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Optimum transportation of relief materials aftermath the disaster

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ABSTRACT

Purpose: Natural disasters disrupt not only the lives of individuals but also the functioning of society. Given the unpredictability of disasters and the uncertainty associated with them, preparation is the best way to mitigate and reduce the effects of the disaster.

Design/methodology/approach: The study presents a mathematical model in the form of a multi-objective linear programming problem for the relief distribution from the airports which minimizes the total operational cost as well as travel time. Further, the solution approach and analytical results have also been discussed.

Findings: The main aims at the preparedness stage are to identify and build infrastructures that might function as useful operation centres during a disaster. The study also provides decisions that include the type and number of vehicles for each affected location.

Research limitations/implications: Airports can function as centres for relief collection and distribution. However, relief operations carried out through airports are often subject to problems such as stockpiling. Further, various modes are available for the transport of relief supplies- air, water, and land transport modes primarily. While aircraft and helicopters are faster, their costs of operation are too high. Instead, trucks are economical but very slow as compared to aircraft.

Practical implications: The choice of model depends on many factors including the availability of vehicles, availability of routes, and criticality of situations. The choices made in turn affect the costs and the time of operations.

Originality/value: The model converts a disaster scenario into a demand-supply problem with the aim being to decide allocations at specified intervals of time.

Keywords: Disaster mitigation, Transportation, Linear programming, Demand and supply, Cost and time

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

The international federation of red cross and red crescent societies (IFRC) [1-3] defines a disaster as “a sudden, calamitous event that seriously disrupts the functioning of a community or a society and causes human, material, and economic or environmental losses that exceed the community’s or society’s ability to cope up with using its resources”. Though often caused by nature, disasters can have human origins. Humankind has, throughout history, continuously suffered the wraths of disasters such as earthquakes, floods, tsunamis, landslides, etc [4,5]. The Indian subcontinent is vulnerable to drought, floods, cyclones, and earthquakes. Among the 32 States/UTs in the country, 22 are multi-disaster prone. Seismic activities, tropical cyclones, and floods cause heavy loss of life and property [6]. Swiss Re [7] estimated a loss of $306 billion along with 11000 lives in natural and man-made disasters in the year 2017 alone. The Bhuj earthquake of 2001 [7] caused around 20000 casualties. The Indian Ocean Tsunami of 2004 affected around 11 countries with the death toll of around 2,30,000- 2,80,000. Disaster management can be defined as all the sets of activities and decisions taken up before, during, and after the occurrence of a disaster to reduce the loss of life and property [8]. This includes the legislations and laws that govern the formulation and functioning of various agencies involved with disaster management operations. In India, such agencies include the national disaster management authority, national disaster response force, and national institute of disaster management. Apart from this, at the state level, there are corresponding state disaster management authorities and state disaster response forces. The disaster management act is the main legislation that governs the functioning of the aforesaid agencies along with the roles of the central and the state governments.

1.1. Types of disaster

Disaster management can be broken down into four from hazards and their effects. This stage involves formulation of policies and legislations stages:

(i) Mitigation: the stage focuses on sustained actions and long-term solutions for reducing or eliminating risks to people and property for emergency management at different levels of government, and measures for their implementation.

(ii) Preparedness: This stage is considered as the building block of emergency management. This stage involves the assessment of the state of readiness to respond to disaster, crisis, or any other type of emergency. Capacity building is also an important part of this stage, which involves planning and training of various agencies and personnel along with infrastructural development for a swift and effective response during a disaster.

(iii) Response: An effective and timely response in an aftermath of a disaster is of utmost priority for the agencies involved with relief operations. Disaster response primarily involves the identification of the affected area and assessment of the impact. It then involves the dispatch of relief personnel and materials to the affected areas. Further, evacuation of victims from the affected areas in a timely and orderly manner is also important. Usually, the first responders are the local police, fire, and emergency medical personnel.

(iv) Recovery: This stage starts after the occurrence of a disaster. It involves rebuilding and redevelopment activities such as the rebuilding of houses, restoring businesses, resuming employment, repairing, and rebuilding the infrastructure, etc.

1.2. Role of transportation aftermath disaster

Logistics during disaster response can be defined as the process of procurement, storage, and supply of relief materials and deployment of relief personnel [9]. However, in the aftermath of a disaster, it is generally not possible to estimate the exact locations and demands for relief supplies. This uncertainty makes it a tough task for the agencies and decision-makers to manage and carry out relief operations. Long-term planning and preparation are essential in ensuring the effectiveness of response during a disaster. A well-planned and well-developed network of infrastructure can equate directly to a reduced number of casualties and financial losses incurred during a disaster. One of the main aims at the preparedness stage is to identify and build infrastructures that might function as useful operation centres during a disaster. For example, airports can function as centres for relief collection and distribution. However, relief operations carried out through airports are often subject to problems such as stockpiling [10]. Further, various modes are available for the transport of relief supplies- air and land transport modes primarily. While aircraft and helicopters are faster, their costs of operation are too high. On the other hand, trucks are economical but very slow as compared to aircraft. The choice of model depends on many factors including the availability of vehicles, availability of routes, and criticality of situations. The choices made in turn affect the costs and the time of operations.

2. Literature review

Apart from the definition of disaster as proposed by IFRC [3], other agencies have also defined disaster. The Disaster Management Act, 2009 [11] defines a disaster as "a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or manmade causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to, and destruction of, property, or damage to, or degradation of, environment, and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected area." United Nations International Strategy for Disaster Reduction (UNISDR) (2009) [12-15] defines a disaster as "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its resources." The various definitions focus on the fact that a disaster has a large-scale impact on society in a way that external resources and aid are required to cope up with it [16-18]. Use of OR and Mathematical Modelling in Disaster Management. Operation research and mathematical modelling have been used to model and analyse various transportation problems for a long [16].

Many strategies for dealing with uncertainty in mathematical programming models have been developed, with stochastic programming (SP) with recourse being highlighted as a general-purpose technique that can deal with uncertainty in any model parameter. Stochastic programming with recourse is used to find nonanticipative decisions that must be made before the realizations of some random variables are known, to minimize the total predicted costs of various recourse actions. Dantzig [19] was the first to formulate stochastic problems with recourse, and later on, Birge and Louveaux [20], and Kall and Wallace [21] examined the fundamental principles, solution methodologies, and application areas of SP. Mulvey and Vanderbei [22] present a proactive approach with the concept of robust optimization. Shapiro and Homem-de-Mello [23], Wallace [24] and Glockner and Nemhauser [25] have all investigated different elements of SP.

Transportation problems, assignment problems, the Hungarian method, and dynamic network problems are some of the common techniques that are profoundly in use for optimizing simple transportation problems. Researchers have developed a model for interactive analysis of helicopter logistics during a disaster [3-32]. The model was based on a two-stage hierarchy where tactical decisions were made at the top level and routing and loading decisions were made at the base level. Use of mathematical modelling has been initiated as a decision support tool for the successful development of a Disaster Recovery Plan [27]. In an article, researchers reviewed 109 articles and characterized them based on different criteria [1]. Based on the reviewed articles they concluded that in disaster response situations and important attributes of the problem (the disaster scenario) is uncertain. Further, they observed that despite the availability of different programs for disaster management, agencies don't adopt them and therefore implementation is rare and inefficient.

A total of 155 articles in continuation to Alter and Green's study using the same methodology and concluded that more research work needs to be carried out in recovery and response phases [28]. A researcher reviewed 101 articles in the period from 2006 to 2012, especially those with stochastic components. They established five major parameters considering uncertainty in humanitarian logistics viz. demand, demand location, affected areas (demography), supply, and transportation network. They further concluded that most of the research work is directed to the mitigation stage, while the recovery and response stage is least researched [29]. Work on the effect of certainty of information about the span of the planning horizon was studied in 2016 [30,31]. The study concluded that the wider the planning horizon, the less reliable the post-disaster information is, and vice versa. Further, they proposed a method in which the entire planning horizon was divided into several small time frames wherein each time frame could be used to predict the demand of relief material with continuous updates. A two-stage optimization problem with multi-supplier, multi-affected area, multi-relief, and multi-vehicle relief allocation problem with three objectives viz. minimization of unmet demand, minimization of time, and minimization of the cost were proposed in a study in which the model has been concluded using a goal programming approach with demand, supply, and path being described by fuzzy random variables. The model was used to determine the optimum locations of relief suppliers for a sample problem.

This study presents a mathematical model in the form of a multi-objective linear programming problem for the relief distribution problem from airports. It aims at developing a multi-objective LPP model for decision-making scenarios at the location or airport for relief distribution in the aftermath of a disaster. The main objective of the study is to develop equations for the objectives viz. time minimization, cost minimization, and supply maximization, and the constraints and to develop a solution method and algorithm for the problem. Further, the algorithm is used to simulate different possible scenarios for demand and supply of relief materials and to find the optimum fleet size, fleet composition based on cost and time for a sample problem.

3. Methodology and data used

A basic four-step methodology was adopted for the study.

In the first step, the problem was defined as a word problem and then in the form of block diagrams. The decision variables in the systems were identified and the limits of the system were specified. In the second step, the mathematical equations for various objectives and constraints of the systems were developed. The third step involved the development of a solution algorithm. Since the model does not solve for conventional optimization, a sequential algorithm was developed that allows users to input decisions manually on a situation-dependent basis. The model was then solved for optimum fleet size. The solution may not be a fixed point and thus may not give an exact answer to our question, but would be indicative of a possible range within which a decision-maker can search for viable alternatives by adding other criteria. The solution was rather conceptual than exact, owing to the complexities involved in solving such a model. Finally, a sample problem was solved to validate the results obtained in the third step.

Each step is explained in detail as

(i) Let there be n no. of suppliers providing relief materials and m no. of demand areas requiring relief. But due to geographical/administrative constraints, all the relief material must first come to a central location from where it can be dispatched to the affected areas.

(ii) The problem describes a decision-making scenario at the central location (CL). The CL can be an admin office or an airport.

(iii) In the event a disaster strikes, let it be that the relief materials are dispatched from the suppliers 1,2,3…n to the CL each taking time t1, t2,…tn respectively.

(iv) The CL would have a fixed holding and handling capacity for the cargo. The relief material's quantity at the CL at any time cannot exceed this capacity. Otherwise, it will lead to stockpiling.

(v) Further there would be a fixed number of vehicles at the CL of given capacities. The quantity of the relief material that can be dispatched cannot exceed this capacity.

(vi) The objective for the decision-maker is to maintain a supply of relief materials to the demand areas in such a way that maximum demand areas are met within the shortest possible time frame in the most economical way possible.

(vii) The decision would include the choice of vehicle type and route, which also influence the time and costs. A basic outline of the problem description is shown in Figure 1 below.

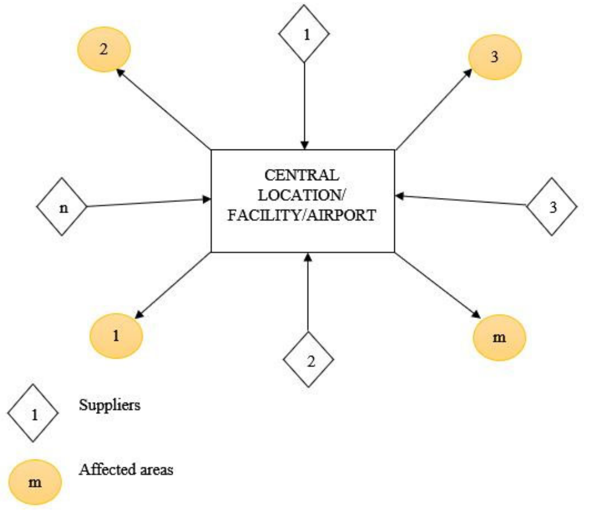

Fig. 1. Problem description

3.1. Data

1. Time and distance alternatives from different suppliers to CL and CL to demand areas.
2. Cost matrices.
3. Vehicle details.
4. Population details of demand areas.

3.2. Mathematical formulation

1. Minimize total time.
2. Minimize total cost.
3. Cover maximum demand.

3.3. Time

Time has 3 components:

1. The time it takes the relief material to reach from supplier to CL.
2. Handling time at CL.
3. The time it takes the relief material to reach demand areas.

Total time is the summation of all these components.

$$T = \sum_n \alpha_n t_{nc} + t_c + \sum_m \alpha_n t_{cm} \quad (1)$$

where, t_{nc} = time from supplier to CL,
t_c = handling time,
t_{cm} = time from CL to demand area,
α_n, α_m are binary operators such that

$$\alpha_n = \begin{cases} 1, & \text{if supplier n is chosen} \\ 0, & \text{when supplier n is not chosen} \end{cases}$$

$$\alpha_m = \begin{cases} 1, & \text{if } m^{th} \text{ demand area is supplied} \\ 0, & \text{when } m^{th} \text{ demand area is not supplied} \end{cases}$$

3.4. Costs

The total costs consist of transportation costs that depend on route length and vehicle type

For each alternative

$$C = \sum_i \sum_j \eta_i U_i \times \eta_j L_j + C_c + \sum_i \sum_k \eta_i U_i \times \eta_k L_k \quad (2)$$

where, U_i = running cost per unit distance for i^{th} vehicle type,
L_j = length of j^{th} route from supplier to CL,
L_k = length of k^{th} route from CL to demand area,
η_i, η_j and η_k are binary operators such that

$$\eta_i = \begin{cases} 1, & \text{if } i^{th} \text{ vehicle type is chosen} \\ 0, & \text{when } i^{th} \text{ vehicle type is not chosen} \end{cases}$$

$$\eta_j = \begin{cases} 1, & \text{if } j^{th} \text{ route is chosen} \\ 0, & \text{when } j^{th} \text{ route is not chosen} \end{cases}$$

$$\eta_k = \begin{cases} 1, & \text{if } k^{th} \text{ route is chosen} \\ 0, & \text{when } k^{th} \text{ route is not chosen} \end{cases}$$

3.5. Demand

For the initial estimate, the total demand at the m^{th} affected area can be assumed to be proportional to the population of that area.

A proportion of the total demand is sent as supply in each batch.

For each affected area the objective is to maximize the total supply

$$\min f_3 = \sum_l \left(\frac{d_i^m - s_i^m}{D^m}\right) \quad (3)$$

where, D^m = Total demand at m^{th} affected area,
d_i^m = Demand at the l^{th} iteration at the m^{th} affected area,
s_i^m = Supply dispatched in the l^{th} iteration to the m^{th} affected area.

3.6. Constraints

$$\sum_m \sum_l s_l^m - \sum_m D^m = 0 \quad (4)$$

$$\sum_m \sum_l s_l^m - \sum_m N_i V_i \leq 0 \qquad \forall N, i \in I \quad (5)$$

$$\sum S_{s-CL} - \sum S_{CL-D} + R_{CL} - W \leq 0 \quad .(6)$$

$$T \leq T_u \quad (7)$$

$$L \leq L_u \quad (8)$$

$$s_l^m,\ D^m,\ N_i,\ V_i,\ T,\ L \geq 0 \quad (9)$$

where, s_l^m= supply variable for m^{th} location at l^{th} iteration,
D^m= total demand at m^{th} affected area,
Ni= number of i^{th} types of vehicles available,
V_i = capacity of i^{th} vehicle type,
S_{s-CL}= Total supply from supplier to Central location or Airport,
S_{CL-D}= Total supply from airport to demand area,
R_{CL}= Relief material available in reserve,
W = Capacity of storage at the central location or airport,
T represents various times,
L represents various route lengths.

Equation (1) sets the first objective function i.e., to minimize the total time of operation. The total time is the summation of three components, viz. the time it takes the relief material to reach the airport from the supplier, second the time it stays at the airport, and third the time it takes the relief material to reach the affected area from the airport. Equation (2) is the second objective function to reduce the total cost of operation. Similar to time, the cost also has three components. Since the time and cost are dependent on the choices made during the operation, binary variables have been used in the equation to account for the decisions regarding the choice of alternatives. For example, if an alternative is chosen the binary variable would take up value 1 otherwise it shall remain 0. Equation (3) sets the third objective for the operation which is to maximize the supply. Equations 4 to 9 are the constraints to which the objectives are subjected. The first constraint is that the total supply must be equal to the total demand. While the second equation puts a constraint on the maximum amount of supply that can be sent in each dispatch. It requires the maximum supply to be less than or equal to the total capacity of vehicles available for transportation in that dispatch. The third equation puts a limit on the input and output rate for a given storage capacity. This constraint provides a check for stockpiling. Equations 7 and 8 specify the upper and lower limits of the time and distances to which the airport must serve. The last constraint accounts for the non-negativity of the variables.

4. Results and discussion

4.1. Motivation for solution

The mathematical model developed above is a multi-objective linear programming model. Although many solutions are available for solving such problems, viz. goal programming, heuristic algorithms, etc., they are good for obtaining a single optimum solution. Further, the decision during a disaster is more situation-dependent. The choice of alternatives would vary for the same problem in different conditions. For example, it might not be necessary that the location with the shortest route or time is the most critical one. The decision-maker is required to ascertain the most critical location first and then distribute the supply so that it reaches that location at the earliest. The chosen alternative might not always be the optimum in the conventional sense. However, the model can be solved by limiting the disaster situation, where the goals become the basis for decisions and the constraints become the criteria for success.

In case of an actual emergency, the decision is situation-dependent and based on the latest information available. For example, just after the disaster, the agency involved in relief distribution or the decision-maker is supposed to send relief personnel along with basic equipment such as medicines, ropes, ladders, etc. to all the possible affected locations. The dispatched teams, consequent upon their arrival collect and report the situation from the ground-based on which further decisions are made by the decision-maker. No doubt that the quality of the information, in the beginning, is very poor and cannot be relied upon. So, the decision-maker must be careful about allocating resources. For example, if he engages the entire fleet available in the first hour after the disaster, he might not have any fleet available at his call later when more reliable information is obtained. This might increase the criticality of the situation at later stages. Similarly, if more allocations are made for a single affected location at the initial stages, the situation at some other location might become more critical due to a lack of support and resources.

4.2. Assumptions

The following assumptions were made for developing the solution algorithm:

1. Initial demand at affected areas is proportional to the population of that area.
2. Route alternatives and Vehicle alternatives are known in advance.
3. Costs of different alternatives are known.
4. Loading-unloading and waiting times are included in the Time alternatives.
5. All relief material is of the same type.

4.3. Model solution: sequential algorithm

The sequential algorithm developed for solving the model has the following components:

1. Database: Creating the environment in which the system works. It fixes the vehicle fleet size, composition, routes and time and cost alternatives, etc.
2. System State: Set of variables describing the system at an instant of time. No. of vehicles at CL or in transit, the ratio of individual demand to total demand (ϵ), total supply received at CL, etc.
3. Decision: Choice of vehicle and route
4. Outcome: Cost and Time, total supply

Criteria for success: No stockpiling and ratio of total supply to total demand exceeds μ. Figure 2 shows the basic outline of the algorithm. Figure 3 shows the entity-relationship diagram for the database. Figure 4 to Figure 9 show the various steps of the algorithm.

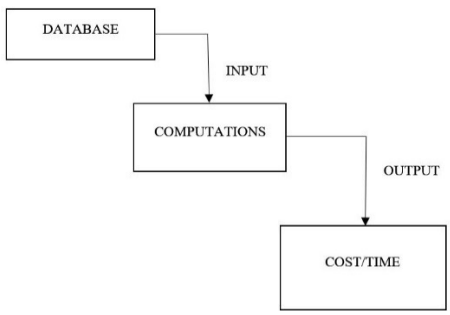

Fig. 2. Basic outline of solution

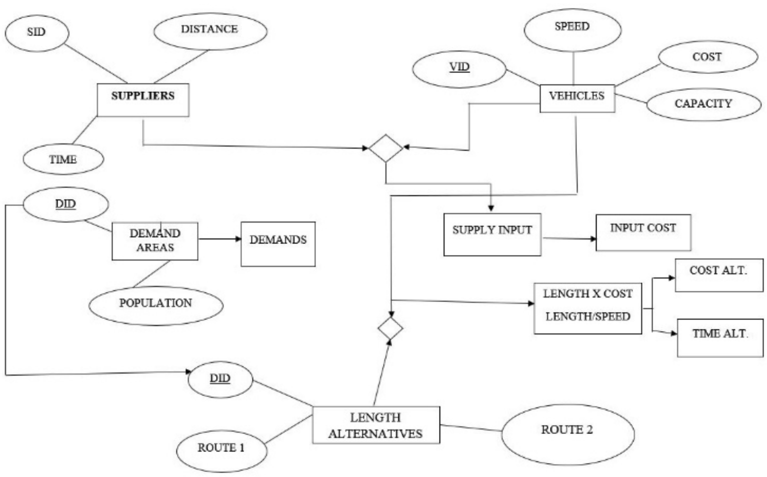

Fig. 3. Database: entity relationships

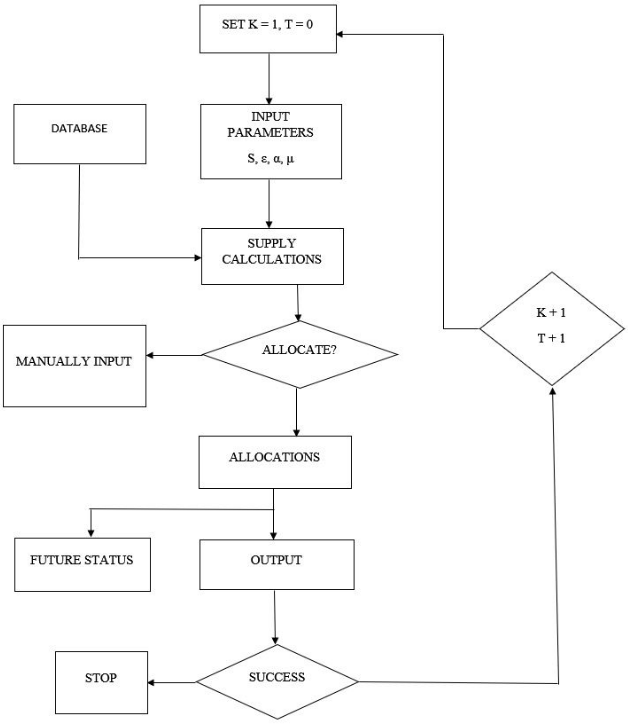

Fig. 4. Computations

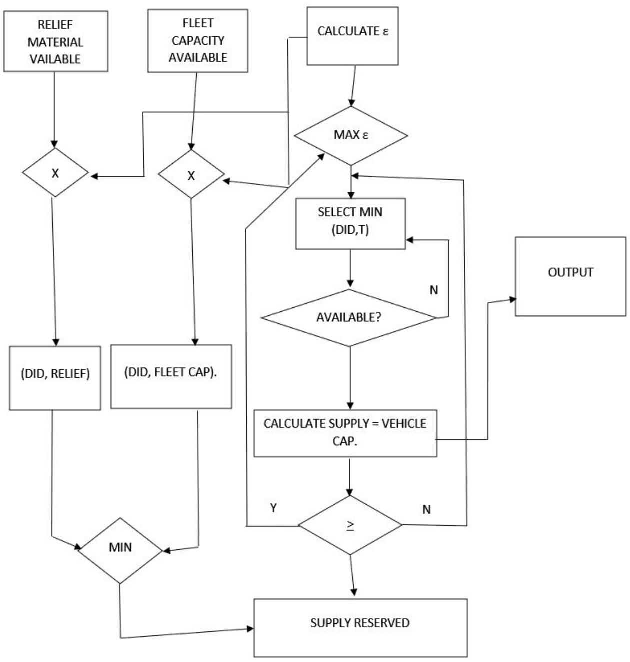

Fig. 5. Supply calculations

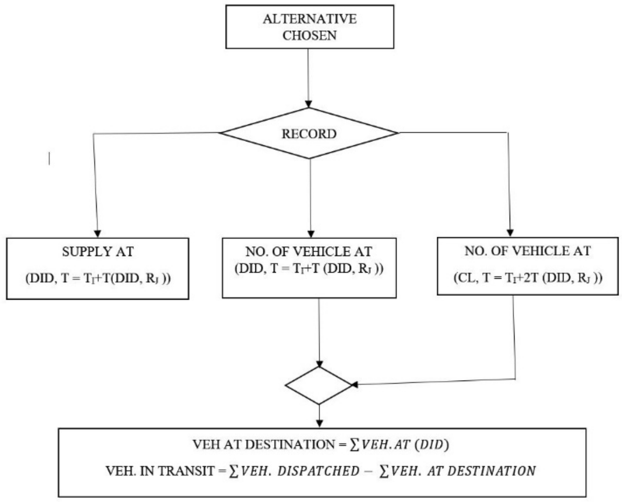

Fig. 6. Future status of vehicles and supply at demand locations

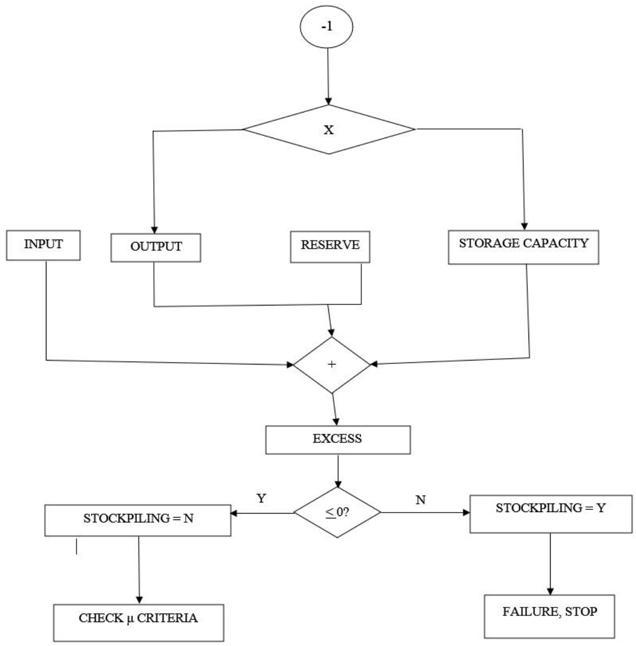

Fig. 7. Check for stockpiling

4.4. Analytical inference

Let [U] be the set of all decisions (allocations) under a specific set of conditions.

Let C_i[U] be the total cost for the decision set [U] for a particular fleet composition with i% of trucks in it.

Let T_i [U] be the total time of operation for the decision set [U] for a particular fleet composition with i% of trucks in it.

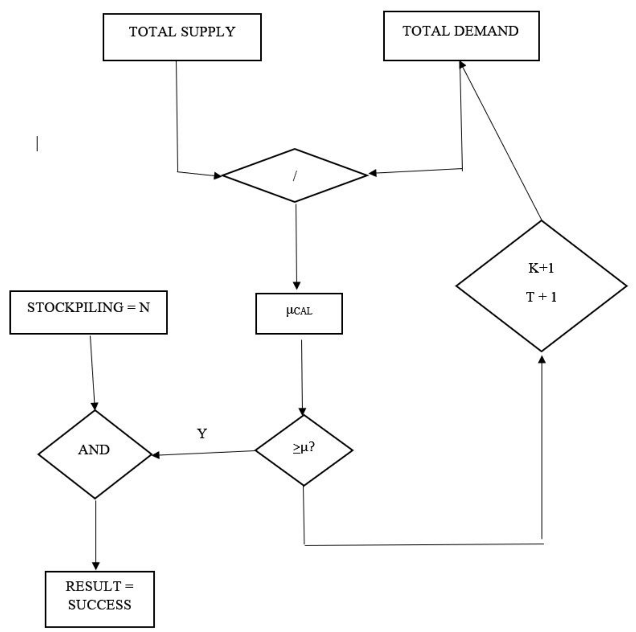

Fig. 8. Check for success criteria

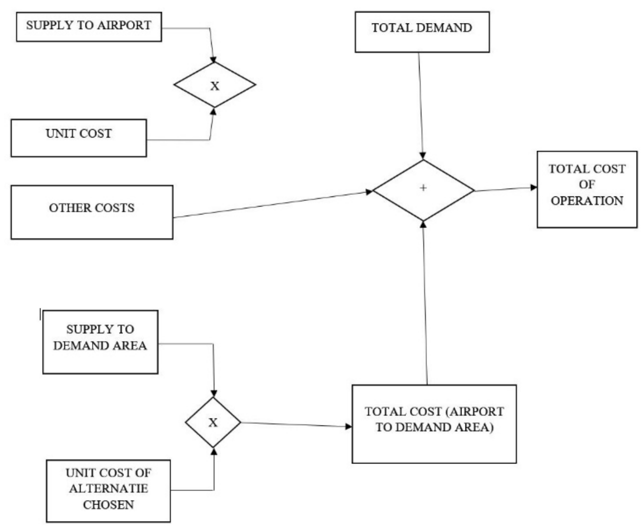

Fig. 9. Computation of total cost

Now, since the Cost of transportation using trucks is very less than that of aircraft, i.e.

$C_t << C_a$.

It is reasonable to infer that as the percentage of trucks in the fleet increases the total cost of decisions shall decrease, i.e.

$C_i[U] > C_{i+1}[U]$ (10)

Similarly, as the percentage of trucks in the fleet increases the time of operation increases since trucks are very slower than aircraft. Mathematically,

Since, $T_t >> T_a$

Therefore,

$T_i[U] < T_{i+1}[U]$ (11)

Now, let {i, $C_i[U]$} be the locus of the point tracing the costs of decision sets [U] for different values of i and let {i, $T_i[U]$} be the locus of the point tracing the time of operations for different values of i.

Let i^* be the point where {i, $C_i[U]$} ~ {i, $T_i[U]$} on a dual axis graph (Fig. 10) with i values on the horizontal axis.

If $i < i^*$,

then,

$C_i[U] > C_{i^*}[U]$……….......................................From (10)

and,

$T_i[U] < T_{i^*}[U]$……...From (11)

Thus, cost objective is not satisfied.

For $i > i^*$

$C_i[U] < C_{i^*}[U]$ …..From (10)

and

$T_i[U] > T_{i^*}[U]$ ……………...............……..…..From (11)

Thus, the time objective is not satisfied. Hence i^* is optimum.

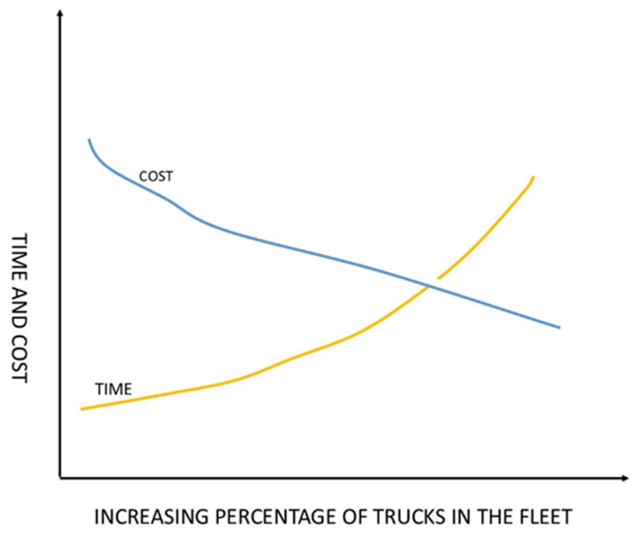

Fig. 10. Variation in cost and time with an increasing percentage of trucks in the fleet

5. Validation of the model

The mathematical model developed above was validated by simulating a sample problem. The problem was solved semi-manually using the MS Excel tool. Below is stated the sample problem and its solution (Tabs. 1-7). An airport has to serve relief operations covering a total of 8 demand areas. There are 4 suppliers which supply relief to the given airport. A fleet size capable of transporting 100000 units of relief material is available with the decision-maker. The ultimate demands are proportional to the populations of the demand areas. The cost and length alternatives are known. Check whether the fleet size is sufficient for attaining success for μ=10%. If the fleet has to be composed of aircraft and trucks of given specifications, find out the optimum fleet composition. The cost of transportation by aircraft and trucks is 5:1.

The problem was solved for a disaster scenario that would generate a demand for relief supply equivalent to 40% of the population. To account for uncertainty in information random numbers were generated for ϵ values. The model was solved for different fleet compositions viz., 0%, 25%, 50%, 75% and 100% trucks. Below are the supply calculations for a fleet made up entirely of aircraft. Supply calculations were done on a ‘serve the most critical area first’ basis. The alternatives were manually chosen in such a way that the most critical area was supplied first, then the second most critical, and so on. A further secondary motive was to ensure that all the demand areas are supplied as far as possible (Tabs. 8-13).

Table 1.
Relief suppliers to the airport

S. no.	SID	Time from CF	Cost /Unit	Distance from CF
1	S1	0.5	625	125
2	S2	1	1250	250
3	S3	3	3750	750
4	S4	5	6250	1250

Table 2.
Demand areas

DID	Population	Ultimate demands		
		10%	20%	40%
D1	350000	35000	70000	140000
D2	80000	8000	16000	32000
D3	320000	32000	64000	128000
D4	450000	45000	90000	180000
D5	380000	38000	76000	152000
D6	300000	30000	60000	120000
D7	800000	80000	160000	320000
D8	437000	43700	87400	174800
		311700	623400	1246800

Table 3.
Alternatives: route length from airport to demand areas (km)

S. no	DID	R1 (Air)	R2 (Land)	R3 (Land)
1	D1	150	200	250
2	D2	150	180	230
3	D3	300	360	400
4	D4	350	400	410
5	D5	450	600	690
6	D6	450	550	580
7	D7	450	540	580
8	D8	600	660	700

Table 4.
Alternatives: cost of transportation from airport to demand area (per unit)

S. no	DID	R1 (Air)	R2 (Land)	R3 (Land)
1	D1	750	200	250
2	D2	750	180	230
3	D3	1500	360	400
4	D4	1750	400	410
5	D5	2250	600	690
6	D6	2250	550	580
7	D7	2250	540	580
8	D8	3000	660	700

Table 5.
Alternatives: time of travel from airport to demand areas (hours)

S. no	DID	R1 (Air)	R2 (Land)	R3 (Land)
1	D1	0.6	5	6.25
2	D2	0.6	4.5	5.75
3	D3	1.2	9	10
4	D4	1.4	10	10.25
5	D5	1.8	15	17.25
6	D6	1.8	13.75	14.5
7	D7	1.8	13.5	14.5
8	D8	2.4	16.5	17.5

Table 6.
Vehicle’s category type

S. no.	VID	Type	Av. Speed	Cost	Unit Capacity
1	V1	Air	250	5	2000
2	V2	Land	40	1	1000

Table 7.
Input of relief materials from various suppliers

SID	0	1	2	3	4	5	6	7	8
S1	0	10000	10000	10000	15000	20000	15000	15000	15000
S2	0	0	5000	10000	15000	15000	15000	15000	15000
S2	0	0	0	10000	10000	10000	10000	10000	10000
S4	0	0	0	0	0	5000	10000	10000	10000
Total	0	10000	15000	30000	40000	50000	50000	50000	50000

Table 8.
Supply calculations; T=1

T=1	total relief input	10000	reserve	0	total relief available	10000	
DID	ϵ	Demand	Relief reserved	V1	V2	Total Supply	total cost
D1	0.2588	140000	2588.39032	1	0	2000	1500000
D2	0.1978	32000	1977.55848	1	0	2000	1500000
D3	0.1055	128000	1054.8468	1	0	2000	3000000
D4	0.0401	180000	401.464742	0	0	0	0
D5	0.0823	152000	822.686249	0	0	0	0
D6	0.2009	120000	2008.56279	1	0	2000	4500000
D7	0.0898	320000	898.263345	1	0	2000	4500000
D8	0.0248	174800	248.22727	0	0	0	0
		1246800	10000	5	0	10000	15000000

Table 9.
Supply calculations; T=2

T=2	total relief input	15000	reserve	0	total relief available	15000	
DID	ϵ	Demand	Relief reserved	V1	V2	Total Supply	total cost
D1	0.1338	140000	2006.4586	1	0	2000	1500000
D2	0.0358	32000	537.630767	0	0	0	0
D3	0.0875	128000	1312.52796	1	0	2000	3000000
D4	0.1578	180000	2367.6675	1	0	2000	3500000
D5	0.1156	152000	1733.41129	1	0	2000	4500000
D6	0.1033	120000	1549.12059	1	0	2000	4500000
D7	0.185	320000	2775.17102	1	0	2000	4500000
D8	0.1812	174800	2718.01227	1	0	2000	6000000
		1246800	15000	7	0	14000	27500000

Table 10.
Supply calculations; T=3

T=3	total relief input	30000	reserve	1000	total relief available	31000	
DID	ϵ	Demand	Relief reserved	V1	V2	Total Supply	total cost
D1	0.0155	140000	480.752907	0	0	0	0
D2	0.2388	32000	7403.98735	4	0	8000	6000000
D3	0.0873	128000	2705.4719	1	0	2000	3000000
D4	0.2171	180000	6731.6171	3	0	6000	10500000
D5	0.1829	152000	5668.52623	3	0	6000	13500000
D6	0.052	120000	1611.26892	1	0	2000	4500000
D7	0.0506	320000	1567.77825	1	0	2000	4500000
D8	0.1558	174800	4830.59734	2	0	4000	12000000
		1246800	31000	15	0	30000	54000000

Table 11.
Supply calculations; T=4

T=4	total relief input	40000	reserve	1000	total relief available	41000	
DID	ϵ	Demand	Relief reserved	V1	V2	Total Supply	total cost
D1	0.123	140000	5044.50576	2	0	4000	3000000
D2	0.071	32000	2912.71398	1	0	2000	1500000
D3	0.1819	128000	7458.7192	4	0	8000	12000000
D4	0.1921	180000	7877.25698	4	0	8000	14000000
D5	0.0812	152000	3330.79993	2	0	4000	9000000
D6	0.048	120000	1968.60667	1	0	2000	4500000
D7	0.098	320000	4017.17185	2	0	4000	9000000
D8	0.2046	174800	8390.22564	4	0	8000	24000000
		1246800	41000	20	0	40000	77000000

Table 12.
Supply calculations; T=5

T=5	total relief input	50000	reserve	1000	total relief available	51000	0
DID	ϵ	Demand	Relief reserved	V1	V2	Total Supply	total cost
D1	0.0905	140000	4616.09254	0	0	0	0
D2	0.0685	32000	3491.05173	0	0	0	0
D3	0.2001	128000	10206.3243	3	0	6000	9000000
D4	0.1726	180000	8800.62773	0	0	0	0
D5	0.2628	152000	13401.0377	4	0	8000	18000000
D6	0.0461	120000	2352.15104	0	0	0	0
D7	0.0736	320000	3751.46222	0	0	0	0
D8	0.0859	174800	4381.25274	0	0	0	0
		1246800	51000	7	0	14000	27000000

Table 13.
Supply calculations; T=6

T=6	total relief input	50000	reserve	37000	total relief available	87000	0
DID	ϵ	Demand	Relief reserved	V1	V2	Total Supply	total cost
D1	0.0999	140000	8693.86252	0	0	0	0
D2	0.1355	32000	11790.9619	1	0	2000	1500000
D3	0.0364	128000	3164.8082	0	0	0	0
D4	0.292	180000	25400.0829	6	0	12000	21000000
D5	0.1094	152000	9516.6657	1	0	2000	4500000
D6	0.0583	120000	5073.41047	0	0	0	0
D7	0.205	320000	17830.9813	2	0	4000	9000000
D8	0.0636	174800	5529.22697	0	0	0	0
		1246800	87000	10	0	20000	36000000

Similar calculations, done in MS excel for the sample problem, were made for fleet compositions with 25%, 50%, 75% and 100% trucks. The results include the computations for total cost and stockpiling which are given in the Tables 14-21.

From the Tables 14-21, it is clear that as the percentage of trucks in the fleet increases, the cost decreases, and time increases. From the stockpiling data, it can be seen that the fleet capacity of 100000 units can sustain only for 4 to 5 iterations, i.e. for a duration of 4 to 5 hours only. The decision-makers either need to increase their fleet capacity or shall build more storage space for holding cargo.

For 0% trucks

Table 14.
Computations for stockpiling; 0% trucks

S. no.	K	T	Input	Relief Material available	Output	Reserve	Capacity	Excess	Stockpiling
1	1	0	0	0	0	0	20000	-20000	N
2	2	1	10000	10000	10000	0	20000	-20000	N
3	3	2	15000	15000	14000	1000	20000	-19000	N
4	4	3	30000	31000	30000	1000	20000	-19000	N
5	5	4	40000	41000	40000	1000	20000	-19000	N
6	6	5	50000	51000	14000	37000	20000	17000	Y
7	7	6	50000	87000	20000	67000	20000	47000	Y

Table 15.
Computations for total cost of operation; 0% trucks

S. no.	K	T	C1	C2	Total
1	1	0	0	0	0
2	2	1	6250000	15000000	21250000
3	3	2	12500000	27500000	40000000
4	4	3	56250000	54000000	110250000
5	5	4	65625000	77000000	142625000
6	6	5	100000000	27000000	127000000
7	7	6	128125000	36000000	164125000
					605250000

For 25% trucks

Table 16.
Computations for stockpiling; 25% trucks

S. no.	K	T	Input	Relief Material available	Output	Reserve	Capacity	Excess	Stockpiling
1	1	0	0	0	0	0	20000	-20000	N
2	2	1	10000	10000	10000	0	20000	-20000	N
3	3	2	15000	15000	15000	0	20000	-20000	N
4	4	3	30000	30000	30000	0	20000	-20000	N
5	5	4	40000	40000	40000	0	20000	-20000	N
6	6	5	50000	50000	29000	21000	20000	1000	Y
7	7	6	50000	71000	18000	53000	20000	33000	Y

Table 17.
Computations for total cost of operation; 25% trucks

S. no.	K	T	C1	C2	Total
1	1	0	0	0	0
2	2	1	6250000	15000000	21250000
3	3	2	12500000	27680000	40180000
4	4	3	56250000	54000000	110250000
5	5	4	65625000	61670000	127295000
6	6	5	100000000	35610000	135610000
7	7	6	128125000	0	128125000
					562710000

For 50% of trucks

Table 18.
Computations for stockpiling; 50% trucks

S. no.	K	T	Input	Relief Material available	Output	Reserve	Capacity	Excess	Stockpiling
1	1	0	0	0	0	0	20000	-20000	N
2	2	1	10000	10000	10000	0	20000	-20000	N
3	3	2	15000	15000	15000	0	20000	-20000	N
4	4	3	30000	30000	30000	0	20000	-20000	N
5	5	4	40000	40000	40000	0	20000	-20000	N
6	6	5	50000	50000	31000	19000	20000	-1000	N
7	7	6	50000	69000	18000	51000	20000	31000	Y

Table 19.
Computations for total cost of operation; 50% trucks

S. no.	K	T	C1	C2	Total
1	1	0	0	0	0
2	2	1	6250000	15000000	21250000
3	3	2	12500000	27680000	40180000
4	4	3	56250000	54000000	110250000
5	5	4	65625000	31750000	97375000
6	6	5	100000000	36810000	136810000
7	7	6	128125000	33000000	161125000
					566990000

For 75% of trucks

Table 20.
Computations for stockpiling; 75% trucks

S. no.	K	T	Input	Relief Material available	Output	Reserve	Capacity	Excess	Stockpiling
1	1	0	0	0	0	0	20000	-20000	N
2	2	1	10000	10000	10000	0	20000	-20000	N
3	3	2	15000	15000	15000	0	20000	-20000	N
4	4	3	30000	30000	30000	0	20000	-20000	N
5	5	4	40000	40000	40000	0	20000	-20000	N
6	6	5	50000	50000	25000	25000	20000	5000	Y
7	7	6	50000	75000	6000	69000	20000	49000	Y

Table 21.
Computations for total cost of operation; 75% trucks

S. no.	K	T	C1	C2	Total
1	1	0	0	0	0
2	2	1	6250000	15000000	21250000
3	3	2	12500000	27680000	40180000
4	4	3	56250000	15500000	71750000
5	5	4	65625000	26960000	92585000
6	6	5	100000000	28470000	128470000
7	7	6	128125000	9500000	137625000
					491860000

Table 22.
Results: summary

i	Cost	Weighted Cost	Time (hrs)	Weighted Time
0	605250000	0.231293063	8	0.078431373
25	562710000	0.215036629	21.5	0.210784314
50	556990000	0.212850761	21.5	0.210784314
75	491860000	0.187961679	21.5	0.210784314
100	400000000	0.152857869	29.5	0.289215686
	2616810000		102	

Table 22 summarizes the results shown in Tables 14-21. Figure 11 the variation of the cost and time wrt the change in fleet composition for the sample problem.

Although the fleet size itself is not optimum, still the best results for the first six iterations are obtained when there are 25-50% trucks in the fleet.

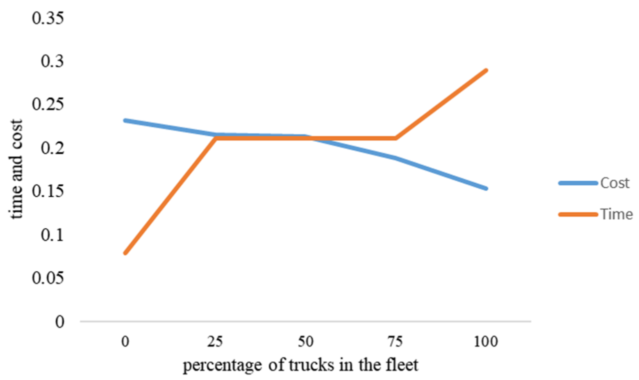

Fig. 11. Optimum percentage of trucks

The results of the sample problem are following the analytical inference. Further, it can be seen from the results that as we reach T=5, relief material starts piling up at the airport. To prevent this, there is a need to build additional storage facilities to hold at least 49000 units of additional relief material, or otherwise more trucks and aircraft are required to move this additional unit.

6. Conclusions

The mathematical model and its solution method proposed in this study provide a new method for planners and policymakers to assess and prepare for future emergencies in terms of building and maintaining transportation and logistical infrastructures such as airports, roads, warehouses, and vehicles and aircraft. The results obtained here can be used in a variety of ways to plan and prepare for emergency response, especially in the cases of a disaster that affects a wide area such as earthquakes, floods, hurricanes, etc. Firstly, the model can be used to analyze the present capacity of an airport or a central facility to carry out an emergency response program, based on presently available fleet size and composition. The fleet may consist of trucks and other public vehicles such as buses and mini trucks as well because in emergencies, the main aim is to transport relief as fast as possible, and the situation itself warrants the call for unconventional decisions. The result of the study gives the optimum value of fleet size which minimizes the total operation cost as well as minimizes the total travel time.

Secondly, the model can be used to assess the future requirement of logistical infrastructure. For example, the requirement for up-gradation of runways or building of new helipads or procurement of new vehicles or aircraft, etc. The attempt should be to bring rationale into the decisions and develop transportation facilities today in such a way that they can be of help during disaster tomorrow.

Disaster management must be considered while planning transportation for a city or state or nation because the same infrastructure proves to be of importance during an emergency. It would be a very irrational decision for a government to procure aircraft or trucks solely for relief transportation. For disaster is uncertain and cannot be predicted and having unused resources for such uncertain phenomenon would be an example of very poor management. However, an area should have running resources or provisions to call for resources when in need. At the state level, the government may upgrade their airports and helipads and coordinate with nearby airbases for aircraft at the time of need. Further at this level, the choice for decision would be between aircraft and trucks. While at the district level, the choice might be between a heavy truck and light trucks, or any other combination of vehicles. Even public transportation can be used in the time of emergency. At the district level, villages can be connected to main cities using small vehicles like light trucks, Autorickshaws, etc. during the time of emergencies even these vehicles can be of great help.

Future scope

Although the above model gives the best-fit solutions for the problem however there are some shortcomings due to some assumptions taken for model development, which may improved in further studies. The proportion of initial demand may be changed from population to the impact of the disaster on a place. Different categories of relief materials may improvised in furure studies.

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