Planning and Optimization of a Post Disaster Multi-Echelon Humanitarian Logistics Network: A Case Study in Bangladesh Perspective

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Abstract

Disaster planning and management has always been challenging for the relief agencies of the underdeveloped counties, since they usually do not have the well organized and well-funded system in place, like the developed counties. The models developed in the previous literatures either did not address all the relevant logistics issues or are often too complicated to be utilized by the underdeveloped countries. To mitigate the casualties caused by disastrous events, post disaster planning is very important. This research has developed a simple but inclusive multi-objective post disaster logistics planning model to addresses issues like distribution of relief commodity and medical supplies, staffing of medical facilities, evacuation of wounded people to the medical facilities, vehicular and transportation management, unsatisfied demands at affected locations etc., while maintaining service equity. The applicability of the proposed model has been tested via a real-world case study based on the recurrent flash flood problem in the Sylhet district of Bangladesh. A Branch-and-Cut algorithm has been used via CPLEX platform to solve the developed linear integer programming model. Results have been demonstrated both numerically and graphically to aid the decision maker to properly visualize the solutions, which has offered several important managerial implications and insights on the post disaster management. This way the proposed research is expected to help the decision makers to plan an efficient and effective post disaster logistics network to minimize human suffering, wastage of relief goods, and associated operational costs.

Keywords
Humanitarian logistics, Multi-objective optimization, Post-disaster planning, Integer programming, CPLEX

1. Introduction
Climate change is an undeniable fact that has already affected the world in adverse ways. Some of the most devastating consequences of climate change are the occurrence of the barrage of natural disasters of various kinds in the recent years. Natural disasters like floods, earthquakes, cyclones, tornedoes, landslides etc. have become very common occurrences now a days (Kovács and Falagara 2021, Kara and Savaşer 2017). Developed western countries often have very well-organized disaster response strategies, which usually results in lesser havoc. However, underdeveloped countries are still straggling in this area. Due to the lack of proper planning and management, disasters cause utmost havoc and devastation in those regions of the world. Hence, proper disaster planning and response system development is very crucial for them to minimize the damages caused by these disasters on their already poverty-stricken population. This research aims to develop a well-designed post disaster logistic model that can greatly reduce human suffering in case of a catastrophic events and thus aid the decision makers to mitigate the impacts of the disaster.
In the post disaster period, several important needs arise among the affected population. Need for food, water, medicines, and medical care are some of the most important needs. Sometimes, decision makers stock or preposition some non-perishable relief goods in the regional Distribution Centers (DCs) to utilize them later in the post disaster period. Such prepositioning is often necessary to reduce load on the logistics network in the post disaster period. While

planning for the distribution of relief goods, those prepositioned relief goods must be considered as well. The flow of the relief goods from the supplier to the DCs and from the DCs to the affected area must be properly balanced to make sure there is neither much unsatisfied demand, nor much unutilized commodities. Large quantity of unsatisfied demands are indicators of poor performance by logistics and aid management system, while large quantity of unutilized commodities indicates higher wastage or spoilage. Hence, both of them must be minimized to improve the performance of the aid operation. The number of paid and unpaid (volunteers) medical workers must be balanced among different nodes to utilize their full potential. Moreover, it is very important to make sure that the equity in distribution is properly maintained, i.e., no specific demand node gets priority over other nodes during the relief distribution. All these issues have not been addressed in a single simple model in any of the previous literatures. Therefore, the proposed research develops a post-disaster distribution, service, and evacuation model that intends address all the above-mentioned issues and can provide decision makers powerful insights on the management of post disaster humanitarian logistics network. Given the simplicity of the developed model, it can be easily utilized by the underdeveloped countries with limited computational resources as well.

This research has used the recurrent flash flooding problem in Sylhet district of Bangladesh to develop a test case to check the effectiveness of the proposed models. During heavy monsoon, a deluge of water rushes from the hilly upstream region through the major rivers of the Sylhet district, which carry that water through the down-steam regions of district and floods the vast surrounding areas. Most of those inundated areas are predominantly agricultural areas and flood destroys all the crops. People living on those area mainly subsist on the crops they grow themselves. Therefore, people will starve to death, if the relief agencies don't promptly respond to their needs for relief after the flooding. The model proposed in this research is expected to help the decisionmakers in the underdeveloped countries to efficiently plan relief logistic network, so that this human suffering can be minimized.

To solve the developed multi-objective integer programming model, a Branch-and-Cut algorithm has been utilized via CPLEX platform. Obtained results have been demonstrated both numerically and graphically in the results section of this paper for an enhanced visual understanding of the solutions. In short, this research work intends to achieve the following objectives:

- To develop the research in such a way so that it can address most of the post disaster logistics issues in a single one step model, which can easily be utilized by the underdeveloped countries with limited computational capabilities
- To determine the optimum quantity of goods that needs to be transported from different supplier locations to different DC locations and from different DC locations to different affected areas or demand nodes
- To make sure that the unsatisfied demands and number of unserved wounded people at the affected areas are minimized
- To make sure proper service equity is ensured, i.e., no certain affected area gets priority over other affected areas
- To solve the model to optimality by using an exact optimization method. In this research, a Branch and Cut algorithm has been used for this purpose.
- To show the obtained results both numerically and graphically for the ease of visualization and understanding by the decision makers

The rest of the paper has been organized as following: Section 2 of this paper contains a brief literature review with background, and related research contributions. Section 3 demonstrates the developed the model and discusses the case study. Section 4 discusses the solution methodology used to solve the problem, and Section 5 discusses the obtained results and insights obtained from the results. Section 6 discusses the implications of this research. Finally, Section 7 discusses the conclusions and recommends some directions for the future research.

2. Literature review

In recent years, the area of post disaster management has been explored by many researchers. Mete and Zabinsky (2010) developed a two-stage mixed-integer programming model for the planning of storage and distribution of medical supplies after a disastrous incident. Rottkemper et al. (2012) proposed a bi-objective mixed-integer programming model for coordinating the relief distribution operation in case of onset of a disastrous event. The objective of their research was to minimize the total unsatisfied demands and the cost of operation. Berkoune et al. (2012) developed a multi-commodity and multi-depot routing problem, which aims to minimize the total duration of all necessary trips during relief logistics operation. Özdamar and Dimir (2012) developed a capacitated network flow model for post disaster relief logistics activity. The model aimed at minimizing the total time required for the relief goods distribution and wounded people evacuation. Abounacer et al. (2014) developed a multi-objective location-transportation model for post-disaster planning. The objectives of the model were to minimize the total transportation time, minimize total number of staffs or operatives required to properly carry-out the relief operation and minimize total amount of the unsatisfied demands across all demand points. Pillac, et al. (2015) developed a mixed integer evacuation planning model to help the decision makers in case of large-scale evacuation and related mobilization of resources. The model objective was to maximize the total number evacuees who reached to safety and minimize the total time required for evacuation. Swamy et al. (2017) developed a two-stage hurricane evacuation planning model using public transportation, which involved determining appropriate pick-up location selection, assignment of shelters, assignment of vehicle for transportation, etc. Kimms and Maiwald (2018) developed a bi-objective urban evacuation planning and disaster response model, which tried to minimize the overall impact of the hazard and to maximize the network capacity. Baryam and Yaman (2018) developed a two-stage post-disaster evacuation planning model. Their model aimed to help the decision makers to determine appropriate locations to set up the shelters, assigning evacuees to the nearest shelter, selecting the shortest route to get to those shelters etc. Ghasemi, et al. (2019) proposed a multi-objective, multi-period post-disaster response planning model. The model aimed to help the decision makers to determine appropriate locations for setting up the relief centers and the hospitals and manage the flow of injured people and commodities to the facilities.

From the literature discusses above, it is evident that post disaster response involves a broad spectrum of activities including transportation of supplies (food, water, medicine), quick evacuation of wounded people and transporting them to temporary or permanent shelters for medical attention, vehicle management for the transportation related activities, ensuring service equity, management of medical service providers, minimization of unsatisfied demand and unserved wounded people etc. However, so far, there has not been much research that has addressed all these operational issues of post disaster management in a single simpler model, which even an underdeveloped country with limited computational resource can easily utilize. This presents a clear research gap, which this research intends to address.

As for solution techniques, to solve the developed models, several researchers (Dirk et al. 2020, Briskorn et al. 2020, Cao et al. 2017) utilized Branch and bound algorithm to solve their mixed integer humanitarian logistics problem. Özdamar and Demir (2012) solved their relief logistics model by using a k-means partitioning heuristic. Kristianto et al. (2014) used a fuzzy shortest path algorithm to solve their logistics model. Besides these, Epsilon-constraint method (Kimms and Maiwald 2018, Abounacer et al. 2014), Lagrangian L-shaped method (Rawls and Turnquist 2010), Goal programming (Chong et al. 2019), Grasshopper Optimization Algorithm (Abazari et al. 2021), etc. methods have also been utilized by various researchers in this area. Thereby, it is evident that different researchers have used different approaches to solve their proposed models, which mainly appears to be dependent on the type of the models that they have formulated and the level of flexibility and accuracy that they desired in their outputs. Given that, a Branch and Cut algorithm has been used to solve the proposed model in this research, since it has been successfully used in many previous research (Wolfinger and Salazar-González 2021, Arslan et al. 2020, Nikoo et al. 2018) to solve integer or mixed-integer programming problems to optimality.

3. Problem Description and Test Case

The proposed model is basically a post disaster distribution, service, and evacuation model. In the post disaster stage, the information about the locations and capacities of the DC warehouses and the tentative amount of the relief goods that was prepositioned in the pre-disaster stage are already known. Hence, these information will be used as inputs to this model. The model determines the amount of different types of relief commodities to be transported from the suppliers to the DC and the from DC to the affected areas, number of wounded peoples to be transported to different medical tents set up at DC locations, amounts of medical supplies brought from suppliers to DCs, required number of medical personnel at DCs to serve the wounded people, number of trips required between different nodes to do these transportations of goods and wounded people, etc. information will be obtained from the proposed model as integer outputs.

3.1 Model Formulation and Description

Several assumptions have been made while developing this model. For instance, data on facility location, capacity of those facilities and the amount of prepositioned goods at DC locations are already known in the post disaster stage. Hence, the developed model will use these data as inputs. The model also determines the number of trips required from the vehicles of different capacity to transport relief goods and wounded people. In case of the transportation of medical supply, volume of medical supplies is difficult to assume, and they usually are not in large volume (as they are not used for serious treatment here, just for primary care). Hence, this small volume of medical supplies can easily be transported along with the relief goods, without any significant change in the network design. Relief goods will be transported and distributed as unit loads only. Table 1 contains the list of sets, parameters, and the variables of the proposed model.

Table 1: Model sets, parameters, and variables

Model Sets

The sets of the proposed model are as follows

I	Set of supplier nodes (indexed by *i*)
J	Set of potential Distribution Center (DC) nodes (indexed by *j*)
K	Set of Affected Area (AA) nodes (indexed by *k*)
M	Set of relief goods types (indexed by *m*)
N	Set of the types of wounded people, who needs medical evacuation (indexed by *n*)
H	Set of capacity types of the DC warehouses (indexed by *h*)
Q	Set of vehicle capacity types required for relief items transportation (indexed by *q*)
E	Set of vehicle capacity types required for wounded people transportation (indexed by *e*)

Decision variables

All the variables are integers in this model

EV_j	Number of voluntary (unpaid) medical personnel at DC location *j*.
E_j	Number of paid medical personnel at DC location *j*.
MS_{jn}	Number of units of medical supplies to serve type n wounded people, who will be served in temporary medical facilities in DC node j.
S_{ijm}	Amount (number of pallets) of relief good of type *m* needed to be transported from supplier node *i* to DC node *j*
X_{jkm}	Amount (number of pallets) of relief good of type *m* needed to be transported from DC node *j* to affected area node *k*
Y_{kjn}	Number of wounded people of type *n* needed to be transported from affected area node *k* to DC node *j*
Z_{km}	Number of pallets of shortage of relief good type *m* at affected area *k*
Z_{kn}	Number of unserved wounded people of type *n* at affected area *k*
V_{ijq}	Number of trips required by vehicle type *q* for relief good transportation from supplier node *i* to DC node *j*

Model Parameters

All volume units are in cubic meter (m^3) and all money amounts are in unit of US$1000

SL	Remuneration for each temporary medical personnel
MC_n	Cost of each unit of medical supply to serve type n wounded people, who will be served in temporary medical facilities in DC nodes.
AMS_{in}	Available medical supply at supply node *i* to treat type *n* wounded people
λ	Acceptable patient to medical personnel ratio
TEV	Available number of total voluntary unpaid medical first aid workers
T1	Cost of post disaster transportation per km for per unit of medical supplies of type *n* transported from supplier *i* to DC *j*.
T2	Cost of post disaster transportation per km for per unit of relief goods transported from supplier *i* to DC *j*.
T3	Cost of post disaster transportation per km for per unit of relief goods transported from DC *j* to affected area *k*
T4	Cost of post disaster transportation per km for wounded people transferred from affected area *k* to DC *j*
LE_{ij}	Actual pre-selected path distance from supplier node *i* to DC node *j*.
LE_{jk}	Actual pre-selected path distance from DC node *j* to affected area node *k*
AV_q	Maximum allowable number of trips via type *q* vehicle.
AV_e	Maximum allowable number of trips via type *e* vehicle.
WH_j	Warehouse capacity at DC location *j*.
D_{km}	Estimated demand of relief good of type *m* at affected area *k*.
D_{kn}	Estimated demand of transporting wounded people of type *n* from affected area *k*.
Cap_q	Volume capacity of cargo vehicle type *q*.
Cap_e	Volume capacity of vehicle type *e*.
WL_q	Weight capacity in kg for type *q* vehicle.
WL_e	Weight capacity in kg for type *e* vehicle.
U_m	Volume of relief good of type *m*.
W_m	Weight of relief good of type *m*.
W_n	Average weight wounded people of type *n*..
C_{im}	Available capacity of supplier *i* for relief good *m* at post disaster period
SFR_{im}	Fraction of the relief good *m* remains usable at supplier *i* at post disaster period
IN_{jm}	Amount of prepositioned relief good of type *m* at DC node *j*
WM_n	Unit weight of medical supply type *n* in kg.

V_{jkq}	Number of trips required by vehicle type q for relief good transportation from DC node j to affected area node k	VF_q , VF_e	Fixed cost associated with each trip made via vehicle type q and e respectively
V_{kje}	Number of trips required by vehicle type e for transportation of people from affected location node k to DC node j.	θ_1 , θ_2	Very small fractional numbers to ensure service equity at the affected areas; usually defined by the decision maker
		τ_1 , τ_2	These are the penalty cost values for unsatisfied relief goods demand and unserved wounded people, respectively.

The objective functions of the model are given as (1)—(5).

Objective functions,

Max $\sum_j EV_j$ (1)

Min SL . $\sum_j E_j +$ T1. $\sum_i \sum_j \sum_n$ LE$_{ij}$. MS_{ijn} (2)

Min T2. $\sum_i \sum_j \sum_m$ LE$_{ij}$. S_{ijm} + T3. $\sum_j \sum_k \sum_m$ LE$_{jk}$. X_{jkm} + T4. $\sum_j \sum_k \sum_n$ LE$_{jk}$. Y_{kjn} (3)

Min $(\tau_1 . \sum_k \sum_m \frac{Z_{km}}{D_{km}} + \tau_2 . \sum_k \sum_n \frac{Z_{kn}}{D_{kn}})$ (4)

Min $\sum_i \sum_j \sum_q VF_q . V_{ijq} + \sum_j \sum_k \sum_q VF_q . V_{jkq} + \sum_k \sum_j \sum_e VF_e . V_{kje}$ (5)

The constraints of the model are given below as (6)—(36).

Medical supply and staffing constraints

$\sum_i MS_{ijn} \geq \sum_k Y_{kjn}$ $\forall j \in J, n \in N$ (6)

$\sum_j MS_{ijn} \leq AMS_{in}$ $\forall i \in I, n \in N$ (7)

$\lambda (EV_j + E_j) \geq \sum_k \sum_n Y_{kjn}$ $\forall j \in J$ (8)

$\sum_j EV_j \leq$ TEV (9)

Capacity constraints

$\sum_j S_{ijm} \leq C_{im} . SFR_{im}$ $\forall i \in I, m \in M$ (10)

$\sum_k X_{jkm} \leq \sum_i S_{ijm} + IN_{jm}$ $\forall j \in J, m \in M$ (11)

$\sum_i \sum_m S_{ijm} . U_m + \sum_m IN_{jm} . U_m \leq WH_j$ $\forall j \in J$ (12)

Demand constraints

$\sum_j X_{jkm} \leq D_{km}$ $\forall k \in K, m \in M$ (13)

$\sum_j Y_{kjn} \leq D_{kn}$ $\forall k \in K, n \in N$ (14)

Unsatisfied demand and unserved people constraints

$Z_{km} = D_{km} - \sum_j X_{jkm}$ $\forall k \in K, m \in M$ (15)

$Z_{kn} = D_{kn} - \sum_j Y_{kjn}$ $\forall k \in K, n \in N$ (16)

Vehicular capacity constraints

$\sum_q V_{ijq} . WL_q \geq \sum_m S_{ijm} . W_m + \sum_n MS_{ijn} . WM_n$ $\forall i \in I, j \in J$ (17)

$\sum_q V_{jkq} . WL_q \geq \sum_m X_{jkm} . W_m$ $\forall j \in J, k \in K$ (18)

$\sum_e V_{kje} . WL_e \geq \sum_n Y_{kjn} . W_n$ $\forall k \in K, j \in J$ (19)

$\sum_q V_{ijq} . Cap_q \geq \sum_m S_{ijm} . U_m$ $\forall i \in I, j \in J$ (20)

$\sum_q V_{jkq} . Cap_q \geq \sum_m X_{jkm} . U_m$ $\forall j \in J, k \in K$ (21)

Maximum availability constraints

$\sum_i \sum_j V_{ijq} + \sum_j \sum_k V_{jkq} \leq AV_q$ $\forall q \in Q$ (22)

$\sum_k \sum_j V_{kje} \leq AV_e$ $\forall e \in E$ (23)

Equity constraints

$\frac{Z_{km}}{D_{km}} \leq \theta_1$ $\forall k \in K, m \in M$ (24)

$\frac{Z_{kn}}{D_{kn}} \leq \theta_2$ $\forall k \in K, n \in N$ (25)

Non-negativity constraints

$EV_j \geq 0$ $\forall j \in J$ (26)

$E_j \geq 0$ $\forall j \in J$ (27)

$MS_{ijn} \geq 0$ $\forall i \in I, j \in J, n \in N$ (28)

$S_{ijm} \geq 0$ $\forall i \in I, j \in J, m \in M$ (29)

$X_{jkm} \geq 0$ $\forall j \in J, k \in K, m \in M$ (30)
$Y_{kjn} \geq 0$ $\forall k \in K, j \in J, n \in N$ (31)
$Z_{km} \geq 0$ $\forall k \in K, m \in M$ (32)
$Z_{kn} \geq 0$ $\forall k \in K, n \in N$ (33)
$V_{ijq} \geq 0$ $\forall i \in I, j \in J, q \in Q$ (34)
$V_{jkq} \geq 0$ $\forall j \in J, k \in K, q \in Q$ (35)
$V_{kje} \geq 0$ $\forall k \in K, j \in J, e \in E$ (36)
All variables are positive integers here

The proposed model has five objectives. Objective (1) aims to maximize the utilization of the volunteering medical personnel within the available limit. Objective (2) minimizes the total amount of salary paid to the non-volunteer medical personal and the total transportation cost of medical supplies to different DC nodes. Objective (3) minimizes the total transportation cost of all relief goods and wounded people. Objective (4) minimizes the total unsatisfied demands for all relief goods and the total number of unserved wounded people in different affected area nodes. Objective (5) minimizes the fixed cost associated with total number of trips required for the transportation of all relief goods and wounded people to and from different network nodes.

There are a total of 31 constraints in this model. The first four constraints, constraint (6) to (9), are medical supply and staffing constraints. Constraint (6) ensures that the total amount of medical supplies brought to a particular DC medical center is adequate to serve all the wounded people, who are coming in there from different affected areas. Constraint (7) ensures that the total amount of medical supplies brought to the DC medical centers, don't exceed the available supplier capacity limit. Constraint (8) ensures that each DC medical center location has sufficient number of medical staffs, volunteer or non-volunteer, to serve all the wounded people who are being transported into that particular DC location for medical attention. Constraint (9) ensures that the total number of volunteer medical staffs assigned to different DC medical centers, do not exceed the total available volunteer limit. Constraint (10) - (12) are capacity constraints. Constraint (10) ensures that the amount of relief goods transported in from different suppliers to the DC locations, stays within the capacity limit of that supplier for that specific good. Constraint (11) ensures that the amount of relief goods transported from a DC location to the affected are locations, do not exceed the amount of relief goods that has been brought in from different suppliers to that DC location, plus the amount of relief goods that has already been prepositioned in that DC location, during the pre-disaster planning phase. Constraint (12) ensures that the total amount of goods that are being received in different DC locations, does not exceed the capacity of that specific Distribution Center facility.

Constraint (13) and (14) are demand constraints. Constraint (13) ensures that the total amount of goods that are being transported from any DC location to the affected area locations, is not more than the reported demand for that good in that specific affected location, in order to avoid wastage of relief goods. Constraint (14) ensures that the total number of wounded people that are being transported into the different DC medical center locations for medical attention, from a particular affected area, is not more than the reported number of wounded people in that specific affected node. Constraint (15) and (16) are equality constraints. Constraint (15) basically defines the amount of unsatisfied demand variables for each affected area node, while Constraint (16) defines the number of unserved wounded people variables for each affected area node. Constraint (17) - (21) are vehicular capacity constraints. Constraint (17) ensures that the weight of the total amount of goods that are being transported from any supplier location to any of the DC location, using a specific vehicle type, does not exceed the safe weight carrying limit of that specific vehicle types in each respective case. Constraint (18) ensures that the weight of the total amount of goods that are being transported from any DC location to any of the affected area location, using a specific vehicle type, does not exceed the safe weight carrying limit of that specific vehicle types in each respective case. Constraint (19) ensures that the weight of the total number of wounded people who are being transported from any affected area location to the DC locations for medical attention, using a specific vehicle type, does not exceed the safe weight carrying limit of that specific vehicle types in each respective case. Constraint (20) ensures that the volume of the total amount of goods that are being transported from any supplier location to any of the DC locations, using a specific vehicle type, does not exceed the safe volumetric carrying limit of that specific vehicle types in each respective case. Constraint (21) ensures that the volume of the total amount of goods that are being transported from any DC location to any of the affected area locations, using a specific vehicle type, does not exceed the safe volumetric carrying limit of that specific vehicle types in each respective case. Constraint (22) and (23) are called maximum availability constraints. Constraint (22) ensures that the total number of trips that are being performed using a certain type of vehicle for transporting relief goods to the different nodes of the network, does not exceed the maximum allowable number of trips that are permitted by using that specific type of vehicle. Similarly, constraint (23) ensures that the total number of trips that are being performed using a certain type of vehicle for transporting wounded people, from different affected areas to different DC medical center nodes, does not exceed the maximum allowable number of trips that are permitted by using that specific type of vehicle. Constraint (24) and (25) are equity constraints for unsatisfied demand and unserved wounded people respectively at various demand points, which makes sure that each affected area node gets equal priority. Constraint (26) to (36) declares that all the variables in this model are positive numbers and integers. The model hence itself is an integer programming model.

3.2 Sylhet test case

To test the efficacy of the model developed in this research, a test case based on the flash flood problem in the Sylhet region of Bangladesh has been used, which happens to be in the underdeveloped part of the world. The test case data used in this research has been mostly obtained from the test case used in Bari et al. (2021). There are some other parameter data, which are also required for this for this study. For instance, transportation cost for both type of medical supplies has been considered to be $9 per unit /km. Weight of each unit of medical supplies of either type has been considered to be 4 kg. Acceptable patient to medical personnel ratio has been taken as 3. Average weight of a wounded person has been considered as 85 kg. Total number of available volunteering (unpaid) medical personnel has been assumed to be 35. It has been assumed that supplier had 90% of their usual capacity available during the post disaster period. Fixed cost for each vehicle trip has been considered 1.2 times higher for the bigger category (vehicle type 2) than the smaller one (vehicle type 1). The salary for each paid (non-volunteer) medical personnel for a 10 days' work period, has been considered to be $1000 per person.

4. Solution Methodology

The proposed model in this research is a multi-objective integer programming model. Scalarization technique has been used in this study, which allows a multi-objective problem to be handled like a single objective one, by multiplying each objective with a suitable and reasonable weight and then adding them together. Weights are usually defined by the user (decision makers) or the Subject Matter Experts (SMEs). Users are free to manipulate the weights in this method, based on the relative importance of the objectives from their point of view.
One of the widely used integer programming problem solving methods is Branch and Cut algorithm. In this research, since the developed model is an integer programming problem, the Branch and Cut algorithm has been utilized here, via CPLEX platform to solve it.

5. Results and Discussion

Using the numerical test case, the effectiveness of the developed model has been demonstrated in this section. The model has been solved by using Branch and Cut Algorithm in CPLEX solver v12.8 platform. The computer that has been used to run the solver had a 2.65 GHz processor and 4 GB of RAM. With the default settings, CPLEX requires only 1.86 minutes to solve the problem.

The weight assigned to each objective is quite important, as the weight value significantly influences the final optimized objective values and the optimal solution. The model has five objectives. In this instance, the authors have considered the weight values for the objectives as 50, 15, 10, 190 and 75 respectively, (as suggested by the SMEs) for which the obtained objective values are 35, $106863, $220881, $0 and $110400 respectively. The decision variable values for this particular solution, obtained from CPLEX, are shown in the Table 2. Only the variables with non-zero output values have been displayed in the tables. All decision variables are positive integers in this model.

Table 2: Results (decision variable values) obtained for the post disaster model, using CPLEX

Number of paid medical personnel to be dispatched at DC locations	
DC location	Num. of personnel
Sylhet Shadar	9
West Barokut	60

Number of voluntary (unpaid) medical personnel to be dispatched at DC locations	
DC location	Num. of personnel
Horipur	10
Sylhet Shadar	25

Number of units of medical supplies to transport to the temporary medical facilities in DC nodes, to serve the wounded people

Supplier Node	DC Node	Medical Supply Type	Quantity In units
Bodikuna	Horipur	1	25
Bodikuna	Horipur	2	3
Bodikuna	Sylhet Shadar	1	63
Bodikuna	Sylhet Shadar	2	39
Phulbari	West Barokut	1	99
Phulbari	West Barokut	2	80

Amount (in units) of relief goods needed to be transported from supplier node to DC node

Supplier Node	DC Node	Goods Type	Quantity In units
Bodikuna	Sylhet Shadar	Food	98
Bodikuna	Sylhet Shadar	Water	43
Phulbari	West Barokut	Food	147
Phulbari	West Barokut	Water	83

Number of wounded people needed to be transported from affected area node to DC node

AA Node	DC Node	Wounded People Type	Number
Bishwanath	Sylhet Shadar	1	29
Bishwanath	Sylhet Shadar	2	18
Gowainghat	Sylhet Shadar	1	34
Gowainghat	Sylhet Shadar	2	21
Kanaighat	Horipur	1	25
Kanaighat	Horipur	2	3
Kanaighat	West Barokut	2	14
Kharavora	West Barokut	1	41

Amount (in units) of relief goods needed to be transported from DC node to affected area node

DC Node	AA Node	Goods Type	Quantity In units
Horipur	Kanaighat	Food	19
Horipur	Kanaighat	Water	9
Sylhet Shadar	Bishwanath	Food	46
Sylhet Shadar	Bishwanath	Water	21
Sylhet Shadar	Gowainghat	Food	58
Sylhet Shadar	Gowainghat	Water	26
West Barokut	Kanaighat	Food	14
West Barokut	Kanaighat	Water	10
West Barokut	Kharavora	Food	48
West Barokut	Kharavora	Water	29
West Barokut	Beanibazar	Food	62
West Barokut	Beanibazar	Water	34
West Barokut	Fenchuganj	Food	53
West Barokut	Fenchuganj	Water	27

Number of trips required by different types of vehicles for relief good transportation from supplier node to DC node

Supplier Node	DC Node	Vehicle Type	Number of trips
Bodikuna	Horipur	1	1
Bodikuna	Sylhet Shadar	2	12
Phulbari	West Barokut	1	2
Phulbari	West Barokut	2	18

Kharavora	West Barokut	2	26				
Beanibazar	West Barokut	1	31				
Beanibazar	West Barokut	2	24				
Fenchuganj	West Barokut	1	27				
Fenchuganj	West Barokut	2	16				
Number of trips required by different types of vehicles for relief goods transportation from DC node to affected area node				Number of trips required by different types of vehicles for transportation of wounded people from affected location node to DC node			
DC Node	AA Node	Vehicle Type	Number of trips	AA Node	DC Node	Vehicle Type	Number of trips
Sylhet Shadar	Bishwanath	1	1	Bishwanath	Sylhet Shadar	2	3
Sylhet Shadar	Bishwanath	2	5	Gowainghat	Sylhet Shadar	1	2
Sylhet Shadar	Gowainghat	2	7	Gowainghat	Sylhet Shadar	2	2
Horipur	Kanaighat	1	2	Kanaighat	Horipur	1	1
Horipur	Kanaighat	2	1	Kanaighat	Horipur	2	1
West Barokut	Kanaighat	2	2	Kanaighat	West Barokut	2	1
West Barokut	Kharavora	1	1	Kharavora	West Barokut	1	4
West Barokut	Kharavora	2	6	Kharavora	West Barokut	2	1
West Barokut	Beanibazar	2	8	Beanibazar	West Barokut	1	2
West Barokut	Fenchuganj	1	1	Beanibazar	West Barokut	2	2
West Barokut	Fenchuganj	2	6	Fenchuganj	West Barokut	1	1
				Fenchuganj	West Barokut	2	2

The logistics information obtained from Table 2 include number of paid and voluntary (unpaid) medical personnel to be dispatched at different DC locations, number of units of medical supplies to transport to the temporary medical facilities in DC nodes to serve the wounded people, amount (in units) of commodities needed to be transported from supplier node to DC node and from DC node to affected area node, number of wounded people needed to be transported from affected area node to DC node, number of trips required by different types of vehicles for relief goods transportation from supplier node to DC node and from DC node to affected area node, number of trips required by different types of vehicles for transportation of wounded people from affected location node to DC node, etc.

Figure 1 shows the flow of medical supplies from suppliers to DC locations (showed by the red directional arrows) and medical evacuation of the wounded people from affected areas to the medical facilities situated at the DC locations (showed by the blue directional arrows). In each box near the red directional arrows, the number on the top row and bottom row indicates the number of units of medical supplies transported for the wounded people of type 1 and 2 respectively and in each box near the blue directional arrows, the number on the top row and bottom row indicates the number of wounded people of type 1 and 2 transported respectively.

Figure 2 shows the flow of two types of relief goods, food and water, in units, to and from different nodes of the logistics network. In each box near the flow direction arrows, the number on the top row indicates the amount of food transported (in units), and the number on the bottom row indicates the amount of water transported (in units). These visual representations (Figure 1 and 2) have been provided here to enhance the apprehension of the obtained results by the decision-makers. This way, the results obtained from the developed model can provide the decision makers important insights about the design of the post-disaster humanitarians logistics network, while ensuring service equity and minimizing the unsatisfied demand for relief goods and unserved wounded people at the affected areas.

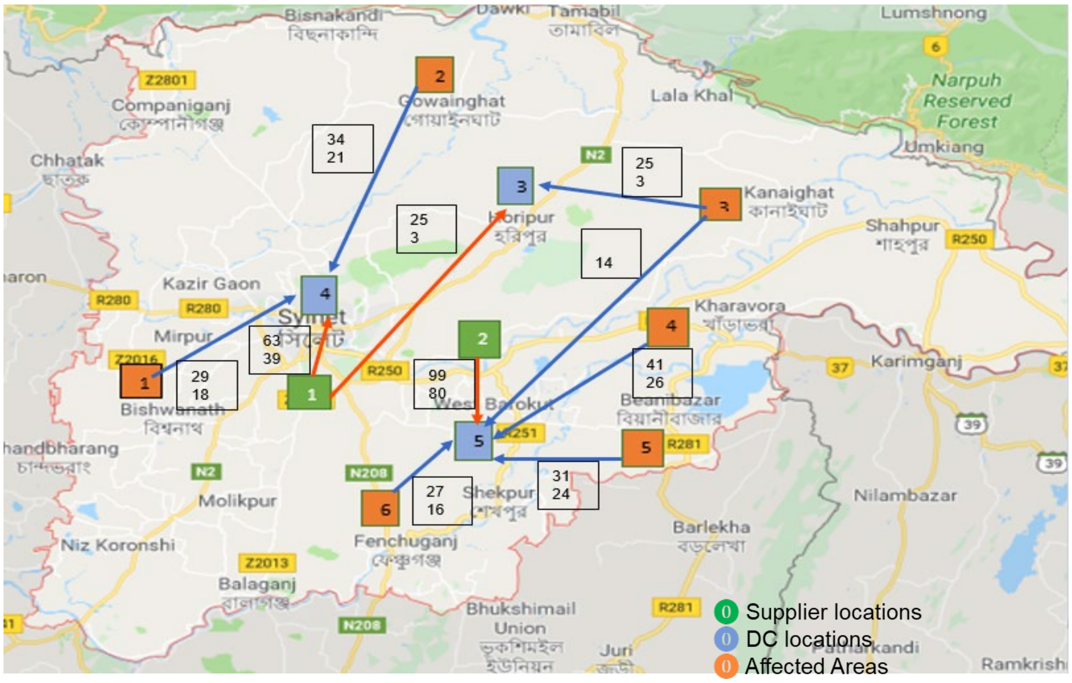

Figure 1: Medical supply and Medical Evacuation Flow result (in units)

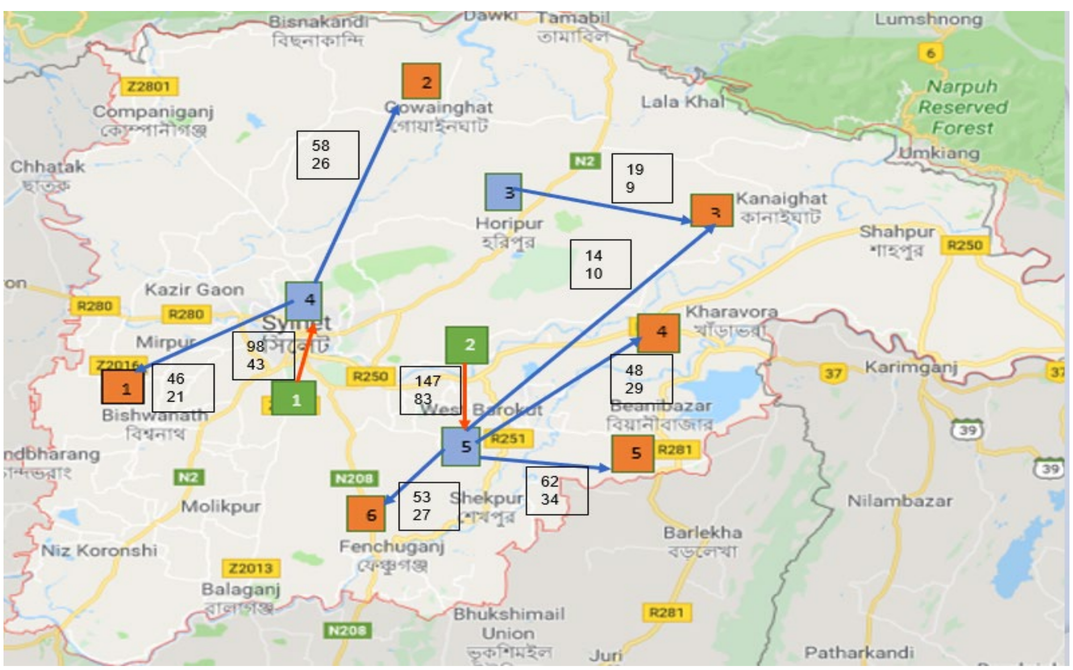

Figure 2: Relief goods Flow result (in units)

6. Research Implications

This research has several important research and managerial implications. For instance, most underdeveloped countries usually have limited computational capabilities, which prevents them from using large and complex logistics models like the ones developed countries use. The proposed research, thereby, has developed a single simpler model, which addresses most of the post disaster logistics issue, and can be utilized by the less developed countries with limited computational capability. Again, in the underdeveloped countries, the decision makers involved in managing the aid operations often do not possess higher level of technical apprehension. In such cases, graphically illustrated results can play important role to ensure proper implementation. Thereby, in this research, the results obtained from the proposed model has not only been demonstrated numerically, but also graphically, to ensure enhanced visual understanding of the decision makers.

The outputs obtained from this research are expected to assist in the development of efficient humanitarian logistics network, which will be able to achieve all the research objectives. Also note that the model developed in this research, being multi-objective in nature, gives decision makers more freedom to obtain the outputs that they desire from this model, through the scalarization technique. Since scalarization technique allows the decision makers to manipulate the objective weights very easily, they can always assign higher weights to the objective(s) that matters to them most and thus can obtain outputs, which can help them to develop the logistic network that they desire.

7. Conclusions and Recommendations

This research tried to address various relevant logistics issues, in order to design and optimize the post disaster logistics network. Making sure that adequate amount of aids reaches the demand points, evacuation of the wounded people from the affected area, vehicle management, ensuring equity of distribution, minimization of the overall operational cost, etc. are some of the important post disaster issues addressed in the study. This research used a recurrent flash flooding problem in the Sylhet District of Bangladesh as a test case, to check the effectiveness of the proposed model. The obtained results have been demonstrated both numerically and graphically in the result and discussion section for better visual understanding of the decision maker. The scalarization method has been utilized to handle multiple objectives in this research. The simplicity and ease of handing the weights of the associated objectives in scalarization method will give the decision makers more freedom to generate the solution that they desire. This research is thus expected to help the decision makers in many underdeveloped parts of the world, to plan and develop humanitarian logistics networks, which will not only minimize human suffering and operational cost but also will improve the overall efficiency of the entire aid logistics operation.

The research has several limitations, which can be addressed in future research attempts. For instance, more flexibility can be added to the model by incorporating 'robust optimization' methodologies in future. Time element has not been considered in this research. Hence, more responsive model can be developed from this research by incorporating time element into it. To make the model more realistic and flexible, a 'Fuzzy rule-based system' can be introduced into the future model design. Finally, a second case study can be added with the current one, to demonstrate the efficiency of the developed model to a greater extent.

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