PREPOSITIONING AID FOR ASIA AND OCEANIA

Rubel DAS
PhD candidate,
Tokyo Institute of Technology
2-12-1-I4-12, O-okayama, Meguro-ku,
Tokyo, 152-8550, JAPAN
TEL/FAX: +81-3-5734-3468
E-mail: rubeldas@tp.ide.titech.ac.jp

Shinya HANAOKA
Associate Professor,
Tokyo Institute of Technology
2-12-1-I4-12, O-okayama, Meguro-ku,
Tokyo, 152-8550, JAPAN
TEL/FAX: +81-3-5734-3468
E-mail: hanaoka@ide.titech.ac.jp

ABSTRACT

Past disasters such as, China's earthquake, Myanmar's cyclone, Pakistan's earthquake, Indian Ocean Tsunami, Taiwan's earthquake, Christchurch earthquake, and Japan's earthquake exhibit the vulnerability of Asia-Oceania zone for natural sudden onset disaster where the mean affected per disaster is the highest. The mean affected people per Meteorological disaster in Asia are about 830 thousands and in the same region mean affected people is more than 100 thousands per earthquake disaster. While Asia-Oceania zone is facing 60% of all natural disasters (1), forecast estimates that natural and man-made disaster will increase five folds both in number and impact over the next 50 years. Hence, need for disaster relief provided by humanitarian organization is inevitable with quick response to minimize the causalities. There is negative relationship between preparedness and response delay, and pre-positioning of emergency supplies is one mechanism of increasing preparedness for natural disasters. In this concern, this paper develops quantitative analysis for effect of prepositioning in Asia and Oceania zone. A series of formulations through P-median formulation predict optimal facility configurations, and corresponding per capita distances. The analysis also provides the insights into the effect of initial conditions. Moreover, demand patterns, along with correlated variables such as population and hazard frequency, offers views of country's vulnerability to natural disaster. Finally, from the variant solutions several recommendations are made to provide guidance on planning for humanitarian relief operation.

Key words: *Preparedness, Pre-positioning, Humanitarian response, Per capita distance*

INTRODUCTION

Cyclone Nargis in Myanmar on 2008 left her footprint through 78,000 dead, 56,000 missing and about 2.4 million victims (2). In the same year, China's Sichuan province was shuttered by massive 7.9 earthquakes which tolls more than 68,500 dead, another 20,000 missing, 300,000 hurt and 5 million people homeless. The consecutive earthquakes in New Zealand on September 4th 2010 of magnitude 7.1 earthquake followed by another major earthquake of magnitude 6.3 on February 22nd 2011 cause the worst disaster in the history of New Zealand in terms of economic losses. While 500 small or large scale disasters affect 200 million people every year (3), forecast estimates that over the next 50 years natural and man-made disasters will increase five-fold both in number and impact (4). The disaster occurrence location distribution is not even in the world. Asia-Oceania region is facing 60% of total disaster (1). Besides high concentration of total number of disaster in Asia Oceania region, the mean affected per disaster is also high in this zone. Asia bears more than 800 thousand affected people per meteorological disaster, caused by short-lived/small to meso scale atmospheric process. The mean affected per meteorological disaster in Africa, America and Europe is 78 thousand, 44 thousand and 23.75 thousand respectively. The geographical location, socio-economic characteristics carry Asia to be the highest impacted from each meteorological disaster. Extensive poverty in South Asian countries is a major cause of the massive human toll that is taken by nature-triggered disaster (5). The mean affected people in Asia per earthquake disaster are more than 100 thousand which is more than any other part of world. The highest impact from each disaster in this zone has led to intense pressure on the humanitarian organizations to improve operational effectiveness of disaster relief efforts in this zone.

The aim of humanitarian organization in the humanitarian relief support is to rapidly provide relief (shelter, water, medicine, and food) to hazard affected areas, so as to minimize the human suffering (6). In general the purpose of humanitarian response is to mitigate the harmful impacts of the hazard on the local population. However, with the increasing trend of disaster, and of perception that the quality of relief is inadequate, the international community is calling for the improvement in the process of delivering aid (7). In this regard, logistics is an issue in which improvement might yield significant benefits because relief operation is conducted in disrupted transport network. The speed of delivery or responsiveness has been identified as the most desired effect (8). Acquisition and delivery of adequate relief supplies from local and/or international suppliers are typically time-consuming and expensive. Relief organizations are seeking alternatives to reduce the delay. Even though, there are heavy debates on best approach to meet this end, pre-positioning has been adopted as a possible logistics strategy in the aim of reducing delay (9). The pre-positioning conception for disaster response is borrowed from the military operation where it become popular since World War II (10), if not earlier. There is similarity between military actions and humanitarian response where demand is unpredictable and rapid response is critical to save lives.

World Vision International (WVI) accepted the prepositioning strategy in 2000 and established facilities in four locations. The locations are USA, Italy, Germany and Dubai (11). The World Food Program (WFP) operates the United Nations Humanitarian Response Depot (UNHRD). Depots are located in Italy, Ghana, UAE, Malaysia, and Panama. The strategy of UNHRD is to reach the emergency location within 24/48 hours. The HRDs serves as regional staging areas to support the humanitarian response through 'pull' strategy rather than 'push' strategy (12).

In nutshell, the impact of natural disaster in Asia and Oceania tends to increase with population growth, and global warming. Although this zone is the most vulnerable Most of the Asian and Oceania countries have not paid serious attention to disaster management (13), per se, especially in terms of preparedness, response and recovery. Logistics is often-cited as an area that might improve this effort, and inventory pre-positioning has been specially suggested as a logistical strategy toward a more rapid response (8). In this study, we take an attempt to explore the distribution network problems to response in Asia and Oceania zone and provide quantitative analysis to provide assistance to humanitarian organizations to design the distribution network. We considered different scenarios under two broad categories Blank page case and Status Quo case. We have used the classical P-median problem to formulate the location decisions. It integrates distance, potential demand and country characteristics. Demand is calculated for two different sudden onset disasters: meteorological disaster and earthquake disaster. The model generates results for two different disasters.

The rest of the paper is organized as follows: section 2 reviews the relevant literature. Section 3 describes the relief chain and explains details for critical and non-critical portion of the chain to formulate the model. Section 4 describes the dataset and analysis of model result. Finally, we conclude in section 5 with recommendation for improvement of distribution network.

SYSTEM AND MODEL

In this section, we delineate the key components of relief distribution network affecting on facility location decisions and formulate the model.

HUMANITARIAN LOGISTICS STAGE

As each disaster has unique characteristics and requires different strategy to response, we make boundary of our study and focus on sudden on-set natural disasters. This group includes meteorological phenomenon such as typhoons, cyclone etc. and geophysical phenomenon such as earthquake etc. Here, it is worth to note that natural disaster can be classified in two groups: sudden on set disaster and slow onset disaster. The sudden-onset and slow-onset disaster have distinct feature in exposure and actions. The slow-onset disaster such as flood, famine etc. does not pose initial time sensitive urge rather it needs consistent support for long time. The response to sudden onset disaster is challenging considering the demand unpredictability, dynamic, and network limitation. Even though the uncertainty and variability of environment prevails just aftermath of sudden onset disaster, quick response to the disaster theater is critical for minimizing human suffering and for overall success of humanitarian operation.

Preparedness → Immediate response → survivor help

Figure 1. Phases of disaster response

The importance of initial response is emphasized in several articles (17). The relief mission life cycle analysis shows that fewer amounts of resources were available in hazard sites after math of sudden onset disaster. The more quickly commodities reach the disaster theater, the better the chance of mitigating disaster related harm. Reducing delivery time in this crucial time is the objective of pre-positioning in humanitarian logistics. The prepositioning of aid is named here as preparedness. Balick and Beamon (2008) states the speed of relief operation during first few days of the disaster significantly affects the lives of many people threatened by the disaster. Sheu (2007) formulates relief distribution model by assuming the critical period is 72 hours for earthquake. This period is known as ‘immediate response’. However, relief activities sustain for little longer time to support the survivors to overcome the losses. Considering less time sensitivity compare to immediate response the supply chain focus also on cost efficiency with the given expected level of service to survivors. This stage is named as ‘survival help’ in this research. In the ‘immediate response’, Most of the critical supplies arriving to the disaster areas are sourced from relief organizations’ global prepositioned stocks (6) by following ‘push’ strategy. ‘Survivor help’ propels pull strategy to bring the product to disaster stricken area. In this perspective humanitarian logistics is characterized by three distinct stages considering time of actions: preparedness, immediate response and survival help. These three stages are interlinked and the success of humanitarian logistics depends on appropriate decision on each stages.

DELIVERY CHAIN

Prepositioning aid aims to support immediate response in sudden onset disaster. However, the relief chain starts before disaster. Delivery chain for prepositioning has two phases: before disaster and after disaster. The chain starts with inventory at vendor’s location. The vendor selection is correlated with location of preposition (here after ‘facility’ indicates the location of preposition). The inbound transit to facility from vendor’s location is one decision making criteria for vendor selection. The inbound transit is not time sensitive action as it takes place before disaster. The time sensitive section starts after approval of relief aid. The delivery chain is represented in figure 2.

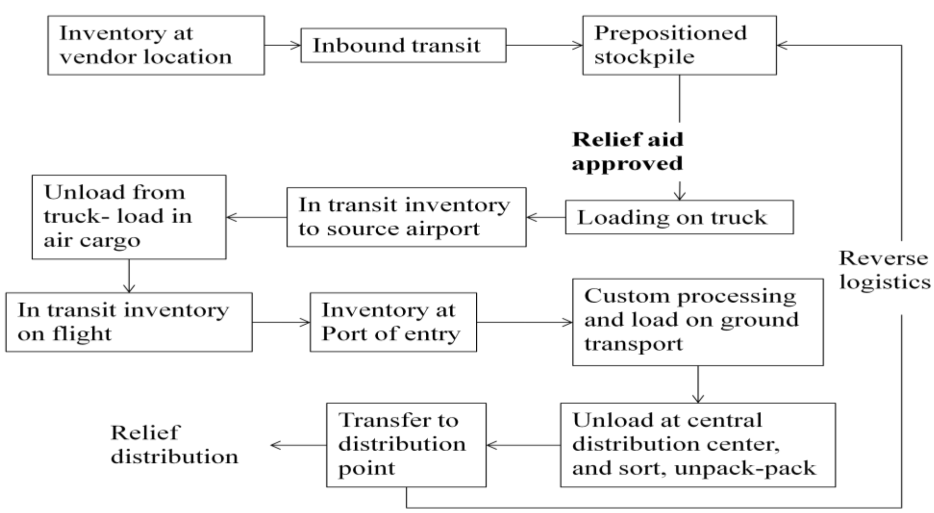

Figure 2. Relief chain (edited from (8))

It is customary that disaster stricken country ask international organizations to assist. The humanitarian organizations assess the appeal and estimate the demand. In response to approved appeal, the pre-stocked commodities load on truck and shift to nearby airports. Herewith, sufficient documents such as invoice, consignee documents, visa (for accompanied personnel) etc. are required before transporting commodities. The documentation is a source of delay to response. Without sufficient documentation, waiting time at port of entry will be prolonged. After customs processing, the commodities transport by using suitable transport mode to central distribution center and distributes through distribution center. The delivery chain ends with distribution of aid to the victims. As demand is unpredictable, there is possibility of supply and demand mismatch. Unused aid or non-consumable aids are returned. The reverse flow of aid is named as reverse logistics.

CHAIN SIMPLIFICATION

We consider a delivery chain in which a relief organization locates facility to response immediately to disaster stricken area. As this study aims to facility location for improving immediate response after disaster, the vendor location and inbound transit are ignored for our model. To make the model tractable, we simplify the delivery chain by assuming some reasonable assumption. One assumption about facility location is that it will be close to airport. Locating facility near airport can reduce the delay by cutting the in-transit inventory to source airport. WFP followed this strategy to establish UNHRD in five locations. Ghana UNHRD is established near Kotoka International airport, Malaysia UNHRD is near Subang Military airport; Italy in military airport, Panama in Tocumen International airport and UAE in Dubai international airport. Herewith, it is assumed that relief aid transports by air cargo to port of entry. Delayed associate with last mile, including the custom processing is consistent across the range of disaster and geographic location. The activities of custom processing and last mile distribution are relaxed in this model. The simplified relief chain consists of facility location (i), in transit inventory on air cargo and destination country (j).

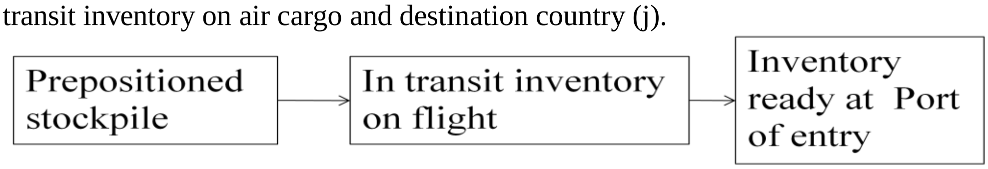

Figure 3. Simplified chain

MODEL FORMULATION

To facilitate the model formulation, the following assumptions are postulated

1) The sudden onset disasters are only considered (earthquake, storms)
2) Stocks are positioned before disaster and there is no capacity limitation of facility
3) Total affected people in stricken area (denoted j) is the proportional to demand for aid
4) Facilities (denoted i) are located in (or near) airport
5) Aids are carrying by only air-craft. It can fly with infinite capacity (8). All air craft is flown in same speed (500km/hr).

Based on these assumptions, we have adopted P-median facility location model (15,16). This model seeks to place p facilities strategically among the demands. It consists of finding of optimal location for exactly p facilities to meet a specified demand at the lowest possible transportation cost. The P-median problem uses the average distance between service and demand points to determine the servicing costs of a given location. The p median problem can be called as the binary program.

$$\min \sum_{i \in I} \sum_{j \in J} f_j d_{ij} x_{ij} \tag{1}$$

subject to

$$\sum_{i \in I} x_{ij} = 1 \ \forall j \in J \tag{2}$$

$$\sum_{i \in I} y_i = p \tag{3}$$

$$x_{ij} \leq Y_i \ \ \forall I, J \tag{4}$$

$$x_{ij}, y_i \in \{0,1\} \tag{5}$$

In this formulation, f_j represent demand at location j. y_i is a binary variable for showing open site and x_{ij} is a binary variable to allocate location j to open facility i.

The distance (d_{ij}) is calculated by using Haversine method which is used to calculate the great circle distance between any pair of latitude (φ) and longitude (λ) coordinates on a sphere.

$$d = 2R \operatorname{atan} 2\left(\sqrt{a}, \sqrt{1-a}\right) \quad (6)$$

$$a = \sin^2 \frac{\Delta\varphi}{2} + \cos \varphi_1 . \cos \varphi_2 . sin^2 \frac{\Delta\lambda}{2} \quad (7)$$

Where $\Delta\varphi$ and $\Delta\lambda$ represent the difference between latitude and longitude difference between two points and R is earth equilateral radius (6377 km). For the sake of computation, capital of a country is considered as demand and generator and coordinates for each capital is collected through Google. The Haversine distance is calculated by using online service (20).

Finally, the objective of this model is to identify the facility location to minimize the deliver lead time. Facility positioned near demand point will yield lower response time; the transportation time is a linear function of distance to the demand point

$$time = \frac{distance}{speed} \quad (8)$$

In order to evaluate the efficiency of logistics decision a metric is adopted here, distance per capita at risk. This measure represent the mean distance per person to be at risk of hazard induced affected from the nearest facility. The mean distance per capita is calculated by using following formula

$$\min \frac{\sum_{i \in I} \sum_{j \in J} f_j d_{ij} x_{ij}}{\sum_j f_j} \quad (9)$$

Until now, it has not been possible to predict the relief demand. However, there are ongoing initiatives to predict the relief demand by using proxy variable. For instance, Dilley et al (2005) portrait high-risk geographic areas, based on historical worldwide disaster frequency and mortality data, population data and economic indicator. Balick and Beamon (2008) use mortality as an indicator for demand. FEMA's Hazus software is an assessment tool that can estimate losses from potential hurricane, earthquake and flood. Since facility location is directly influenced by demand data, realistic forecast of demand data can significantly contribute to effectiveness of facility location (Balick and Beamon, 2008). In this study, we model demand quantities as the proportional of the total affected people as a result of hazard. The total affected people for each hazard from 1980 to 2011 in a country are collected and the maximum value for single disaster in each country from this list is identified.

$$f_j = \max\ (total\ affected\ people\ from\ one\ hazard\ for\ region\ j) \quad (10)$$

Data for total affected people for each disaster is collected from EM-DAT database. EM-DAT defines the 'total affected' as the sum of injured, homeless and people requiring immediate assistance during a period of emergency. EM-DAT stores hazard data for events if at least one of the following criteria is fulfilled

- 10 or more people reported killed
- 100 people reported affected
- Declaration of a state of emergency
- Call for international assistance.

EM-DAT database store data about country, disaster group, disaster type, date, killed, injured, homeless, affected, total affected, estimated damage. We have analysis the facility location for meteorological disaster and earthquake disaster. Both disasters are sudden onset disaster and cause wide spread damage. Some countries in Asia Oceania zone are prone to meteorological disaster and others are earthquake prone. Some countries such as Japan, China, and India are vulnerable to both type of disasters. EM-DAT database does not have any entry for Brunei and Singapore of meteorological and earthquake history.

RESULT

We group the study area in 29 regions based on geographic location. Here regions indicate the geographical boundary for each country except for Oceania. Oceania consists of hundreds of islands and we use clusters of Oceania in four groups: Australia and New Zealand, Polynesia, Melanesia, and Micronesia. One point to note, we have not included UN defined Western-Asia considering proximity from two UNHRD depots: one is in Dubai and another one is in Italy. It is noted that the purpose of this study is to see the optimal facility location for immediate response on sudden onset disaster. The study area regions are shown in table 1. The fourth and fifth column represent that demand data for each zone.

id	country	population (thousand)	max affected in a year for earthquake disaster (1980-2011)	max affected in a year for meteorological disaster(1980-2011)
c1	Australia	22,327	5,025	2,860,414
c2	Bangladesh	164,425	15,200	15,439,149
c3	Bhutan	708	20,016	65,000
c4	Brunei	407	0	0
c5	Cambodia	14,138	0	178,091
c6	China	1,338,300	47,437,647	107,403,094
c7	East Timor	1,171	0	8,730
c8	India	1,170,938	6,321,812	13,870,008
c9	Indonesia	232,517	3,215,982	10,000
c10	Japan	127,380	543,187	331,039
c11	Lao PDR	6,436	0	1,000,000
c12	Malaysia	27,914	5,063	41,000
c13	Maldives	314	27,214	23,849
c14	Melanesia	8800	14,100	117,500
c15	Mongolia	2,701	0	1,071,000
c16	Myanmar	50,496	21,277	2,420,000
c17	Micronesia	546	71	8834
c17	Nepal	29,853	7,367	165
c18	New Zealand	4,371	301,845	2,000
c19	Korea, Dem. Rep.	23,991	0	88,625
c20	Pakistan	173,383	5,128,309	1,650,000
c21	Papua new Guinea	6,888	20,200	162,140
c22	Philippines	93,617	1,632,072	12,221,663
c23	Polynesia	668	5,585	195,000
c24	Singapore	5,140	0	0
c25	Korea, Rep.	48,875	0	627,180
c26	Sri Lanka	20,452	1,019,306	375,000
c27	Taiwan	23,071	108,918	2,307,523
c28	Thailand	68,139	67,007	1,894,238
c29	Vietnam	88,362	0	15,651,884

Table 1. Zonal data for population and disaster impact (18,19)

In the first step of our analysis, we assume that humanitarian organization will not use UNHRD. we named this situation is ‘free form’ distribution network configuration. In this situation, we calculated the number of facility requirement to ensure the less than 500 km per capita. The solution of this query for earthquake is 2 (Figure 4). The potential location is c6 and c8 for earthquake disaster. Two facilities can ensure the distance per capita is 464 km in this zone. The single facility c6 make the distance per capita is 1131 km. The maximum distance of demand point from facility location is 9024 km.

The similar analysis for meteorological disaster, the minimum required facility is four (Figure 6). The potential locations are c6, c28, c8, c1. The mean distance per capita is 397 km/person. The maximum distance of demand point from nearest facility is 3288 km. The facility c1 significantly impact on reducing the maximum distance.

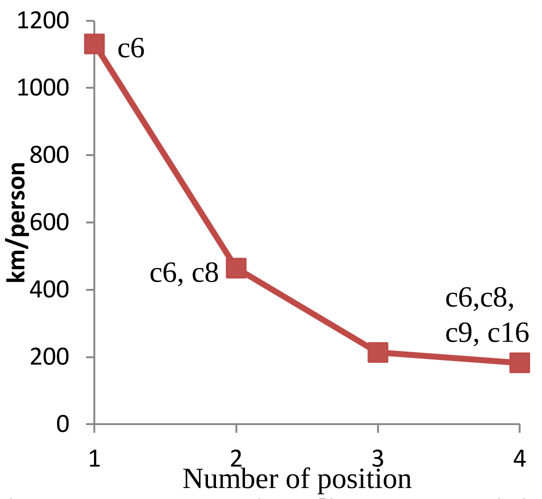

Figure 4. Per capita distance sentivity for earthquake disaster (free form)

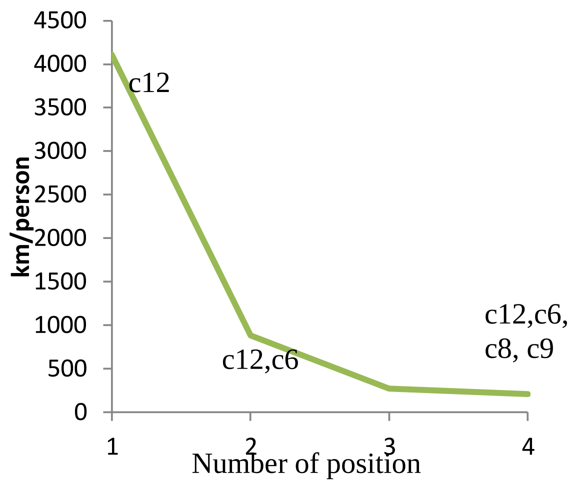

Figure 5. Per capita distance sensitivity for earthquake disaster (status quo)

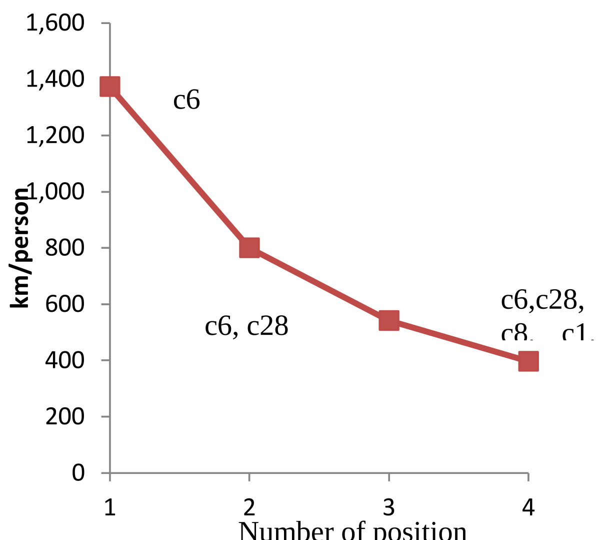

Figure 6. Per capita Distance sensitivity for metorological disaster (free form)

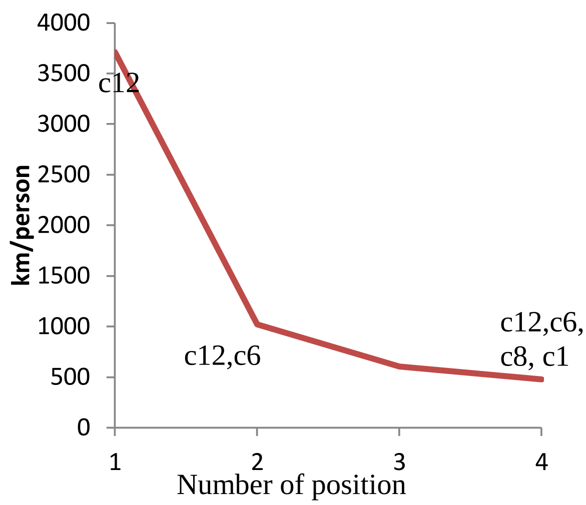

Figure 7. Per capita distance sensitivity for meteorological disaster (status quo)

EQ=Earthquake; met = Meteorological

Status Quo situation represent the current location of UNHRD in Malaysia (c12) and humanitarian organization is willing to expand the network with respect to pre-existing UNHRD. Since any humanitarian organization can use UNHRD to stock the commodities, the extension of network is designed with respect to c12. With the single pre-positioned in c12, the mean distance per capita for earthquake reveals 4110 km/per person (Figure 5). After addition of one new facility in c6, the mean distance per capita downs to 885 km/person. After addition to one facility in c6, the mean distance per capita for meteorological disaster was 1020 km/person (Figure 7). Both measures are more that desired service level which is 500 km/ per capita. To achieve this target, another facility in c8 is required.

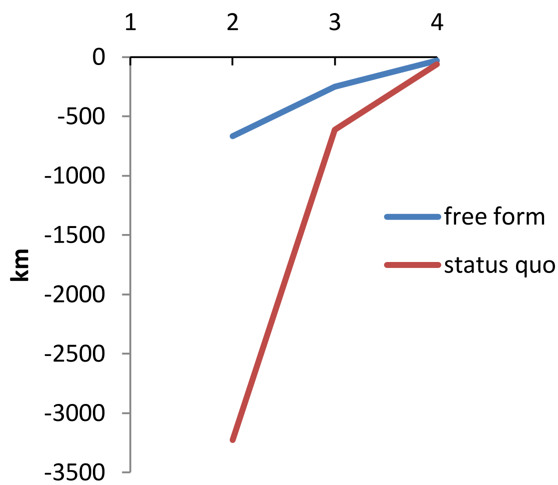

Figure 8. Diminish return on position for earthquake

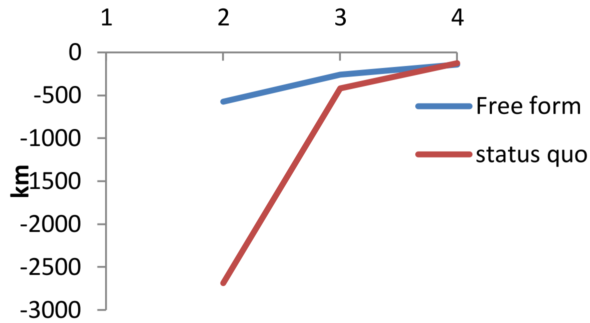

Figure 9. Diminish return on position for meteorological disaster

Number of facility	1	2	3	4
status quo		-3224	-612	-62
free form		-667	-251	-31

Table 2. Diminish return on position for earthquake

Number of facility	1	2	3	4
status quo		-2685	-419	-128
free form		-573	-259	-145

Table 3. Diminish return on position for meteorological

The improvement (reduction) in distance gained by adding single facility to the system is calculated as the distance per capita minus the distance per capita from the previous iteration. A steeper slope indicates a more significant impact in the reduction of per capita distance. It is observed that each additional facility makes a lesser impact. It shows the trend of diminishing return on positions. The slope of curve in figure 8 and figure 9 indicate the marginal impact of each additional position to the system. The status Quo situation has vast impact after adding first facility in network.

CONCLUSION

The data suggest that the majority of affected people in both earthquake and meteorological disaster belong to China. India and Pakistan are the second and third most affected country for earthquake hazard respectively. The meteorological disaster shows different demand structure where second and third most affected countries are Bangladesh and Vietnam respectively. The strategic design of humanitarian network requires including both types of disasters since humanitarian organization responses to all type of disasters. The network design will be sub-optimal if the design consideration is only single type of disaster. Slow-onset disaster is not considered here since quick response is not required for slow-onset disaster; rather it requires constant supply of commodity.

The model was evaluated by using two criteria distance per capita and maximum distance. The single facility location in c6 can minimize the distance per capita while location in c1 can minimize the maximum distance from facility to demand point. Herewith, it is required to mention that according to our analysis it shows that Malaysia UNHRD is not in optimal location. However, facility location decision also depends on other criteria such as land availability, political stability, land suitability, transports mode availability etc besides the distance per capita criteria. Since other criteria are not measureable, we use single most important factor to show prepositioned sensitivity for immediate response.

Finally, Funding structure in humanitarian organization is one obstacle for making decision about facility location that donors are not interested to invest for network design. Since preparedness can reduce probable impact from disaster and Asia-Oceania is highly vulnerable, the proposed solution may be helpful for humanitarian organization to make decision in network design.

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