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Optimization of an Emergency Relief Supply Model using Genetic Algorithm along with a Framework for Structuring Humanitarian Logistics Distribution Network

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ABSTRACT
The work is aimed towards formulating a disaster related emergency relief supply model of humanitarian relief goods and then solving with Genetic Algorithm and a more traditional approach of Linear Programming by considering collected data of a sample relief work. The model includes surpluses and shortages goods as variables and vehicle space as constraint. The constraints on demand, available minimum inventory and maximum labor level, load capacity of the vehicle, distribution center (DC) space all of which affect a relief distribution system directly used in the model. The model determines and optimizes the amount of relief supplies to be stocked, loads to be transported in each trip, labor level required, and the amount of surpluses and shortages goods so that the total cost is minimized. We compared results obtained by Genetic Algorithm and Linear Programming techniques. It is found that the Genetic Algorithm has better performance than the traditional Linear Programming. Finally a comprehensive framework for restructuring the transportation and distribution system of humanitarian relief items is provided.

Keywords: Optimization; Emergency relief logistics; Vehicle constraint; Penalty cost; Genetic algorithm.

1. Introduction

In recent years, the number of natural disasters has increased to great extent and the severity has grown. As a result some people lose their lives. Many people are deprived of food. The objective of disaster response in the humanitarian relief chain is to rapidly provide relief (emergency food, water, medicine and supplies) to areas affected by large-scale emergencies, so as to minimize human suffering and death. Cost control is a vital aspect in this regard although mostly it is ignored thinking about the non-profit nature of the work. But as the number of relief activities carried out has increased with the number of disaster occurrences, hence comes the importance of looking at budgetary aspects and optimization of goods to be distributed among sufferers [15].

Emergency relief supply problems are a class of optimization problems in the domain of operations research (Zhang et al. 2014) [18]. Classical relief supply problems are modeled as linear programming problems for minimizing the cost of delivering integral quantities of goods from m sources to n demand points while balancing supply and demand. In emergency situations, there can be various kinds and a huge number of supplies to be delivered in a cost effective, timely and efficient manner. The relief supply work is heavily constrained by bottlenecks, such as the availability of DC and vehicle space, maximum labor level and the capacity of transportation network [1, 3]. Also the available information is often uncertain, incomplete and inconsistent.

In order to solve optimization problems various methods have been implemented previously. Initially Linear Programming method was widely used [13]; but as the name suggests it was helpful only in case of solving linear problems. Later on with the advancement of several computational techniques many nature inspired algorithms have been developed. Genetic Algorithm is one of the older such algorithm. The proposed emergency relief supply model is solved with such Linear Programming (IPM) and Genetic Algorithm techniques [7, 10].

Chansiri Singhtaun (2015) proposes a mathematical model and examines the performance of an exact algorithm for a location-storage-transportation problem in humanitarian relief. The model determines the location of distribution centers in a relief network, the amount of relief supplies to be stocked at each distribution center and the vehicles to take the supplies to meet the needs of disaster victims under capacity restriction, transportation and budgetary constraints. Branch and bound algorithm is applied for these problems. The results show that this algorithm can solve problem sizes of up to three candidate locations [14].

Min-Xia Zhang, Bei Zhang and Yu-Jun Zheng (2014) conducted a survey of recent advances in bio-inspired meta-heuristics. They proposed a typical transportation planning problem and develop a new algorithm based on the BBO meta-heuristic for the problem. They demonstrated the competitive performance of BBO algorithm (which provided better result) with Linear Programming and GA algorithms [17].

Complex transportation planning may also involve multiple criteria or objectives, such as time and cost [2]. A simple approach to handle multiple objectives is to transform them into a single objective. For example, in the study of an urgent relief distribution problem, Liu and Zhao (2007) combined the objective functions of transshipment time and cost into a single one based on weight aggregation [8].

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The relief-distribution model by Tzeng et al. (2010) considers three objectives, including minimizing total cost, minimizing total travel time and maximizing satisfaction of fairness. The model is resolved by maintaining the third objective while transforming the first and second objectives into constraints [16].

Xie and Hu (2009) modeled an inventory routing problem in emergency logistics with fuzzy demands which are converted to deterministic demands by Yager's fuzzy number ranking method. They solve the problem using a heuristic algorithm that coordinates inventory control and route optimization for minimizing total cost. Computational result shows that the benefits can be obtained from the integration of inventory and routing [19].

Yan and Shih (2009) also integrated roadway repair and relief distribution along with storage function into a network flow model, which is a multi-objective, mixed-integer and multiple-commodity problem. They transformed it to a single-objective problem using the weighting method and developed a heuristic algorithm that first solves a sub-problem and then, repeatedly incorporates the remaining tasks, until a complete solution is obtained [20].

Jin Qin, Yong Ye, Bi-rong Cheng, Xiaobo Zhao and Linling Ni (2016) formulated an optimization model for emergency relief goods supply problem with insufficient supplies, in which the objective function was to minimize distribution and labor operation costs [12].

There have been many works on planning, routing, transportation, distribution and logistics management of humanitarian relief work system. Authors have signified one subsystem over another in most papers. An emergency relief supply network does not include only carrying goods to destination, but other aspects of purchasing, storing, transporting items to end users etc. all are part of the whole system. Thus more comprehensive work on realizing all aspects of humanitarian relief network is needed indeed.

2. Model Development

The proposed mathematical model is formulated with the help from various literatures; by creating a new objective function, adding budgetary constraints and changing the transportation cost function to make the problem match the real situation. The formulated model considers inventory cost, vehicle related cost, labor level and wage, finally penalty cost for both surpluses and shortages of relief goods. Both the penalty costs are borne by the suppliers due to incorrect amount of relief supplies to the distributors. These penalty costs incur because of the fact that the distributors can hardly delay the supplies as the demand needs to be fulfilled as quickly as possible. The sole purpose of this model is to identify the quantity of relief items to be stored, and determining the assignment of vehicles to supply the humanitarian aid items so as to minimize the total cost [4, 6, 7, 9 and 11]. Considering all these aspectsthe mathematical model is formulated as follows:

2.1 Notations:

IC_{nt} = Inventory cost per unit for nth item in period t (TK/unit)

IQ_{nt} = Inventory level for nth item in period t (Units)

VC_{nt}= Vehicle cost per unit for delivering nth item in period t (TK/unit)

VQ_{nt}= Vehicle loads to be delivered for nth item in period t (Kg's)

LC_{nt} = Labor cost to hire one worker for nth item in period t (TK/man-hour)

LQ_{nt} = Labor hours hired for nth item in period t (Man-hours)

$PC1_{nt}$ = Penalty cost per unit surplus for nth item in period t (TK/unit)

$PQ1_{nt}$ = Quantity of surpluses goods for nth item in period t (Units)

$PC2_{nt}$ = Penalty cost per unit shortage for nth item in period t (TK/unit)

$PQ2_{nt}$ = Quantity of shortages goods for nth item in period t (Units)

FD_{nt}= Forecasted demand for emergency supplies at demand point (Units)

IQ_{ntmin} = Minimum inventory level for nth item in period t (Units)

DCS_{nt} = Distribution center space per unit for nth item in period t (Sq meter)

DCS_{tmax} = Maximum distribution center space available in period t (Sq meter)

VQ_{ntmax}= Maximum vehicle loads to be delivered for nth item in period t (Kg's)

VS_{nt} = Vehicle space per unit for nth item in period t (Sq meter)

W = Maximum load capacity of the vehicle (Kg)

LQ_{ntmax} = Maximum labor hours hired for nth item in period t (Man-hours)

G_{nt} = Number of goods remaining in inventory after transportation (Units)

T_{work} = Time spent for loading, unloading and distributing emergency goods (Hours)

T_{travel} = Time spent by vehicle for travelling with emergency goods (Hours)

2.2 Formulation of Objective Function

(1) Inventory cost: $\sum_{n=1}^{N}\sum_{t=1}^{T} IC_{nt}\, IQ_{nt}$

(2) Vehicle cost: $\sum_{n=1}^{N}\sum_{t=1}^{T} VC_{nt}\, VQ_{nt}$

(3) Labor cost: $\sum_{n=1}^{N}\sum_{t=1}^{T} LC_{nt}\, LQ_{nt}$

(4) Penalty cost for surplus: $\sum_{n=1}^{N}\sum_{t=1}^{T} PC1_{nt}\, PQ1_{nt}$

(5) Penalty cost for shortage: $\sum_{n=1}^{N}\sum_{t=1}^{T} PC2_{nt}\, PQ2_{nt}$

Objective function,

Minimize,

$$Z = \sum_{n=1}^{N}\sum_{t=1}^{T} [\, IC_{nt}IQ_{nt} + VC_{nt}VQ_{nt} + LC_{nt}LQ_{nt} + PC1_{nt}PQ1_{nt} + PC2_{nt}PQ2_{nt}]$$

2.3 Formulation of Constraints

(1) Constraints on carrying inventory and distribution center space

The level of inventory should be typically more than forecasted demand so that there is no shortage of relief items. On the other hand, there should not be too much excess of stocks that the space of local warehouse is incapable of storing them.

$FD_{nt} \leq IQ_{nt}$ for □n,□t

$IQ_{nt} \geq IQ_{ntmin}$ for □n,□t

$\sum_{n=1}^{N}\sum_{t=1}^{T} DCS_{nt} * IQ_{nt} \leq DCS_{tmax}$ for □n, □t

(2) Constraints on load capacity and available space of vehicle

There are some restrictions on the total weight and the total volume of vehicles. The use of vehicles with relief goods for transportation actually distinguishes the proposed emergency model from the normal relief supply model. This signifies the necessity of quick response.

$VQ_{nt} \leq VQ_{ntmax}$ for □n,□t

$\sum_{n=1}^{N}\sum_{t=1}^{T} VS_{nt} * VQ_{nt} \leq W$ for □n, □t

(3) Constraints on labor level

Availability of labor for both inventory control and relief distribution is a crucial aspect in this type of activity. A maximum time for each vehicle type is imposed. Each vehicle trip is assumed to visit only one demand point at a time.

$LQ_{t} \leq LQ_{tmax}$ for □t

$LQ_{t} = T_{work} + T_{travel}$ for□t

(4) Constraints on surpluses and shortages goods

The amount of emergency supplies distributed to each demand point should be consistent with that of actual demands as much as possible, and both the excessive and insufficient distribution could affect the whole system.

$\sum_{n=1}^{N}\sum_{t=1}^{T} PQ1_{nt} \leq (IQ_{ntmax} - FD_{nt})$ for □n, □t

$\sum_{n=1}^{N}\sum_{t=1}^{T} PQ2_{nt} \leq G_{nt}$ for □n, □t

(5) Non negativity constraint

$IQ_{nt}, VQ_{nt}, LQ_{t}, PQ1_{nt}, PQ2_{nt} \geq 0$ for □n,□t

3. Data Description

We have used primary data (table 1 to table 6) for emergency relief goods which were collected from project integrate department under UNO office of Ishwarganj upazila, Mymensingh. There was a major flood occurred in several remote unions in the year 2017. The government used the UNO office and local food storage for providing relief goods to the victims. In our case, we have used the data of a relief work in which the humanitarian items were distributed among two demand points. Around 1000 people were served in the demand points. A truck of 4 ton of capacity was used as a transportation mode for 2 days of several trips. Penalty costs were incurred from the suppliers' side in this relief work. All the other relevant data are given as follows:

Here, Number of items, n = 3 (n_1= Water bottle, n_2= Rice sack, n_3= Dry food packet)

Number of period, t = 2 (days)

Table 1: Inventory Cost
(TK/unit)

n	t	
	1	2
1	4.5	4.5
2	30	30
3	12.85	12.85

Table 2: Vehicle Cost
(TK/unit)

n	t	
	1	2
1	2	2
2	1.8	1.8
3	8	8

Table 3: Labor Cost
(TK/man-hour)

n	t	
	1	2
1	80	100
2	80	100
3	80	100

Table 4: Penalty cost for Surplus
(TK/unit)

n	t	
	1	2
1	4.5	1.3
2	30	10
3	12.86	5

Table 5: Penalty cost for shortage
(TK/unit)

n	t	
	1	2
1	6.5	4.6
2	43	35
3	19	17.5

Table 6: Data for Constraints

Item	Period	
	1	2
FD_{1t} (Units)	3000	3800
FD_{2t} (Units)	420	660
FD_{3t} (Units)	855	1100
IQ_{1tmax} (Units)	3500	4000
IQ_{2tmax} (Units)	500	700
IQ_{3tmax} (Units)	975	1200
DCS_{1t} (Sq meter)	.045	.045
DCS_{2t} (Sq meter)	.075	.075
DCS_{3t} (Sq meter)	.05	.05
DCS_{tmax} (Sq meter)	200	200
VQ_{1tmax} (Kg's)	1500	1500

VQ_{2tmax} (Kg's)	2000	2000
VQ_{3tmax} (Kg's)	500	500
VS_{1t} (Sq meter)	.0036	.0036
VS_{2t} (Sq meter)	.0058	.0058
VS_{3t} (Sq meter)	.0045	.0045
LQ_{tmax} (Man-hours)	15	10
G_{1t} (Units)	63	80
G_{2t} (Units)	20	25
G_{3t} (Units)	50	58

Also, (I) W= 4000 Kg. (II) T_{work} = 7 Hours, 5 Hours; T_{travel} = 3.5 Hours, 4 Hours.

4. Result Analysis

In this case we use Genetic algorithm (GA) because it is more robust than conventional techniques. Unlike older systems, they do not break easily even if the inputs changed slightly, or in the presence of reasonable noise. GA is much more efficient in solving single objective situation and can solve both discrete and continuous problems.

Here all the programs were run in MATLAB 2013a in core (TM) i3 1.7 GHz pc with a 4 GB of RAM. The results Obtained from Genetic Algorithm and Linear Programming are tabulated in table 7.

Table 7: Result Obtained from Genetic Algorithm & Linear Programming

Variables	Genetic Algorithm	Linear Programming
IQ_{11}(Units)	3500	3500
IQ_{12}(Units)	4000	4000
IQ_{21}(Units)	500	1200
IQ_{22}(Units)	700	1400
IQ_{31}(Units)	975	975
IQ_{32}(Units)	1200	1200
VQ_{11}(Kg's)	1560	914
VQ_{12}(Kg's)	342	1609
VQ_{21}((Kg's)	800	1677
VQ_{22}(Kg's)	1276	1677
VQ_{31}(Kg's)	450	526
VQ_{32}((Kg's)	303	152
LQ_{11}(Man-hours)	10.50	10.50
LQ_{12}((Man-hours)	9	9
LQ_{21}(Man-hours)	10.50	10.50
LQ_{22}(Man-hours)	9	9
LQ_{31}((Man-hours)	10.50	10.50
LQ_{32}(Man-hours)	9	9
$PQ1_{11}$(Units)	115	0
$PQ1_{12}$(Units)	0	80
$PQ1_{21}$(Units)	67	10
$PQ1_{22}$(Units)	8	10
$PQ1_{31}$(Units)	56	94
$PQ1_{32}$(Units)	0	0
$PQ2_{11}$(Units)	0	16
$PQ2_{12}$(Units)	10	0
$PQ2_{21}$(Units)	6	0
$PQ2_{22}$(Units)	11	0
$PQ2_{31}$(Units)	26	0
$PQ2_{32}$(Units)	0	58
Obj. Function Value, Z (Tk.)	**103020**	**144920**

Results obtained from the two solution technique as shown in table 7, it is found that Genetic Algorithm approach is found to be inferior to IPM of Linear Programming technique as cost minimization being the main objective..

I. The demand, for 1st item (water bottle) was 3000 units in 1st period and 3800 units in 2nd period; for 2nd item (rice sack) was 420 units in 1st period and 660 units in 2nd period; for 3rd item (dry food packet) was 855 units in 1st period and 1100 units in 2nd period. Between the GA and LP, the major difference of total cost is incurred due to the significant variation of required quantity of rice sack to be stored. Also according to both the solution technique, there should be 3500 units and 4000 units of water bottle, 975 units and 1200 units of dry food packet inventoried in two periods. These values equal the maximum inventory level for the two items in each period.

II. In case of vehicle loads to be transported, the result obtained from GA shows that a significant larger loads of water bottle (1560 Kg's) should be transported in the first period. Whereas result from LP specifies to transport a relatively smaller loads of water bottle (914 Kg's) in the first period. On the other hand, GA assigns 800 Kg's and 1276 Kg's of rice sack for transportation in two periods respectively. But result from LP tells to transport 1677 Kg's of rice sack in both the periods which is quite larger.

III. The required labor level of 10.50 man-hours in the first period and 9 man-hours in the second period found out to be similar for both the solution technique.

IV. The highest number of surplus goods is found out to be water bottle (115 units) and dry food packet (94 units) with GA and LP respectively. These large surplus goods will help to response quickly for emergency supplies. But this also affects the cost minimization function adversely.

V. From the solution obtained from LP, it shows us that there is no shortage of rice sack in any of the period. It means that there is enough supply of units which will fulfill the demand. Again, the total number of shortage items is found out to be less with GA (53 units) than with LP (74 units). Hence we can say that GA provides solution in which there is better continuous supply of humanitarian items.

5. Framework for Relief Goods Transportation & Distribution

Humanitarian logistics is a complex environment which needs a better management of the relief operations. One of the key issues that relief organizations can address is the distribution network configuration which has a great impact on delivery time and costs; two major elements; whose central purpose is to rapidly provide aid to the affected population [5].

5.1 Identification of Critical Problems

i. Humanitarian supply chains lag behind in technology implementation, best practices, and operating efficiency.
ii. The associated large demands for relief products pose challenges to the logistics planning authorities with the level of uncertainty adding to the complexity.
iii. There may exist irregularities in the size, the timing, and the location of relief product demand patterns.
iv. In addition, disaster-driven supply chains are typically formed as incident-responsive ones with temporary configurations of disparate resources.
v. Lack of communication, information and collaboration with local forces, ignoring systematic network formulation, less response planning are other key elements that affect a humanitarian relief distributing system adversely.

The cause-effect diagram in figure 1 shows the specific reasons or causes which ultimately lead to adverse effect (e.g., excessive cost incurs, missed delivery, extra time requires).

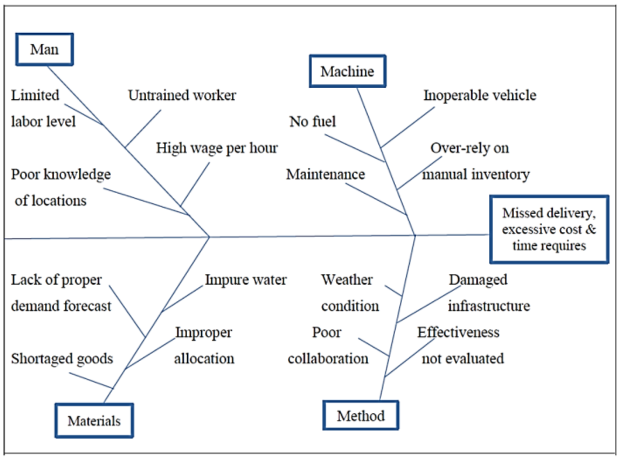

Figure 1: Cause-effect Diagram for Finding out Problems in Relief Work

5.2 Implication of a Structured Process

On the basis of reviewing of various literatures, data and result analysis, a proper structured relief distribution network is presented as shown in figure 2. This includes five different phases of operation:

Phase 1: Time varying relief demand forecast.

It should be taken into account the pre-disaster preparations including the procurement, the pre-positioning, and the storage of disaster relief items.

Phase 2: Affected area grouping.

There can be multiple area points which can be taken under a single network. The evaluation of number of disaster affected points, distances from the distribution center (DC), transportation mode available, and integration with locals.

Phase 3: Determination of distribution priority.

Depending on the damage scale of a disaster, various relief items, be it water, food or medicines of forecasted quantities are stored in a local DC. Major affected area point should be prioritized so that the most vulnerable people get first.

Phase 4: Group based relief distribution.

The affected areas can be grouped as individual demand points. The distance of a demand point from DC; along with level of necessity are considered while prioritizing relief materials distribution.

Phase 5: Dynamic relief supply.

This phase comes into picture when urgent relief demand is not satisfied. The shortaged items need to be procured quickly because of the emergency condition. There can also be excess of items which remain in inventory.

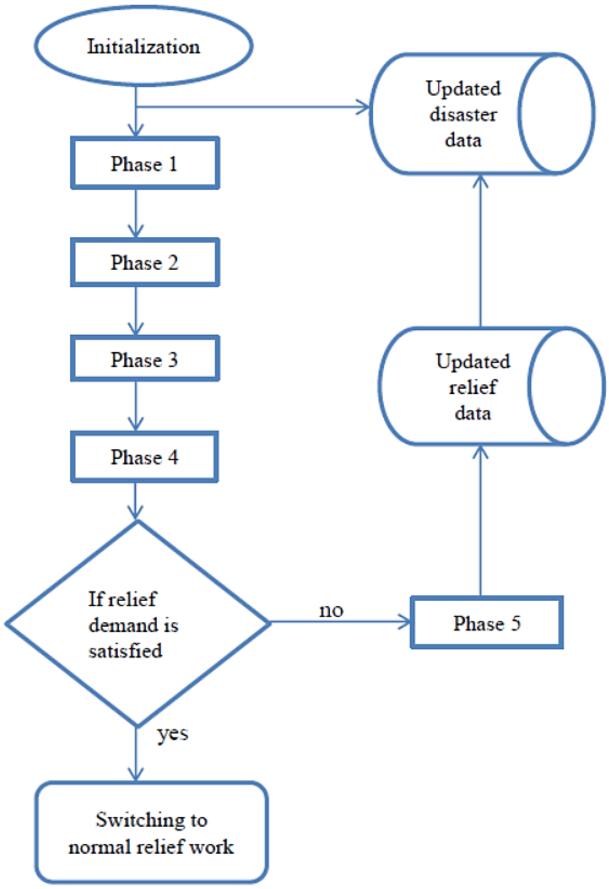

Figure 2: Relief Distribution System Design

6. Conclusions & Discussions

In this paper, we formulated an emergency relief supply model for real world situation. Then GA and Linear Programming method was implied to get optimized value. The optimized results from Genetic Algorithm and Linear Programming are Tk.103020 and Tk.144920 respectively. Since the mentioned problem is concerned about minimization of cost, the Genetic Algorithm shows better result here. Besides, the framework which is provided for structuring such relief work in phase-wise system; including from determining the amount of humanitarian logistics required to proper distribution of these items. However the model cannot be applied in case of situation where relief goods are not inventoried before go for transportation. Penalty cost for surplus and shortage per unit items were assumed to an extent because there was no absolutely accurate data available. Where cost minimization was our main purpose, the sensitivity analysis of the vital resource restrictions such as the number of DC's, the number of vehicles, etc. is an interesting area for future research.

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