the most suitable mode of transportation considering possible road network disruptions and place isolation; (2) to determine as to what degree will the new air mobility support the disaster response operations, and (3) to analyze the effect of the variations in transportation cost, operation cost, isolation cost, and demand change in the location of emergency ports and cost of operations. To realize these objectives, a mixed-integer linear programming (MILP) model was developed.

Lastly, to further illustrate how road disruptions affects disaster response, an enhanced model was introduced focusing on the degree of cooperation between the land and air transportation network. The model measures the usefulness of the emergency ports in reducing place isolation and using different means of transportation altogether. Since road network disruption patterns are unknown before the disaster, identification of suitable location is challenging. Therefore, the enhanced model was tested in a real network considering the probability of road disruption derived from a case study. It also determines the distribution of each mode of transportation used in the disaster response such as (1) land transportation; (2) air transportation; and (3) air and land transportation using eVTOL aircrafts through emergency ports. The goal of the enhanced model is not to replace one mode with another but to supplement the deficiencies of each mode and to test the potential of the new mobility not only as a public transport but as an additional mode of transportation during disaster.

Results showed that locations some candidate locations have high probability of being selected. With the given parameters, these locations are suitable for emergency ports considering both the transport cost as well as the condition of the road network. Additionally, the location of the emergency ports has very little variation for each scenario with an average of five emergency ports per scenario. Total cost varies depending on the number of emergency ports chosen as well as the mode of transportation used. The higher number of isolated disaster shelters serviced by conventional air transport such as helicopters results to a higher cost. There is an overall reduction of 8.64% in the number of isolated disaster shelters when the emergency port is introduced in the network. The distribution of transportation mode used to deliver goods and services to the disaster shelters comprised of 57% by land, 43% via emergency ports, and 1% via air (helicopter). While transport cost using eVTOL shows that lower cost promotes the use of eVTOL using emergency ports, in some situations, the need to establish emergency port can still lessen the overall cost of operation since place isolation serviced by conventional air transport still incurs higher cost when isolation cost is considered.

The sensitivity analysis showed that the number and location of emergency ports may vary due to changes in eVTOL aircraft transportation cost, operation cost, and demand change but some locations are common even with the variation of the said parameters. These locations exhibit characteristics that are tolerant to both the changes in different cost parameters and also to road disruptions since road disruption is also part of the model when the sensitivity analysis was done. Also, isolation cost directly affects the overall cost of transporting relief goods and also dependent on the number of isolated disaster shelters. Since isolation is inevitable, lower isolation cost would be preferable. The total travel time of the whole operation may vary depending on the number of trips performed by each mode as well the vehicle capacity. More trips performed by eVTOL aircraft and larger capacity vehicles are more advantageous to overall operation. From the results, several advantages can be derived by utilizing eVTOL aircraft in an integrated transportation network in humanitarian logistics, such as the reduction of isolated areas that resulted from road disruptions. By combining land and air networks, the disadvantages of each mode of transportation are complemented by the other.