

Risk Based Humanitarian Logistics Facility Location Model

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Disaster in recent years warrant robust logistics network such that response operation can run smoothly. Since information, just after hazard, are difficult to obtain and are fuzzyfied, logistics network considering the stochastic programming approach can meet the needs of humanitarian environment. Uncertainty may arise from demand side uncertainty, link uncertainty and provider side uncertainty. Several studies incorporated demand side uncertainty and link uncertainty in humanitarian logistics context. This study incorporates provider side uncertainty in humanitarian logistics network design. Provider uncertainty may arise from different sources in humanitarian perspective such as consecutive disaster events (aftershock after the main shock earthquake), worker unavailability, looting etc. This paper first draws the source of provider side uncertainty and then proposed a mathematical model as an extension of simple plant location problem through multilevel assignment. This model is solved by genetic algorithm for a case study in Bangladesh. The model compute the prepositioned location and the safety level of each district in Bangladesh.

Key Words: *humanitarian logistics, reliable facility, genetic algorithm, uncertainty, preparedness*

1. INTRODUCTION

A disaster is an unforeseen and often sudden event that causes great damage, destruction and human suffering¹. Worldwide major disasters occur frequently and threats posed by disasters are likely be worse in future. Cyclone Nargis in Myanmar on 2008 left her footprint through 78,000 dead, 56,000 missing and about 2.4 million victims². In the same year, China's Sichuan province was shattered by massive 7.9 earthquakes which tolls more than 68,500 dead, another 20,000 missing, 300,000 injured and 5 million people homeless. Besides the above stated dreadful events, Tohoku earthquake (2011), Haiti earthquake (2010), Hurricane Katrina (2005) and Indian Ocean Tsunami (2004) pose the destituteness of people. While 500 small or large scale disasters affect 200 million people every year³, forecast estimates that over the next 50 years natural and man-made disasters will increase five-fold both in number and impact⁴.

The disaster in recent years bears the fact that, increasing preparedness is essential to minimize the human suffering and cost. Preparations enable quick

response activities including vulnerable people evacuation, relief distribution, search and rescue, aid personnel allocation and distribution. It needs a robust network such that response operation can run smoothly.

In the last some years, several studies have investigated scopes for the disaster preparedness and most of these studies pointed out that the presence of uncertainty confound the preparation strategy. Very recently after acknowledging the importance of logistics planning in disaster, few studies^{5,6,7} have proposed model incorporating uncertainty in logistics planning. Those models address mostly the uncertainty in receiver side such as demand side uncertainty. Demand uncertainty in humanitarian logistics is apparent as disaster per se parameter like location, time, and intensity cannot be predicted. Ukkusuri and Yoshimoto⁸) address the uncertainty in distribution link. Disaster vastly affect the communication and transportation network and direct impact of this disruption increase distribution time and cost. Barbogsoglu and Arda⁹) also incorporated distribution link uncertainty and formulated two-stage optimization model for

routing during generic disaster response. It is noted that there are three types of uncertainties, namely, demand side uncertainty, link uncertainty and supply side uncertainty¹⁰). Studies in humanitarian logistics have commenced incorporation of uncertainty parameter recently and no study has included yet the provider side uncertainty.

Past studies assume that after establishing facility it can provide services for all time. Recent experiences put mark on the validity of this assumption. The 2010 monsoon flood in Pakistan has been massive and unprecedented impact on citizens. This flood damaged stored food and commodities in warehouse owned by government. Even humanitarian agency like World food program (WFP) lost its aid commodity¹¹). Besides aid commodity loss, Pakistan flood damage 450 health facilities. Without the backup facilities planning, people will be at risk not to have access of necessary support. British Broadcasting Corporation (BBC)¹² reported that Haiti earthquake damaged Haitian Red Cross warehouse. The World Food Program reported UN warehouses in the Haitian capital have been looted¹³). Facility malfunctioning will put the victims in dire situation. In planning stage, a decision maker needs to incorporate all uncertainty for designing robust network. This paper explores the provider side uncertainty and proposes a solution to improve the humanitarian support capability after disaster. This study has the following distinctive features and fills the research gap of provider side uncertainty.

In the wake of frequent disaster events, a robust aid distribution network is essential to ensure reliable aid distribution to affected people. The proposed model incorporates provider side uncertainty in the framework of simple plant location model which includes the properties of multi-level assignment to decide multiple facilities in a large scale disaster context.

This analysis is helpful to identify the hierarchy of facility and fortification strategy of facilities. To begin addressing the provider side uncertainty, we first describe the source of provider side uncertainty in the context of humanitarian logistics. Next a mathematical model is formulated incorporating the provider side uncertainty for logistical network design. Genetic Algorithm based solution methodology has been proposed after model description. The case study and experimental result are reported. This paper is ended with the conclusions and outline of future research.

2. UNCERTAINTY IN PREPOSITIONING

Facilities –along with physical transport infrastructure– give the supply chain structure which

facilitates the storage, and distribution of goods. From this point forward, the term ‘Facility’ represents aid prepositioned location. Recently a number of facility models⁵) has been addressed the importance of facility location model in humanitarian response perspective. Facility location problem (FLP) typically tries to determine where to locate the facilities among a set of candidate sites, and how to assign customers to the facilities, so that the total cost can be minimized. A common assumption in this literature is that the input parameters of the problems (costs, demands, facility capacity etc.) are deterministic and another assumption in FLP is that established facility would never fail, in other words they are completely reliable and operational. But recent disaster response experience shows that facility also may subject to fail for several reasons: not able to provide service. Here, we provide a short list of possible reasons for network failure based on recent phenomenon.

(1) Consecutive events

Sudden onset hazard hit a vast area suddenly leaving its consequence and the affected area may suffer again from similar or different type of another hazard in close interval of time. For example, large earthquake hit a vast area with associate ‘aftershock’. According to SCEC (Southern California Earthquake Center) aftershocks follow closely in the wake of a larger earthquake and in roughly the same location as its predecessor (‘Main shock’). Hundreds of strong aftershocks hit Japan after the deadliest earthquake in Japan Tohoku area of 11 March, 2010. Aftershocks may hit even after three months of main shock. Some time, one hazard event is followed by other events. For example, tornado and hurricane Tomas hit Haiti in close interval after the major earthquake in Haiti in 2010. Tornado destroys 8,432 shelters in Haiti¹⁴). Such consecutive events manifest the consideration of facility failure in designing disaster response distribution network.

(2) Worker unavailability

An adequate workforce is a necessary component of a functional system and is a major determinant of service delivery and outcome. Aid distribution requires experience to accomplice the job. Skilled staffs are always in short supply during disaster response³). Hurricane Katrina aid distribution experience shows that there were limited number of aid worker available in field which hamper the aid distribution operation¹⁵). Besides, security of worker is a cause of worker unavailability. UN has been reporting several kidnapping and life risk events

during humanitarian activities. Worker unavailability may lead to facility not functioning.

(3) Looting

Chaos after disaster is a widely reported event. Quarentelli's¹⁶⁾ assessment of work in the field indicates that disaster victims as a whole don't panic and don't take part in anti social activity like looting. He also found that looting or anti-social activities are not absent rather done by outsider. During disaster relief, trucks are often stopped and looted and deviated from their intended destination¹⁷⁾. Looting was observed in different disaster events including Hurricane Katrina relief operation and Haiti earthquake (2010) relief operation. Looting may occur from storage facilities or while transporting to storage facilities.

The above mentioned reasons of facility malfunctioning demonstrate the relevancy of consideration of facility uncertainty while making plan for emergency response. In this study the assumption of facility reliability is relaxed.

3. ROBUST SIMPLE PLANT LOCATION PROBLEM

Facility location models have been extensively studied in literature. The considerations for humanitarian logistics networks differ from business logistics. One noting difference between humanitarian logistics facility and business logistics facility is that the decision maker in business logistics can make decision not to serve one demand point by considering the total profit. In humanitarian logistics context, each demand point needs to be served. So, each demand point needs to be assigned in group of operational facilities and demand can fulfill from one operational facility. While operational facility is too far and takes longer time, the demand point faces social cost. Social cost also rise in system while some part of facility is destroyed and repositioned become unusable. Another properties of humanitarian logistics network is that one demand point can have multiple coverage to increase the delivery certainty.

The objective is thus to minimize the facility opening cost plus the expected connection and social cost. This problem will be referred as Robust simple plant location problem (RSPLP).

We consider single failure probability facility location problem, assuming that the failure probabilities are independent and each facility has only one failure probability. Let p_i denotes the probability that facility i fails. Without loss of generality, we assume that $0 \leq p_i < 1$. The major difficulty here is to compute the expected distribution cost. To overcome this difficulty, here

multi-level assignment approach is adopted^{10,18)}. The facilities assigned to any demand point can be differentiated by the levels: in case a lower level facility fails, the next level facility, if operational, will provide service instead.

To represent the level assignment a variable x_{ij}^k is introduced here. In particular, $x_{ij}^k = 1$ if facility i is the k -th level backup facility of demand point j and otherwise $x_{ij}^k = 0$. Level assignment variable is used to calculate the expected distribution cost. Consider a demand point j and its expected distribution cost at its level- k facility. Demand point j is served by its level- k facility only if all its assigned facilities at lower levels become non-operational. On the other hand, for any facility l , if it is on the lower level (i.e. less than k) for demand node j , then $\sum_{s=1}^{k-1} x_{lj}^s = 1$, otherwise $\sum_{s=1}^{k-1} x_{lj}^s = 0$. It follows that for demand point j , the probability that all its lower level facilities fail is $\prod_{l \in F} P_l^{\sum_{s=1}^{k-1} x_{lj}^s}$. If j is served by the facility i as j 's level- k backup facility, then facility i has to be operational which occurs with probability $(1 - P_i)$. Therefore, the expected distribution cost of demand point j at level k is $\sum_{i \in F} d_j c_{ij} x_{ij}^k (1 - P_i) \prod_{l \in F} P_l^{\sum_{s=1}^{k-1} x_{lj}^s}$ where d_j and c_{ij} are demand at point j and distribution cost from i to j respectively. Addition to expected distribution cost, system social cost is calculated similarly. While a designated facility fails, it will take extra cost to supply the demand point from other source. To represent the failure of all k -level facilities for a demand point j , a new binary assignment variable z_j^k is introduced here. We have formulated such social cost by following the same explanation of expected distribution cost for late delivery.

$$\begin{aligned} & \sum_i f_i y_i + \sum_{j \in D} \sum_i \prod_{l \in F} P_l^{\sum_{s=1}^{k-1} x_{lj}^s} d_j r_j z_j^k \quad (1) \\ & + \sum_{j \in D} \sum_{k=1}^F \sum_{i \in F} d_j c_{ij} x_{ij}^k (1 \\ & - P_i) \prod_{l \in F} P_l^{\sum_{s=1}^{k-1} x_{lj}^s} \end{aligned}$$

Subject to

$$x_{ij}^k \leq y_i \quad \forall i \in F, j \in D, k = 1 \dots F \quad (2)$$

$$\sum_i x_{ij}^k = 1 \quad \forall j \in D, k = 1 \dots F \quad (3)$$

$$\sum_{i \in F} x_{ij}^k + \sum_{t=1}^k z_j^t = 1 \quad \forall j \in D, k = 1, \dots, F + 1 \quad (4)$$

$$\sum_{k=1}^F x_{ij}^k = 1 \quad \forall i \in F, j \in D \quad (5)$$

$$x_{ij}^k, y_i \in \{0,1\} \quad (6)$$

The above formulation is a two stage formulation. First stage decision is opening decision of facility and second stage is the expected distribution cost. The decision variables x_{ij}^k are defined earlier. The indicator variable $y_i = 1$ if facility i is open in the first stage; otherwise $y_i = 0$. The objective function (1) is the summation of the facility cost, the expected distribution cost and expected social cost. constraint (3) ensure that demand point j must be served from one distribution center. Constraint (2) makes sure that no client is assigned to unopen facility. Constraint (5) prohibits a demand point being assigned to a specific facility at more than one level. Constraint (4) represent for demand point j is either assigned to a facility or subject to a penalty at each level k . One properties of this model is that a closer open facility be assigned as a lower level facility to a particular demand point. Since capacity of the facilities has no limit, if every customer choose the most suitable facility (with minimal transportation cost), the total cost is minimal. However, the procedure for choosing of the most suitable facility participated only established facilities ($y_i = 1$).

4. SOLUTION METHODOLOGY

Simple plant location problem has already proved as a NP hard problem. Genetic algorithm (GA) has been suggested as a robust technique for solving NP-hard optimization problem¹⁹⁾ Here we propose a genetic algorithm for solving RSPLP.

In general GA is perceived as a search through a space of potential solutions. GA improve fitness upon random restart by mimicking the evolutionary process through the use of a ‘survival of the fittest’ strategy. In general, the fittest individuals of any population tend to reproduce and pass their genes on to the next generation, thus improving the successive generation. The following is the basic steps for genetic algorithm

Step 1. Set generation counter $i = 0$,

Step 2. Create the initial population, $Pop(i)$, by generating N sets of n random locations,

Step 3. Determine the fitness of each individual (i.e., each set of NF locations) in the population by applying the RSPLP local improvement procedure to the individual,

Step 4. Increment to the next generation, $i = i + 1$,

Step 5. Create the new population, $Pop(i)$, by:

- (a) selecting N individuals stochastically based on the fitness from the previous population, $Pop(i-1)$, and

- (b) randomly selecting R ($R \ll N$) parents to produce children through the application of genetic operators

Step 6. Evaluate the fitness of the newly formed children by applying the RSPLP method as in step 3

Step 7. If i is less than the maximum number of generations to be considered, go to step 4

Step 8. Print out the best solution found.

(1) Representation scheme

For any GA, a chromosome representation is needed to describe each solution or individual in the population of interest. The representation scheme determines how the problem is structured and which genetic operators are used. Each individual is made up of a sequence of genes from a certain alphabet. An alphabet can be represented as a binary string, an integer string or a real number string. To encode the prepositioned location, we require each chromosome to represent a feasible solution to the problem and require the genes of the chromosome to symbolize the elements of the feasible solution. Hosage and Goodchild²⁰⁾ encoded a solution as a string of m binary digits for solving P-median problem. They found the result was constraint in local optima. Hence, we use a digit as a gene to indicate the ID of a facility site and a string of digits as a chromosome to represent all the selected facilities²¹⁾. For example, the following string of digits (3, 4, 2) denotes a chromosome consists of three genes, each representing the prepositioned location. It is noted that the length of the chromosome must be the same as the number of prepositioned are desired (parameter of the location problem). We avoid the duplication of a facility index in the string during the course of the algorithm.

(2) A feasible initialization

The initial population is important in the computational performance of a GA heuristics. To begin the search for the best chromosome and the corresponding prepositioned location solution, a number of chromosomes are initialized as follows:

- Create a list of IDs for all eligible sites from 1 to J , each representing a gene.
- Generate the first chromosome by selecting P facilities based on set enumeration heuristic (SEH) (figure 1) which is greedy heuristic.

Assuming that the size of the initial population is s , to generate N number of initial population, repeat the algorithm for N best solution produced by SEH. Initial population generation largely determines the solution of optimality. The diversity and presence of each possible solution leads the success of GA operator. If one facility does not

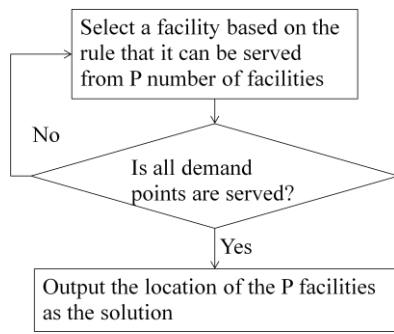


Fig. 1 Procedure of set enumeration heuristics

present in initial population, GA operator cannot reach that facility even after thousand times iteration. Besides, after producing initial population we have checked whether there are duplicate chromosomes. The duplicate chromosomes were deleted and generate another chromosome by following same procedure. After confirming the uniqueness of all chromosomes, we have examined the presence of all potential location at least for once.

Small number of population size creates founder effect (reduction of genetic variation) and larger population size creates calculation complexity. In our calculation we have generated 60 initial population.

(3) Fitness checking

Once the initial population is created, each individual is evaluated using the evaluation function to determine its fitness value. Here RSPLP objective value is used. The best objective value for each generation are recorded and compared with previous generation. The chromosome for concerned best value is also recorded.

After the population (of size N) has been evaluated, a new population of size N individuals is selected from the previous generation. This step is the key step for finding quality result from GA method. If there is no specific restriction on how mating partner should be chosen, an individual mates with any other regardless of its parenthood or likeness. This type of mating scheme is referred to as random mating²²⁾. The chromosome is selected based on ranking of each performance from best to worst. Other available selection method such as Roulette wheel selection method is not suitable in our case. One chromosome can take part for only single crossover. We have also experimented by using the elitism strategy where 15% of total

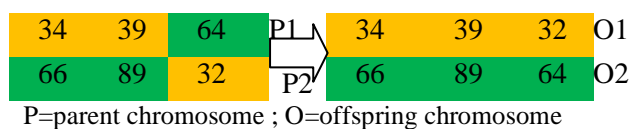


Fig. 2 Single point cross over

population was declared as elite group for preserving the purity of elite group. However, this strategy does not lead us optimal solution.

(4) Operator

In general, crossover operator transfers a portion of genetic codes between two parent chromosomes selected from the mating pool. It leads to an exploitation of the solution space by introducing variations to the parent chromosomes. The properties of two parent chromosomes are merged to generate off-springs. A pair of parent chromosomes is chosen from the mating pool without replacement. Then we applied single point cross-over strategy where the cut point is selected randomly (figure 2). After cross-over operator, a gene can be duplicated in a chromosome. To avoid this pitfall, we checked each gene in the chromosome and if duplicate gene is found one gene is replaced by randomly selected gene from parents.

Mutation operators tend to make small random changes in one parent to form one child. Since this model is multi-level assignment model. Mutation operator take place by re-arranging the higher level of assignment.

5. CASE STUDY

We present a case study to demonstrate the effectiveness of our model for sudden onset disaster preparation for facility location and predetermined route plan for aid distribution. It is based on freely available data from Bangladesh government and public organization websites, and interview with Bangladesh earthquake expert named Mehedi A. Ansary, Israt Jahan.

Bangladesh is a country which have experienced a number of strong earthquakes. Those earthquakes were generated within the country boundary or near the country border. Figure 3 shows the historical earthquake event in Bangladesh and diameter of circle in the figure is propotional to the intensity of earthquake. The strongest earthquake that shaked the country had intensity more than 8 in Mercalli intensity scale. Due to the long history of earthquake and presence of techtonic plate fault inside the country boundary, Bangladesh is considered one of the high earthquake vulnerable countries and Dhaka is the most vulnerable city in the world²³⁾ due to lack of disaster preparation. Acknowledging this fact, Bangladesh Government got focus on strengthening the preparation for disaster response.

Demand data in humanitarian logistics is not readily available since there is no existing method to compute aid demand. Akkihal²⁴⁾ adopted disaster generated total homeless people for global aid location and the Pacific region. Ballick⁵⁾ used scenario based demand for earthquake specific global aid location for aid provider World Vision. These stated studies considered facility location for multinational context on historical disaster database provided by EMDAT. In this study, demand is computed as deterministic and is a function of total people in coverage area and vulnerability of area.

$$d_j = f(pop_j, vul_j) \quad (7)$$

where pop=population, vul=vulnerability

The earthquake vulnerability are collected from Bangladesh National Building Code (BNBC). The potential facility is collected from shelter locations which are situated in different earthquake vulnerable zone defined by BNBC. Herewith, it is worth to mention that Bangladesh National Building Code (BNBC) divides the country in three distinct earthquake vulnerable zones: high, medium and low vulnerable zone. Table 1 shows the facility id and measure of earthquake prone index according to Bangladesh National Building Code (BNBC). Population database collected from 2011 census by Bangladesh government. Then the demand data are assigned to each location and aggregated in center of boundary area. We have used GIS based layers to compute the aid demand following the above rule.

Each demand point is considered as node and it is assumed that each node is positioned at the one end of connecting link. Thus whole system creates a network where demand point is served from minimum distribution cost facility. The network data is collected by using Google map shortest distance tool for car navigator. 'R' software 'igraph' package can be used for finding shortest route by using "dijkstra", "bellman-ford", or "johnson"

Table 1 Potential facility location id

Division	facility id	Earthquake Vulnerability*
Dhaka (dhk)	1-20	2
Chittagong (ctg)	21-40	2
Sylhet	41-50	3
Rajshahi	51-60	2
Kulna	61-70	1
Barisal	71-80	1
Rangpur	81-90	3

*1(low),2 (medium), 3(high)

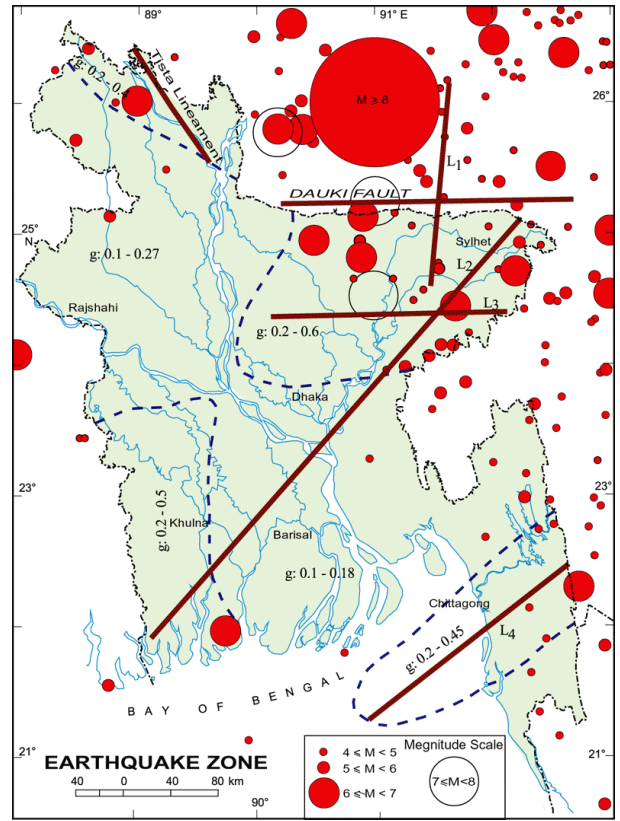


Fig. 3 Historical earthquake events at (or near) and faults in Bangladesh

algorithm. It requires shape file of transport network. We could not acquire the GIS format Bangladesh transport network. Hence, we have not utilized igraph functionality of R platform. Here network is deterministic input with travel time and travel cost for a fixed route. However, it acknowledges that the travel time and cost can be changed. For the sake of simplicity, the cost between the demand point and the facility point situated in same area with demand point is negligible and assumed as zero.

We have a 90X90 matrix for solving robust network design. Since simple plant location model is NP-hard problem, small network is easy to be solved. Enumeration based algorithm are not suitable for NP-hard model. We have coded the model in open source software 'R' which is written in statistical language 'S'.

6. RESULT AND ANALYSIS

In our computation, we have identified the location of prepositioned to the aim of multi-level assignment. We run the model for 5000 iteration and model converge to its optimal solution very quickly. The selected facility locations are in (7, 16, and 60). The fitness improvements in subsequent generations are presented in figure 4. Some demand point has single level assignment and most of the demand points have multi level assignment within threshold time. The system reliability improvement

Table 2 Selected facility for multi level service

Facility id	Geographical location	Earthquake vulnerability
7	Dhaka	2
16	Dhaka	2
60	Rajshahi	2

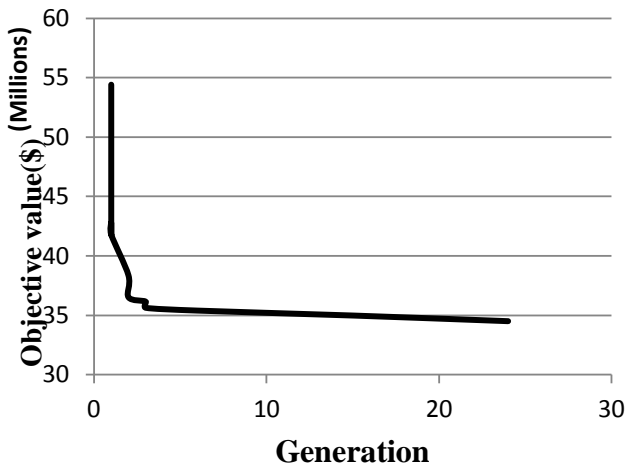
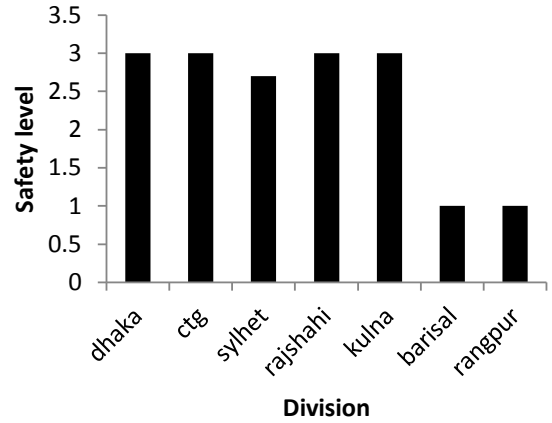
through multi-level assignment is presented in figure 5.

The reliability and performance of selected facilities are explored on the geographical location of these facilities. Two facilities are selected in capital city Dhaka. Dhaka is located at the center of country and act as center of gravity for nationwide distribution system. It is easy to access other part of the country from Dhaka. Id 7 is located in western part of Dhaka and id 16 is located in souther part of Dhaka. These two facilities are the robust for the system for several reasons.

Here with, Commercial logistics development is additional benefit for prepositioning in Dhaka city. During emergency period, commercial transport providers also take part in humanitarian response. World Food program made logistics capacity assessment during SIDR (a tropical cyclone hit Bangladesh in 2007) response and found Dhaka host a vast number of logistics operators compare to other division of the country. Besides logistics service opportunity, both facilities are located in medium level earthquake prone zone.

Facility id 60 is the first level supply source to the high earthquake zone Rangpur and medium vulnerability zone Rajshahi. This facility increase safety level of the system.

After identification of facility location we have checked the safety level of demand point. We have computed the safety on the basis of primary condition quick response time and the threshold time is 15 hour.

**Fig. 4** Objective value with generation**Fig. 5** Service safety (within 15 hours) of each division in Bangladesh

$$sf_{ij} = \begin{cases} 1 & \text{if } tt_{ij} \leq 15 \text{ hr} \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

Here sf_{ij} represent the safety level for each demand point j with respect to facility i . Figure 5 shows the safety level of each division in Bangladesh for the selected prepositioned location. Dhaka, Chittagong, Kulna and Rajshahi have a number of high rise buildings and population density is higher in those region. These four regions are situated in medium level vulnerable zone. Since population density and building conditions are the determinant for earthquake vulnerability, these four cities pose high vulnerable zone and got maximum safety level in the proposed selected facilities.

Barisal and Rangpur are in opposite situation considering the earthquake vulnerability. But both divisions have lowest safety level. This output can be explained based on earthquake engineering literature. Barisal is the least earthquake vulnerable zone and has less multi-storied building. On the other hand Rangpur is in high earthquake vulnerable zone and this zone is the least developed zone. This zone has very little infrastructure development. Those conditions put these two zones in similar safety level.

Sylhet zone is located in high earthquake vulnerable zone and has a number of multi-storied buildings. 70% of total demand in sylhet can be met within threshold limit in safety level 3 and while 30% of demand point has safety level 2.

7. CONCLUSION

Earthquake is such an event that science at this stage can not predict the time and occurrence of this hazard. Earthquake hazard affects community all on a sudden without giving any prior sign. In this

regard, country need to be ready for search and rescue in initial critical period and relief distribution in recovery stage. Since established facility can also be affected by the hazard, multi safety level preparation can increase the certainty of quick response. In this research, we have proposed a novel approach for increasing the response certainty by adopting multi-level assignment framework. While one facility fails to deliver the victims that are assigned to it have to be reassigned to other facilities that are operational. The possibility of facility failure is named provider side uncertainty. Other two type uncertainty demand uncertainty and link uncertainty are less controllable by the aid provider. Hence, reduction of provider side uncertainty can build a robust humanitarian relief network. RSPLP model is applied to identify the location of prepositioned and multi-level assignment that can enhance the earthquake preparation in Bangladesh. It was found that this county is not equipped with logistics capability to response to large scale hazards.

A number of constraints have affected the result of this model. The biggest constraint is the development of commercial logistics system. The more a city has dense transport facilities, the less time it will take to get to the destination. Since initial 72 hours is the critical time for earthquake, the emphasis should be targeted to the strategy for the emergency response within the determined time. This model can enable the decision makers to re-think about the designing humanitarian logistics network and get ready for the worst scenarios.

Since our interest were to show the presence of provider side uncertainty and solution methodology, we consider the demand and link uncertainty were fixed. As an extension of this research, a new model can be made by incorporating demand uncertainty and link uncertainty in addition to provider side uncertainty.

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