WAREHOUSE LOCATION DETERMINATION FOR HUMANITARIAN RELIEF DISTRIBUTION IN NEPAL

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The use of warehouses for storing emergency relief items has been proven to improve overall responsiveness, efficiency and effectiveness of the humanitarian supply chain while decreasing the cost incurred in the process. Driven by the same goals, this study determines the optimal number and locations of warehouses to be placed in different parts of Nepal for a humanitarian relief chain that would respond to sudden-onset disasters. The study utilizes a modified version of the maximal covering location problem which introduces additional constraints that reflect the real scenario of Nepal. The problem is solved using simplex algorithm with branch and bound applied to the relaxed integer. The novelty of the study lies in the introduction of indexes for development, disaster safety and transportation accessibility constraints to reflect socioeconomic, geo-climatic and topographical features of Nepal respectively. Three scenarios are chosen based on coverage distance. The results show the number and spatial locations of the warehouses for each scenario, as well as their maximum and minimum coverages.

Key Words: *Location problem; integer programming; linear solvers; maximum coverage; emergency logistics*

1. INTRODUCTION

Disasters destroy the very infrastructure of the country, affecting eh social, financial, economic and physical structure of the society and can be triggered by natural, political and economic events (Whybark 2007[1]). Recently, the frequency and scale of disasters have been increasing exponentially, gaining growing attention in the field of disaster response operation. Thus the role of national and international disaster relief organizations and their disaster response strategies become very important. The success and failure of the disaster response activities highly depends upon the level of preparedness such as building up country's resilience in advance. However, over 90 percent of international relief aid is still dedicated to disaster response and less on advance preparedness. Thus focus on preparedness activities like emergency planning, construction of emergency operation centers, and prepositioning of emergency supplies could translate to better aid outreach and level of service to beneficiaries. Among several forms of preparedness activities, this study focuses on warehousing for inventory prepositioning in Nepal. Warehousing is an integral part of humanitarian logistics because it directly helps reduce suffering of affected people by reducing the time to reach them.

Located in the central of Himalaya range, Nepal is prone to various types of natural disasters due to its fragile geophysical structure; characterized by very high peaks, complex geology, active tectonic processes, and unplanned settlement, variable climatic condition and weak economic and political condition (Nepal Hazard Risk Assessment, 2010; Nepal Hazard Risk Assessment, 2010[2]). Each year flood, landslide, fire, epidemic, avalanche, and various other natural and man-made disasters causes loss of thousands of human lives and destruction of physical properties worth billions of rupees. The earthquake of 1934, 1980, 1988, 2015 and the flood of 1993 and 2008 are devastating natural disasters which not only caused loss of human lives and physical properties but also adversely affected the development process of the country. Figure 1 and 2 show the statistics of different disasters and number of lives claimed from the year 1900-2014 in Nepal.

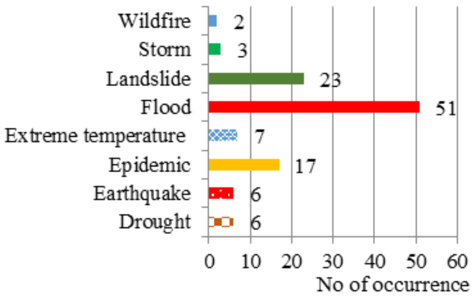

Fig. 1 List of disasters with number of occurrence in Nepal (1900-2014) Source: EM-DAT[3], 2014

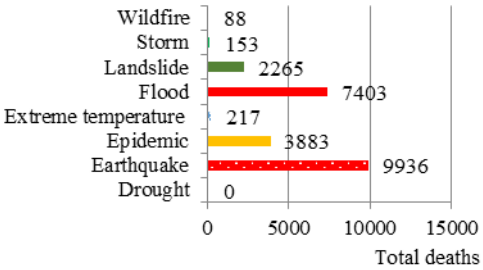

Fig. 2 Total deaths claimed by different disasters in Nepal (1900-2014) Source: EM-DAT[3], 2014

As a landlocked country with rugged landscape facilitating an incoming humanitarian response from regional and international partners to a major disaster is challenging. Nepal has one international airport and only three major roads leading to the valley, none of which are resilient to a major earthquake. The difficulty in facilitating international assistance from outside the country would hinder Nepal's ability to effectively respond to a natural disaster. Intuitively, investing all public resources in disaster risk reduction measures would be inefficient, since we could not be certain of the expanse of a disaster's effect, since there would be instances when the effects are small and can be coped with ex-post. But neither can society wait until disasters to strike and only deal with them ex-post, especially when they can bring about large numbers of deaths and destruction.

Despite the importance of preparedness, less has been done in Nepal in terms of inventory prepositioning. Therefore this study aims to determine the optimal locations for placing warehouses intended for storage of humanitarian relief. This is one of the initial steps in building up country's resilience from preparedness perspective. The problem can be categorized as facility location problem. The study takes into consideration the factors unique to Nepal such as transportation accessibility, disaster safety and level of development.

The remaining portion of the paper is constructed as follows. Section 2 reviews relevant literatures and novelty of the paper. Section 3 details methodology framework to determine optimal number and location of the warehouses using Maximal covering location problem, which is solved using LINGO as the optimization software. Section 4 discusses results thus obtained. It also includes sensitivity analysis which highlights the importance of constraint values. Section 5 concludes the study and its implication in Nepalese context.

2. LITERATURE REVIEW

Many studies have addressed the importance of the preparedness phase and the need for pre-positioned warehouses in humanitarian relief logistics, but only a small number of papers are related to the location decision (Dekle et al., 2005[3]; Balcik and Beamon, 2008[4]; Ukkusuri and Yushimoto, 2008[5]; Dessouky et al., 2009[6]; Rawls and Turnquist, 2010[7]; Gatignon et al., 2010[8]; Campbell and Jones, 2011[9], Roh et al., 2015[10]). Among the different forms of preparedness activities for disaster management, storing disaster relief items in a pre-positioned warehouse is considered to be best for maximizing the effectiveness of humanitarian supply chains (Roh et al., 2015) [10]. However, Farahani et al., (2012)[11] and Balcik and Beamon (2008)[4] are among the few literatures which highlights the lack of application of facility location models in real-world problems and minimal application of facility location models for coverage problems in humanitarian sector unlike in commercial sector until recently.

Facility location models determine the most suitable place for inventory prepositioning in the relief network. These models consider several stochastic as well as deterministic factors like cost, response time, location safety, demand coverage, distance etc. Based on data type and number of levels and objectives, structure of facility/warehouse location models can be classified as single-objective or multi-objective and deterministic or stochastic. Facility location models are classified either for evacuation operation, stock-prepositioning, or stock prepositioning and relief distribution. Studies use the term facility and warehouse interchangeably. In this study the warehouses serve as places for stock prepositioning and relief distribution.

Klose and Drexl (2005) [12] summarize the details of continuous location models, network location models, and mixed integer programming models. The authors also classify different types of facility location models based on topological characteristics, objective, capacity constraint, demand, input parameters, and model type. Balcik and Beamon (2008)[4] develop a model that determined the number and locations of the distribution centers in a relief network and amount of relief supplies to be stocked at each distribution center using a variant of maximal covering location model. Similarly, Akkilal (2006)[13] identifies the optimal locations for warehousing non-consumable inventories required for initial deployment by solving p-median problem. Duran et al. (2011)[14] determine the optimal supply network configuration for CARE International using mixed-integer programming inventory location model using demand, and up-front investment. Rawls and Turnquist (2010)[7] use a two-stage stochastic mixed integer program to develop an emergency response planning tool that determines the location and quantities of various types of emergency supplies to be pre-positioned, under uncertainty of occurrence of disasters. Basdemir (2004)[15] uses MCLP with additional constraints to determine the minimum number of search and rescue stations required to cover all the areas of operation in Turkey.

Location problems can be formulated either as covering problems or as center problems or as median problems. Covering problems can be solved either as maximal covering location problem (MCLP) or as set covering location problem (SCLP). MCLP and P-median problem deals with similar problem categories. P-median problem attempts to minimize the sum of distances (average distances) between demand nodes and their nearest facilities. So the objective here is to minimize the total demand-weighted distance between each demand node and the nearest facility which can also be interpreted as to find the location of P-facilities on a network so that the total distance is minimized. However, some studies have found that P-median problem approach do not optimize the covered demand as well as site location because in this model distance and time parameters can outweigh the demand values and result in selected locations that are outliers (Lee and Yang, 2009)[16]. MCLP approach successfully addresses this shortcoming because the objective is changed from minimizing travel distance to covering maximum population. In addition, coverage models are known to be best for “worst case problem” because we want to ensure good response for even the most remote demand node in the network.

MCLP was first introduced by Church and ReVelle (1974)[17], which maximizes the total demand covered within a maximal service distance subjected to limited number of facilities or resource constraint. Coverage, a notion that is central to facility location models indicates whether a demand location is within a pre-specified radius of its nearest facility. A source of demand is defined as covered if it is located within a specified response distance or time from the facility. The problem can be formulated as static or dynamic, single stage or multi-stage, single period or multi-period. The solution technique used for MCLP varies depending upon the type as well as size of the problem.

Taking into consideration the existing research gaps and current disaster scenario, this study applies modified version of MCLP to determine warehouse locations for disaster relief distribution in Nepal. The novelty of the study lies in the introduction of indexes for development, disaster safety and transportation accessibility constraints to reflect socio-economic, geo-climatic and topographical features of Nepal respectively. In this way this study highlights the applicability of the model in real scenario.

3. METHODOLOGY

(1) Methodology framework

The determination of optimal number and location of warehouses for disaster relief distribution during immediate aftermath of disaster has been modelled as Maximal covering location problem (MCLP) with additional constraints in this study. The problem is solved using simplex algorithm with branch and bound applied to the relaxed integer. The model includes candidate points which serve as potential locations for warehouse and demand points that needs to be covered. The selection of warehouse is subjected to transportation accessibility, development level and disaster safety constraints. As user accessibility and response time are two key factors that affect selection of facilities in emergency services, we use the notion of response distance in this study. The threshold values which refers to the minimum value for the three indices are obtained taking the average of values assigned to each of the districts, and the model is constrained to obey this value. Additional calculations were done with priority values assigned to each demand nodes to identify the impact of population on overall coverage and location selection.

(2) Mathematical model formulation

The model has been formulated using following assumptions:

- All the warehouses are considered incapacitated, hence can fulfill all the demands.

- All the demand points have proper road access to and from the candidate warehouse locations.
- There are no existing warehouses in Nepal.
- The demand points are either fully covered or uncovered, there is no provision of partial coverage.

$$Maximize \quad \sum a_i y_i \qquad (1)$$

$$\text{s.t.} \quad \sum x_j \geq y_i \qquad \forall i \in I \; j \in N \qquad (2)$$

$$\sum x_j \leq P \qquad j \in J \qquad (3)$$

$$\sum T_j x_j \geq N_T \sum x_j \qquad j \in J \qquad (4)$$

$$\sum V_j x_j \geq N_V \sum x_j \qquad j \in J \qquad (5)$$

$$\sum S_j x_j \geq N_S \sum x_j \qquad j \in J \qquad (6)$$

$$x_j \in \{0,1\} \qquad \forall j \in J \qquad (7)$$

$$y_i \in \{0,1\} \qquad \forall i \in I \qquad (8)$$

Where,

I = denotes the set of demand nodes

J = denotes the set of warehouse locations

a_i = demand at node $i \in I$

P = number of warehouses to locate

$x_i = \begin{cases} 1 \text{ if a warehouse is located at candidate site } j \in J \\ 0 \text{ otherwise} \end{cases}$

$y_i = \begin{cases} 1 \text{ if a demand node } i \in I \text{ is covered} \\ 0 \text{ otherwise} \end{cases}$

N_T = the minimum value for transportation accessibility index

N_V = the minimum value for development index

N_S = the minimum value for disaster safety index

T_j = the minimum value for transportation accessibility for site j

V_j = the minimum value for development index for site j

S_j = the minimum value for disaster safety index for site j

Constraint (2) is the coverage constraint which entails node $i \in I$ cannot be covered unless at least one of the facility sites that cover node i is selected. Constraint (3) shows the maximal number of warehouses that can be located. Constraint (4), (5), and (6) are the limiting constraints for transportation accessibility, level of development and disaster safety.

The model is subjected to several restrictions which affects the selection of warehouse location: first restriction is on the coverage distance which determines the maximum distance within which a candidate warehouse can cover the nearby demand nodes. The other restriction is on the maximum number of facilities that can be opened. Third restriction is on the minimum values of transportation accessibility index, development index and the disaster safety index which the candidate points needs to fulfil to be selected as the warehouse location. The study considers transport of relief materials via road only which in reality may not be appropriate all the time and can be considered a limitation of this study.

(3) Input parameter setting

a) Demand point selection

Disaster mapping is done to identify the demand points which are the districts prone to earthquake, landslide and flood. These three disasters have the highest frequency of occurrence and are the ones claiming largest number of damages to human beings and infrastructure. The study considers sudden onset disasters only. Data regarding disasters have been obtained from Nepal Hazard Safety Assessment report 2010.

Disaster mapping resulted into 54 districts to be prone to three disasters. Figure 3 shows the spatial location of the same where districts coloured light green are prone to earthquakes, those coloured light red represents districts prone to flood, and districts prone to landslide are represented by light blue colour. Maroon colour represents districts prone to earthquake and flood, red coloured districts are prone to earthquake and landslide and the districts prone to landslide is coloured pink. The rest of the districts without colour are potentially free from disasters.

b) Candidate point selection

There are in total 75 districts in Nepal which are eligible to be considered candidate points, however due to inaccessibility via road network four districts are removed leaving 71 districts as potential candidates for warehouse location.

c) Distance calculation

The study uses a web based application called shortest distance calculator provided by Department of Roads, Nepal[18] to calculate coverage distance.

d) Index selection

The study uses transportation accessibility index, development index and disaster safety index as constraints for model formulation to incorporate accessibility via road network, socioeconomic aspects and disaster vulnerability of the selected warehouse locations. Transportation accessibility index values are derived from road density data which show kilometers of existing road per square kilometer of land for each districts. It represents the accessibility of demand nodes from the candidate points. Development index values has been derived from human development index (HDI)[19], which is a measure of life expectancy, education and per capita income indicators. It represents the level of development of each of the districts, higher value of this index means the district has easier access to manpower and materials essential for storage and management of warehouse. Disaster safety value has been derived from Nepal hazard risk assessment report 2010. It represents the vulnerability of districts to landslide, flood and earthquake.

4. RESULTS AND DISCUSSION

Due to the geographic variation in Nepal travel time for covering the same distance in different parts of the country is considerably different. Thus, in an attempt to incorporate the varying needs of the response times, three different distances were used for the calculation of demand node coverage subjected to the three considered constraints. A standard criterion was set for all three constraints to calculate the number of demand points covered, wherein the candidate points/warehouses to be selected are required to have the values of transportation accessibility, development and disaster safety higher than 12, 0.345 and 8, respectively. Each scenario determines the maximum coverage obtained with minimum number of warehouses. In each of the scenarios, the demand nodes are treated as binary variables. Binary solution seeks to cover each of the demand nodes at least once. Multiple coverages do not improve quality of the solution. The model was run several times until all the demand points were covered under full coverage constraint. The term full coverage constraint refers to a situation where the P value was increased until all of the demand points were fully covered.

(1) Scenario dependent solution

Three coverage distances of 100 km, 200 km and 300 km are considered based on authors understanding of the travel time in Nepal. Under normal circumstances, it takes about 7 hours to travel 200 km in hilly region under normal road condition. The travel time varies in each of the regions due to the geographic differences. In addition, there are no set standards for selecting appropriate response time and/or distance in case of disaster, rather it is on earliest possible convenience depending upon the severity of the situation on hand. The objective here is to find the minimum number of warehouses which will provide maximum coverage for all three scenarios. The solution set provides the list of various options with different number of warehouses and their corresponding coverage.

Figure 3 shows the spatial distribution of the warehouses and Figure 4 shows the percentage coverage obtained with varying number of warehouses for all three scenarios throughout Nepal. A total of 26 warehouses need to be located in Nepal to cover all of the 54 demand nodes for 100 km scenario, 12 warehouses for 200 km scenario and 7 warehouses for 300 km scenario. Redundant coverage will be obtained by further increasing the number of warehouses above 26, 12 and 7 in each of the scenarios. However, the solution does not seek for redundant coverage, hence solution was stopped when 100 percent demand coverage was obtained. It is worth to note, when limiting the number of warehouses to only one, the candidate point at Bhaktapur was found to be a significant location as it was common to all three scenarios. Nevertheless, final decision regarding the choice of optimal number of warehouse will depend upon several factors like organization's willingness, available resources, and their capacity etc. If we assume a case when humanitarian organization has resources enough to open six facilities only, then the corresponding coverage obtained will be 44 percent with 100 km coverage distance, 81 percent with 200 km coverage distance and 96 percent coverage with 300 km coverage distance.

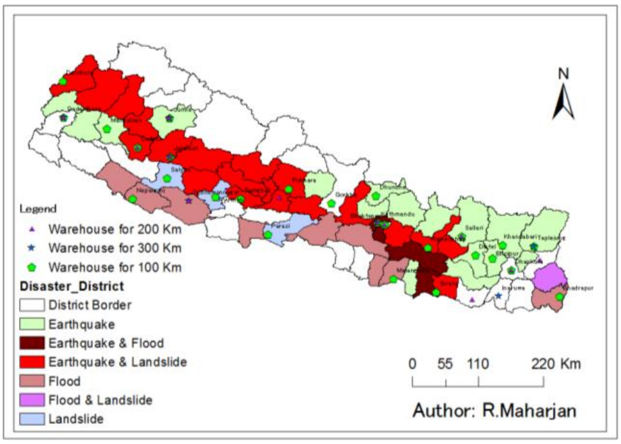

Fig. 3 Warehouse locations for 100 Km, 200 Km, and 300 Km scenarios

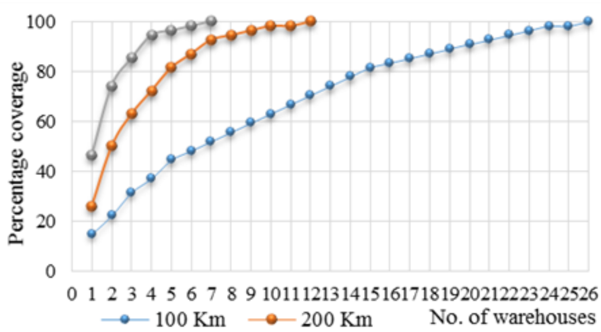

Fig. 4 Coverage rates for 100 Km, 200 Km and 300 Km scenarios

(2) Priority values

Furthermore, the model has been modified to increase its applicability in real life scenario by incorporating population of each of the demand nodes. The modified objective function is;

Maximize $$z = \sum p_i a_i y_i \qquad (9)$$

Where,

p_i = priority value for each demand node based on population density

Each of the demand nodes were given a priority value (p_i) based on the population density of each district such that precedence will be given to locations with higher population density. The priority values were assigned based on hierarchy by grouping the entire population size into ten different categories. The higher the population density, the larger are the priority values assigned to each district, hence will ultimately receive more (prior) preference in terms of coverage. Figure 5 shows the details of the calculation for 300 km coverage distance. The objective value in the figure refers to the sum product of demand nodes and their associated priority values. When the number of warehouses were increased further, the objective value remained same but the redundant coverage increased.

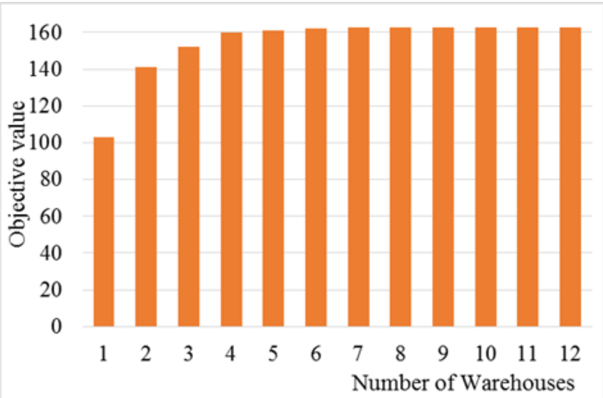

Fig. 5 Solution for 300 Km coverage with bonus values

(3) Sensitivity analysis

Sensitivity analysis is performed to see the impact of changing threshold value of transportation accessibility constraint on overall coverage and location selection. The locations changed for every ten percent increase in the constraint value, but there was no significant impact on coverage. Figure 6 show the change in location selection. The change in location is because the model seeks for higher values of transportation accessibility. However some of the locations are selected even though they do not comply with the constraint, due to mandatory full coverage constraint.

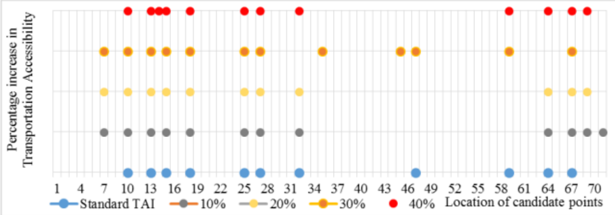

Fig. 6 Sensitivity analysis for transportation accessibility for 200 Km

5. CONCLUSION

The study determines the optimal number and location of warehouses utilizing the maximal covering location problem (MCLP) as an integer task. The optimal number of warehouses was calculated for different values of coverage distance and their respective locations. Three different scenarios were considered to weigh the pros and cons of having larger number of warehouses versus larger coverage distance. In each case, the main concern is the desired service level, the higher the desired service level, the larger should be the number of warehouses and shorter should be the coverage distance and vice versa. The study also provides several alternative solutions so that decision maker can choose the one which will meet both the desired service level and the organizational resource constraint. While doing so the study assumes that if the relief items are maintained by the host country there will be significant decrease in response time which would enable access to relief materials sooner while also reducing problems related to unsolicited items delivered to the affected people and places. Sensitivity analysis was performed to see the impact of changing the number of warehouses to a fixed value and changing the values of additional constraints on the number of warehouses and their coverage. The number of warehouses and the geographical constraints were found to be important factors affecting overall location decision.

Determining optimal location for establishing warehouses where inventories of emergency relief items can be stored is only a first step in an effort to help build national resilience from preparedness perspective. The significance of this study and more specifically warehousing is highlighted from the recent survey made by authors. It would be worth to note that among the 15 of the most affected districts, 14 of them were among the ones considered vulnerable in this study, which proves that the data used in the study are a close approximate to reality. The contribution of the study is not only limited to determining the warehouse number and location for a disaster prone country like Nepal but also, to the data used in the study which includes, demand nodes, population density, transportation accessibility, human development index, disaster scenarios. This study is the closest we have in terms of application of academic research in real life, which is among one of the aspects lacking in terms of humanitarian field. Despite the attractive results, the contribution of this study in terms of modelling and solution technique is limited except for the additional constraints included.

The model used in this study can be replicated for other vulnerable countries too with slight modifications. The applicability of the model is not only limited to determining warehouse location for prepositioning inventories for disaster relief distribution, but also to determine the location for search and rescue centers with some adjustments and improvisation. With minor modifications, the same technique can also be applied for determining facility location for both military and civilian purposes, public facilities like fire station location, and health center location etc.

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