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Redistribution for cost minimization in disaster management under uncertainty with trapezoidal neutrosophic number

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ABSTRACT

The activity of humanitarian logistic is urgently employed in the aftermath of the disaster. The sudden shock of disaster emerges high demand in the society. In this context, this research has introduced a mathematical model for humanitarian logistic applying the fact of redistribution of resources. The model aims to minimize the total cost of whole operation and the total time for redistribution phase so as to response the emergency situation quickly. According to the model distribution of humanitarian items to the affected areas are commenced by a governing authority in the first phase. The phase of redistribution is started after a certain period of time when some areas get relief and some are still unable to recover their vulnerable condition after the disaster. The concept of redistribution, established in the logistic model is beneficial for better response in the emergency condition as it quickly redistributed the resources from the areas which are recovered to the areas still being affected. The performance of the model is analyzed with some numerical data considering the uncertain parameter in the form of a trapezoidal Neutrosophic number. The model is solved through three different techniques: Neutrosophic programming approach, goal programming, and Pareto optimal solution approach. Moreover, a comparative analysis is performed in this study among the results obtained by three different techniques which are useful for the decision maker to make a practical decision in emergency response.

1. Introduction

In the recent year, there is an increasing attention towards the problem of mitigation and resilience of the disaster. The vast history of demolition and devastation have attracted the practitioners to show their perfect concern regarding efficient emergency logistic management. The growing concentration of disaster response is based on some calamitous events happened on the earth and ruined the living condition of people in the society. There are several such examples: Haiti earthquake (2010), the Indian Ocean Tsunami (2004), Chennai flood (2015), Nepal earthquake (2015), Typhoon Komen in India, Bangladesh and Myanmar (2015), earthquake in Ecuador (2016), flood in Kerela (2018), Assam and Bihar flood (2017) are some deadliest disaster recorded in history caused the worst condition with thousands deaths of people and damaged million dollars' worth. In prospect of large scale disaster, recovery phase can be categorized in two phases: short term and long term. The short term recovery basically focuses on the restoration of vital life support for surviving in the catastrophe. The activities of short term recovery comprises of many individual component and corresponding service such as collection of information about victims, evacuation, sheltering, feeding operation, first aid service, distribution of humanitarian items, etc. with minimum time [1]. The growing awareness of human suffering in the catastrophe, lots of humanitarian organizations come forward and give their proper response in the recovery phase following some efficient logistic plan [2–4]. According to the disaster recovery plan of state of Illinois, aforementioned emergency service have to be operated within 8 h [5]. Immediate service within 8 h of the aftermath is not probably easy for humanitarian logistic management to execute without any proper transportation plan to convey the humanitarian items to the location where it is exactly required. Therefore, this research has introduced a mathematical model for multi-objective solid transportation problem (MOSTP) for emergency service in disaster. It considers

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two optimization criteria for efficiency and effectiveness mentioned in the article [6] applicable in the humanitarian supply chain which are minimization of cost and time for disaster operation.

Humanitarian supply chain basically indicates the flow of humanitarian items from some storing point to the affected areas (AAs) in order to serve victims in disaster management operation and can be designed in the form of solid transportation problem (STP). STP is first developed by Haley in the literature in the year 1962 [7]. STP is basically formed considering an extra constraint called conveyance capacity which is missing in transportation problem (TP) introduced by Hitchcock [8]. TP is a form of linear programming problem (LPP) [9]. To develop the MOSTP in disaster response, we have considered central distribution center (CDC) as source point and relief centers (RC) are the demand point established in the affected areas (AAs). Again for calamitous environment some selected vehicles are reachable to the proper demand point; so in the research problem such vehicle like truck, dumper, etc. are considered. Moreover, some areas are visited by machinery such as excavator due to the impediment of road for catastrophe.

After the strike of disaster vulnerable people are responded by the co-ordination of humanitarian organizations. Sometimes the organization sent a group of expert for investigation of AAs and after proper evaluation, some distribution center (DC) or RCs are established as resource transferring point from where people can collect their necessary things [10,11]. The flow of humanitarian items are started from CDCs to RCs through some conveyance by the logistics network which has three parts: non-governmental organization (NGO), governmental organization (GO) and AAs [12]. With the collaboration of NGO and GO, CDCs are arranged in some unaffected regions brimming with humanitarian items. Generally, humanitarian items or resources for responding disaster are categorized into two types according to [11]: one is daily consuming resources such as food, water, medicine, etc. and other types included tent for shelter, machinery instruments for rescue, evacuation, etc. In this research humanitarian items are supposed as daily consuming items. As daily consuming rate of items are different in different AAs, so requirements of humanitarian items are varied. Sometimes, initial communication path between CDCs to AAs are blocked or crashed and causes high cost in the shipping of humanitarian items. One fact is consider in the research that after some days, some particular affected areas are getting relief while some others areas are still being faced by the affect of disaster. Therefore, it is obvious that consumption rate of humanitarian items are lowered in those areas which are recovered from the effect than those areas which are still affected. Lubahevskiy et al. [1] proposed a general principal for redistribution of vital resource between affected cities and neighboring cities. The developed principle has two component: one determines the current city priority in resource delivery and another one is minimization of delivery time. It has considered the initial communication is crashed and formation of new one with resource redistribution. Following this concept in our research investigation we have considered that RCs redistributed the resources after some days when less amount is consumed in some of the RCs to those RCs where it is required. The concept of redistribution is defined through the mathematical model proposed in the paper for developing a STP in emergency response. The mathematical model defined in the manuscript describes a two phase problem of conveying humanitarian aid. First phase is started when distribution of humanitarian items are urgently required at the RCs immediate after the disaster. As mention earlier some areas are recovered from the effect of disaster after a certain period of time, the underutilized humanitarian items are available in those RCs. But in some areas which are not recovered from the effect of disaster require more humanitarian items. Regarding this situation redistribution phase is initiated with the transfer of excess amount of humanitarian items from those RCs where it is available to those RCs where it is required. The model aims to minimize the total cost of the disaster response operation including redistribution phase and total time for redistribution phase. The model is solved through three different techniques to get a compromise solution. The three different techniques are presented to perform a comparative analysis to choose the best option for the decision maker (DM).

Since disastrous environment is very chaotic, complexity arises in the logistic management for humanitarian aid [13]. One of the complex matter is to estimate the demand of the AAs in the event like catastrophe which is frequently varied [14]. Therefore, the demand of AAs are considered as uncertain for the model. Sometimes disaster creates blockage of road and normal communication is difficult in this situation. Since transportation of humanitarian items are essential to cover the demand of AAs, authority should manage it even with the high cost also. Hence about the transportation cost, cost for redistribution are not easily predictable by the previous information. Therefore, cost is also taken in uncertain form. There are various article defining the mathematical model in STP or MOSTP in the literature considering the uncertain parameter [15–17].

2. Literature review

In this section a brief review on disaster management operation and importance of humanitarian logistic are provided. Different article by researchers in the literature have shown their disaster response performance designing new mathematical model for deploying humanitarian logistic in emergency response.

2.1. Activities of humanitarian logistic in emergency response

The basic operation of humanitarian logistic comprises of collection of information about demand, delivering the requested resources and service at the time and place of their requirement in the immediate aftermath of disaster [18]. More explanation of activities and aim of humanitarian logistic are performed by Tomasini and Wassenhove [19]. The review of operation research (OR) and management science (MS) has been addressed in the literature by Green and Atlay in [20]. This study has been continued further in [21–23]. Gutjahr and Nolz [6] reviews some multi-criteria optimization for the disaster operation management. Cauchy et al. [21] review optimization model in the area of emergency response logistic considering pre-disaster (consisting of facility location, stock pre-positioned, evacuation) and post-disaster (involving casualty transportation and relief distribution). Initial resource allocation through proper logistic designing mathematical model has been reflected in the literature through the article [24]. The mathematical model is based on multi-commodity, multi-model network flow for relief response generating routing and scheduling plan for different transportation mode transporting different items from different supply point to demand point. Similarly another model for transportation network have been formulated by Nikoo et al. [25] considering three main objective functions designed to identify the optimal routes for emergency vehicles considering the length, the travel time and the number of paths as performance metrics of network vulnerability in the emergency time of catastrophe. Humanitarian logistic focus on evacuation, facility location, stock pre-position, relief distribution in emergency operation. Sherali et al. [26] developed a location allocation model through evacuation planning minimizing the total congestion-related evacuation time and generating computer based tool for resource allocation. An integrate location distribution logistics model for evacuation and support in disaster response is defined in [27]. The model included the fact of transportation of relief commodities to distribution center in affected areas and evacuation of wounded people to emergency unit. Balcik and Beamon [28] developed a facility location decision for relief distribution to preposition the stock in distribution center in humanitarian aid. A stochastic optimization approach for the storage and distribution problem of medical supplies in disaster management operation for storage locations of medical supplies and required inventory levels for each type of medical supply has been formulated in [29]. Jia et al. [30] developed a general facility location problem suitable for large-scale emergencies after surveying general facility location problems and identified the models which are used for common emergency situations, such as house fires and regular health care needs. One of the important issues for the event of disaster is stock preposition which is defined through some model in the literature for early response [31,32]. Mashi et al. [33] discuss a critical appraisal in disaster risks and management policies of Nigeria National Emergency Management Agency (NEMA) in order to mitigate or prevent or minimize the risk of disaster.

2.2. Management of resource with proper decision making

After disaster, many organization like non-governmental organization (NGO) and government aid agencies, many expertise struggle to provide relief commodities to the AAs. But resource management in the crucial period is not quite easy. Some unavailability of conveyance also creates problem in catastrophe [34]. To manage resource from some supply point to the AAs through logistic network some challenging factor arises define by Sheu [35], Balcik and Beamon [28] and Cook et al. [36]:

- Demand is uncertain according to time and location.
- Resource are shortage for accessing the AAs.
- Efficient organization of resources to deliver in accurate time.
- Critical communication in the complex environment for some technical problem.

These challenges are more underpinned for some reason of unplanned co-ordinate management [37] given below:

- Participation of several organization.
- Lack of standard activity among these organization.
- Independent donor and initiation of self organized participant.
- Different supply of material resource and human employee with different activity by various organization.

These challenges have to be restricted through some constraint and objective functions following proper decision making process. A framework for concerning DM in the resource distribution by humanitarian logistic is presented to support theory, decision criteria, methodology and assumptions in [38]. Concept and characteristic of emergency decision making for quick response in different stages for natural disaster are elaborated in [39]. The mathematical model designed for risk management basically constructed involvement of decision making process. Tofighi et al. [40] developed a model with minimization of cost in stock prepositioning in first stage and minimization of total distribution time, maximization of weighted distribution time for items and total cost for unused inventories and unmet demand in the second stage. Abounacer et al. [41] proposed a model with minimization of transportation time, personal needs and uncovered demand in emergency response. A two-stage model is designed when supply and demand are uncertain in the article [42]. Noham and Tzur [43] developed a new humanitarian constraint incorporating with actual post disaster decision making through a mathematical model. Some mathematical models have focused on medical relief aid distribution formulating new algorithm are seen in [44,45]. In this paper one conception of redistribution of resources among the AAs after completion of a normal distribution process is developed defining through a mathematical model for humanitarian logistic in emergency situation. A few article in the literature have considered redistribution in disaster which influences to define a model with an essential fact of redistribution of resource. Redistribution of resources from unaffected cities to affected cities is considered in the article [1]. As disaster arises for creating chaos surrounding, uncertainty arises in estimation of demand and other parameters of the model. In this context, trapezoidal Neutrosophic number is used for dealing the uncertainty in this model. The vague, imprecise and inconsistent information of calamitous environment is dealt well by the usage of trapezoidal Neutrosophic number which presented in the literature by Smarandache et al. [46–52]. The three membership functions of Neutrosophic number viz. truth, indeterminacy and falsity simulates strongly in decision making process in the uncertain environment including all the practical aspect of a decision in real life. Significance of three membership function of a Neutrosophic number is more useful and pragmatic over the existing fuzzy number with one or two membership function.

3. Preliminaries

In this section, we have discussed some basic ideas of Neutrosophic sets with definition and some notation explaining the general concept.

Definition 1. [53]A single-valued Neutrosophic set Ψ over X taking the form as in [54] Ψ={$\langle x, T_\Psi(x), I_\Psi(x), F_\Psi(x) : x \in X\rangle$}, where $T_\Psi(x) : X \longrightarrow [0, 1]$, $I_\Psi(x) : X \longrightarrow [0, 1]$, $F_\Psi(x) : X \longrightarrow [0, 1]$ and $0 \le T_\Psi(x) + I_\Psi(x) + F_\Psi(x) \le 3\ \forall x \in X$. $T_\Psi(x)$, $I_\Psi(x)$, $F_\Psi(x)$ are the degree of truth membership, indeterminacy membership and false membership of x to Ψ respectively.

Definition 2. [53]The single valued trapezoidal Neutrosophic number $\tilde{\Psi}$ denoted by $\langle(a_1, a_2, a_3, a_4), T_\Psi, I_\Psi, F_\Psi\rangle$ is a Neutrosophic set in R with the truth, indeterminacy and falsity membership functions are given below:

$$T_\Psi(x) = \begin{cases} \alpha_{\tilde{\Psi}}\left(\dfrac{x-a_1}{a_2-a_1}\right) & \text{if } a_1 \le x \le a_2 \\ \alpha_{\tilde{\Psi}} & \text{if } a_2 \le x \le a_3 \\ \alpha_{\tilde{\Psi}} & \text{if } a_3 \le x \le a_4 \\ 0 & \text{otherwise} \end{cases}$$

$$I_\Psi(x) = \begin{cases} \dfrac{(a_2 - x + \beta_{\tilde{\Psi}}(x - a'_1))}{a_2 - a'_1} & \text{if } a'_1 \le x \le a_2 \\ \beta_{\tilde{\Psi}} & \text{if } a_2 \le x \le a_3 \\ \dfrac{(x - a_3 + \beta_{\tilde{\Psi}}(a'_4 - x))}{a'_4 - a_3} & \text{if } a_3 \le x \le a'_4 \\ 1 & \text{otherwise} \end{cases}$$

$$F_\Psi(x) = \begin{cases} \dfrac{(a_2 - x + \gamma_{\tilde{\Psi}}(x - a''_1))}{a_2 - a''_1} & \text{if } a''_1 \le x \le a_2 \\ \gamma_{\tilde{\Psi}} & \text{if } a_2 \le x \le a_3 \\ \dfrac{(x - a_3 + \gamma_{\tilde{\Psi}}(a''_4 - x))}{a''_4 - a_3} & \text{if } a_3 \le x \le a''_4 \\ 1 & \text{otherwise} \end{cases}$$

where $\alpha_{\tilde{\Psi}}, \beta_{\tilde{\Psi}}$ and $\gamma_{\tilde{\Psi}}$ are the maximum degree of truth, indeterminacy, falsity respectively.

$\alpha_{\tilde{\Psi}}$, $\beta_{\tilde{\Psi}}$ and $\gamma_{\tilde{\Psi}} \in [0,1]$.

Also, $a''_1 \le a_1 \le a'_1 \le a_2 \le a_3 \le a'_4 \le a_4 \le a''_4$.

The definition of ranking function and the arithmetic operation of the trapezoidal Neutrosophic number are refer to [53].

Definition 3. [55]A fuzzy set $\tilde{\Psi}$ on $\mathbb{R}$ is said o be a symmetric trapezoidal number if there exists real number $a_1, a_2, a_1 \le a_2$ and $h \ge 0$ such that

$$\tilde{a}(x) = \begin{cases} \frac{x}{h} + \frac{h - a_1}{h} & \text{for } x \in [a_1 - h, a_1] \\ 1 & \text{for } x \in [a_1 - h, a_1] \\ \frac{-x}{h} + \frac{h - a_1}{h} & \text{for } x \in [a_2, a_2 + h] \\ 0 & \text{otherwise} \end{cases}$$

We denoted it by $\tilde{a} = [a_1, a_2, h, h]$ when h=0; $\tilde{a} = [a_1, a_2]$

Symmetric trapezoidal numbers with three membership functions is symmetric trapezoidal Neutrosophic number. Symmetric trapezoidal Neutrosophic numbers are in the form $\tilde{\Psi} = (\Psi^l, \Psi^u, \alpha, \alpha, T_{\Psi}, I_{\Psi}, F_{\Psi})$, where Ψ^l, Ψ^u, α, α represent the lower, upper bound and first, second median value of trapezoidal number respectively [55,56].

3.1. De-neutrosophication method of trapezoidal Neutrosophic number

A new approach is developed to find equivalent crisp number for a trapezoidal Neutrosophic number by Basset et al. [53]. According to their method the crisp conversion formula has been defined bellow.

Let $\tilde{\Psi} = (\Psi^l, \Psi^{m1}, \Psi^{m2}, \Psi^u; \alpha_{\tilde{\Psi}}, \beta_{\tilde{\Psi}}, \gamma_{\tilde{\Psi}})$ be a trapezoidal Neutrosophic number, where Ψ^l, Ψ^{m1}, Ψ^{m2} and Ψ^u are lower bound, first and second median and upper bound respectively. Again, $\alpha_{\tilde{\Psi}}$, $\beta_{\tilde{\Psi}}$ and $\gamma_{\tilde{\Psi}}$ are the truth, indeterminacy and falsity degree of a trapezoidal Neutrosophic number respectively.

(a) If function is maximization problem then $R(\tilde{\Psi}) = \left(\frac{\Psi^l + 2(\Psi^{m1} + \Psi^{m2}) + \Psi^u}{2}\right) + (confirmation)$.
Mathematically it can be formulated as
$R(\tilde{\Psi}) = \left(\frac{\Psi^l + 2(\Psi^{m1} + \Psi^{m2}) + \Psi^u}{2}\right) + (T_{\tilde{\Psi}} - I_{\tilde{\Psi}} - F_{\tilde{\Psi}})$

(b) If function is minimization problem then $R(\tilde{\Psi}) = \left(\frac{\Psi^l - 3(\Psi^{m1} + \Psi^{m2}) + \Psi^u}{2}\right) + (confirmation)$.
Mathematically it can be formulated as
$R(\tilde{\Psi}) = \left(\frac{\Psi^l - 3(\Psi^{m1} + \Psi^{m2}) + \Psi^u}{2}\right) + (T_{\tilde{\Psi}} - I_{\tilde{\Psi}} - F_{\tilde{\Psi}})$

4. Motivation

The problem mentioned in Section 2 centralized its focus on the allocation of resource, minimization of different multi-criteria optimization techniques, mitigate the risk of disaster, etc. in different environment. But there are some facts which motivate us to make the mathematical model for humanitarian logistic. These are:

- Disaster is a world wide burning problem.
- To response disaster, an efficient plan is required quickly so that victims can get proper relief.
- Few researchers have considered the redistribution of resource in disaster.
- Few articles are developed considering Neutrosophic number in mathematical model for humanitarian logistic which is very interesting to define a practical aspect arising in disaster to handle uncertainty.

5. Problem statement and model formulation

Due to the calamitous event society is demolished and proper care is needed for their survive. This paper has brought a mathematical model for STP regarding humanitarian logistic for emergency response in the catastrophe. Also redistribution of resource to give more quick response is also defined by the mathematical model.

5.1. Concept of redistribution

When high intensive disaster like earthquake, Tsunami, flood, drought demolish a society, hurriedly it is required to convey the humanitarian items to the particular affected society. Regarding the injury of people and devastation of the AAs, humanitarian organizations e.g. the Federal Emergency Management Agency (FEMA), the International Federation of Red Cross and Red Crescent Societies (IFRC), etc. come forward and perform their best co-ordination to provide better response in the affected areas. The authority has arranged CDCs with humanitarian items for quick response. The govern authority has specified some RCs in particular AAs for keeping the humanitarian items after a proper evaluation about the region by a group of expert. For distribution of humanitarian items, some special type of conveyances which are reachable to the AAs in the midst of obstacle due to calamitous environment. According to Sheu [57] the first three days are the most crucial days for the emergency operation by the humanitarian logistic. After completion of the allocation in these crucial period, some areas get relief and the rate of consume amount of humanitarian items are decreasing. At the same time, it is not possible for all the AAs to get relief and recovering their normal stage as before the disaster. Consequently, they require more humanitarian items. So the response authority have initiated the stage of redistribution. The concept of redistribution in income, property, unemployment benefit for equality measure are seen in the literature [58–60]. This fact motivates to use the redistribution phenomenon in disaster response. The phase redistribution under this research basically is the re-arrangement of humanitarian items from the RCs where it is available due to low consumption rate of resources to the RCs where it is urgently required. Actually some places are recovered earlier from the effect of disaster and people in those areas consume little or a little amount of humanitarian items which make the RCs with excess humanitarian items and able to redistribute. The graphical abstract is represented in Fig. 1.

5.2. Mathematical model

Through the research, a mathematical model has introduced in emergency response for humanitarian logistic, which optimizes the two optimization criteria such as efficiency and effectiveness for humanitarian supply chain defined in [6]. For this model, optimization criteria used are minimization of total cost of the disaster operation and total time for redistribution. The mathematical model is constructed by the concept of STP employing in disaster operation. To deal the proper logistic network, there are CDCs from where humanitarian items are shipped to RCs established in the AAs through some conveyance. The demand arises in the AAs are not quite easy to measure in appropriate time. For smooth functioning of the logistic operation, demand of AAs

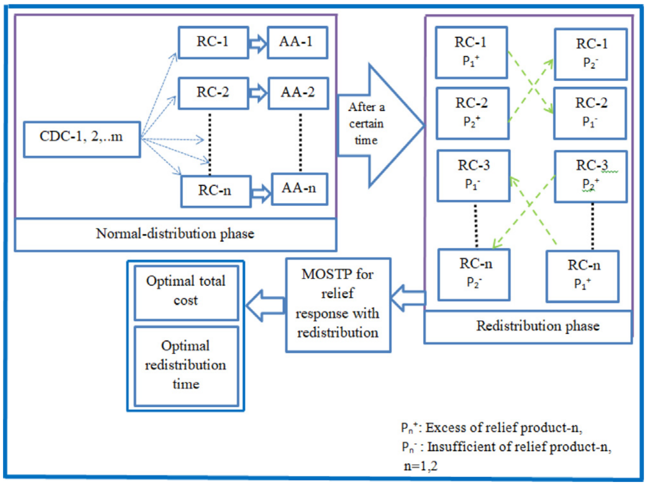

Fig. 1. Graphical representation of the mathematical model.

are considered as uncertain parameter. As the calamitous events destroy the communicating path, therefore to measure the cost for transporting the humanitarian items are quite difficult. So the transportation cost of the model is considered as uncertain parameter. In humanitarian logistic operation, the humanitarian items in the CDCs are arranged by the authority. In practical purpose, when disaster strikes many more humanitarian aid agencies are actively involved to manage the humanitarian items collecting from different region and stored in CDCs. The amount of storing items are not always same. When the RCs require humanitarian items, then it is shipped and again authority arranges humanitarian items if RCs urge for demand. The amount of storing items are not always same in the CDCs as there is a continuous flow from CDCs to RCs. Therefore, the amount of humanitarian items kept in the CDCs are considered in uncertain parameter. This model has initiated a redistribution phase after the completion of delivery circle to fill up RCs. Disaster like extensive flood when occurs it submerges many areas for some days. But after some days, the effect of flood is decreased in some particular areas and consequently the rate of consumption of humanitarian items are also decreases. Therefore the humanitarian items are become excessive in the RCs assign for the specific areas. At the same time it is obvious that some areas are still submerged in flood and require more humanitarian items. Regarding this incident, the authority can add phenomenon of redistribution in the transportation plan so as to redistribute the humanitarian items from RCs with excessive amount to the RCs where items are unavailable. When the authority have decided for redistribution, the transportation cost is not previously predictable due to damage condition of road and hence it is taken as uncertain parameters for our proposed model. The fact of redistribution is constructed by a constraint in the model. The other constraints and objective functions are formulated mathematically in the following Section 5.4.

5.2.1. Assumption for the model

- The mathematical model for MOSTP is an unbalanced problem.
- Different types of humanitarian items are transported from CDCs to the RCs where people can obtain relief.
- One RC is assigned for a particular AA and situated near to the AAs.
- The RCs are interconnected by communicating path.
- The phase of redistribution is started after a certain time period which is determined specifically for the model according to the degree of devastation by the disaster.
- Possible redistribution is not occurred between same two RCs.
- Same types of conveyances are used to distribute humanitarian items in both phases.
- Budget is restricted for the redistribution process.

5.3. Notations and parameters

5.3.1. Indices

- I: Set of CDCs indexed by i.
- J: Set of RCs indexed by j.
- K: Set of conveyances indexed by k.
- P: Set of humanitarian items indexed by p.
- J′: Set of RC with the requirement of pth humanitarian items in the redistribution phase indexed j'.

5.3.2. Parameter

$\tilde{c}^p_{ijk}$: Transportation cost for shipping the pth humanitarian items from ith CDCs to jth RCs through kth conveyance.

s^p_i: Processing cost for transporting pth humanitarian items from ith CDCs.

$\tilde{q}^p_{jj'k}$: Transportation cost for transferring the pth humanitarian items from jth RCs where it is available to empty j'th RCs through kth conveyance in redistribution phase.

s^p_j: Processing cost for transporting pth humanitarian items from jth RCs in redistribution phase.

$t^p_{jj'k}$: Transportation time for redistributing pth humanitarian items from jth RCs to j'th RCs through kth conveyance in redistribution phase.

τ^p_j: Service time for transporting pth humanitarian items from jth RCs available with items to empty RCs.

$\tilde{a}^p_i$: Availability pth humanitarian items at ith CDC

$\tilde{b}^p_j$: Demand of the pth humanitarian items at the jth RCs.

e^p_k: Capacity of the kth conveyance.

$b^{Ec}_{j'}$: Amount of pth humanitarian items which is left after consumption in the jth RC after the certain period of time and delivered to j'th RCs.

b^{Cp}_j: Amount of pth humanitarian items consumed in the jth RC after the certain period of time.

B: Budget for redistribution phase.

5.3.3. Decision variables

- x^p_{ijk}: Amount of pth humanitarian items shipped from ith CDCs to jth RCs through kth conveyance.
- $y^p_{jj'k}$: Amount of pth humanitarian items transferring from jth RCs to j'th RCs through kth conveyance in the phase of redistribution.
- $u^p_{jj'k}$ is binary variable defined as follows: $u^p_{jj'k} = \begin{cases} 1 & \text{if } y^p_{jj'k} > 0 \\ 0 & \text{otherwise} \end{cases}$
- $z_{jj'}$ is binary which takes the value 1 if redistribution phase arises, otherwise 0.
- ϕ^p_j is 1 if humanitarian items are available in RCs for redistribution, otherwise 0.

5.4. Mathematical formulation of the model

The mathematical model is designed in two phase of distribution where first phase is considered for the allocation of humanitarian items from CDCs to RCs and second phase is considered for redistribution of humanitarian items among the RCs. The model is presented below:

$$Min\, Z_1 = \sum_{k=1}^{K}\sum_{p=1}^{P}\left[\sum_{i=1}^{I}\left(\sum_{j=1}^{J}\tilde{c}_{ijk}^{p} + s_i^p\right)x_{ijk}^{p} + \sum_{j=1}^{J}\left\{\left(\sum_{j\prime=1}^{J\prime}\tilde{q}_{jj\prime k}^{p} + s_j^p\right)y_{jj\prime k}^{p}\right\}z_{jj\prime}\right] \tag{1}$$

$$Min\, Z_2 = \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{j\prime=1}^{J\prime}\sum_{k=1}^{K} t_{jj\prime k}^{p}u_{jj\prime k}^{p} + \sum_{j=1}^{J}\sum_{j\prime=1}^{J\prime}\sum_{p=1}^{P}\sum_{k=1}^{K}(\tau_j^p y_{jj\prime k}^{p})\phi_j^p \tag{2}$$

subject to

$$t_{jj\prime k}^{p} \in [T_1, T_2] \tag{3}$$

$$\tau_j^p \in [\tau_1, \tau_2] \tag{4}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} x_{ijk}^{p} \le \tilde{a}_i^p \quad \forall i, p \tag{5}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} x_{ijk}^{p} \ge \tilde{b}_j^p \quad \forall j, p \tag{6}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ijk}^{p} \le e_k^p \quad \forall k, p \tag{7}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} y_{jj\prime k}^{p} = b_{j\prime}^{Ep} \quad \forall j\prime, p \quad and \quad j \ne j\prime \tag{8}$$

$$b_{j\prime}^{Ep} = \tilde{b}_j^p - b_j^{Cp} \quad \forall j \ne j\prime \tag{9}$$

$$\sum_{j=1}^{J}\sum_{j\prime=1}^{J\prime}\sum_{k=1}^{K}\sum_{p=1}^{P}\left[\left(\tilde{q}_{jj\prime k}^{p} + s_j^p\right)y_{jj\prime k}^{p}\right]z_{jj\prime} \le B \quad \forall j \ne j\prime \tag{10}$$

$$\sum_{j=1}^{J}\sum_{j\prime=1}^{J\prime} y_{jj\prime k}^{p} \le e_k^p \quad \forall k, p \tag{11}$$

$$x_{ijk}^{p}, y_{jj\prime k}^{p} \in R^{+}, \tag{12}$$

The objective function (1) minimizes the total cost of the disaster operation including the transportation cost for shipping humanitarian items from CDCs to RCs in the first phase and transportation cost due to redistribution among the RCs in the second phase and the processing cost for humanitarian items in both the phases. The objective function (2) minimizes the total time in the redistribution stage including transportation time and the service time for humanitarian items. The constraints (3) and (4) define the time for transporting redistributed amount and processing time should be restricted by a particular interval. The constraint (5) defines that shipment from CDCs to RCs cannot exceed the availability of humanitarian items in the CDCs. The constraint (6) defines that transporting amount of humanitarian items are able to fulfill the demand of RCs. The constraint (7) is the capacity of conveyance to transport humanitarian items. The constraint (8) defines the redistribution of humanitarian items after a certain time interval according to the requirement of empty RCs by the other RCs which have available amount of items. The constraint (9) defines to measure the amount of humanitarian items redistributed to the RCs where items are finished after the consumption by the AAs from the RCs where items are excess i.e. amount of redistribution is the left amount of humanitarian items in some RCs which are available to deliver. The constraint (10) is the budget cost for redistribution. The constraint (11) is the capacity of conveyance for redistribution phase which is same as the previous stage. The constraint (12) is the non-negativity restriction.

6. Methodology for solution

The proposed model presented in Section 5.4 is a MOSTP. To solve this problem we have used following three techniques:

- Neutrosophic compromise approach,
- Goal programming approach and
- Pareto optimal solution approach

6.1. Neutrosophic compromise approach

Neutrosophic compromise approach is used to solved multi-objective transportation problem in the article [61]. Since the model introduced in the paper is also a form of MOSTP therefore, we have used this method to our problem.

- Solve MOSTP is solved considering each objective function Z_l at a time neglecting the others.
- For each objective function compute the minimum and maximum value for each function ($L_l = minZ_l$ and $U_l = maxZ_l$) to bound the functions in a range.
- The bound of Neutrosophic environment is defined as follows:
  $U_l^T = U_l$, $L_l^T = L_l$ for truth membership.
  $U_l^F = U_l^T$, $L_l^F = L_l^T + t_l(U_l^T - L_l^T)$ for falsity membership.
  $L_l^I = L_l^T + s_l(U_l^T - L_l^T)$, $L_l^I = L_l^T$ for indeterminacy membership.
- Construct the Neutrosophic compromise program as follows:

$$Max\, \alpha - \beta - \gamma \tag{13}$$

$$\begin{array}{l} \text{subject to} \\ Equation\,(3)\, to\, Equation\,(12) \\ Z_l + (U_l^T - L_l^T)\alpha \le U_l^T \end{array} \tag{14}$$

$$Z_l - (U_l^I - L_l^I)\gamma \le U_l^I \tag{15}$$

$$Z_l - (U_l^F - L_l^F)\beta \le U_l^F \tag{16}$$

$$\alpha \ge \gamma, \alpha \ge \beta, \alpha + \beta + \gamma \le 3, \quad \alpha, \beta, \gamma \in [0, 1], \quad k = 1, 2 \tag{17}$$

$$x_{ijk}^{p}, y_{jj\prime k}^{p} \in R^{+}, \tag{18}$$

- Solve the Neutrosophic compromise programming by LINGO optimization solver.

6.2. Goal programming approach

Implementation of goal programming approach to our model are described by the following steps:

- Solve the MOSTP taking one objective function at a time and find the ideal objective vector for developed model i.e. Z_1^{min} and Z_2^{min}.
- Formulate goal program using the objective vector as shown bellow:

  $Min\{\sum_{l=1}^{L}(d_l^+)^p+(d_l^-)^p\}^{\frac{1}{p}}$
  subject to
  $Z_l+d_l^+-d_l^-=Z_l^{min}$
  $d_l^+\geq 0,\ d_l^+d_l^-=0$
  Eqs. (3)–(12)
- Solve the goal program with single objective obtained in Step-2 using GRG method based LINGO software and obtain the compromise solution for the MOSTP.

6.3. Pareto optimal solution approach

If an optimal solution x^* to a problem is unique then x^* is called an M-Pareto solution of the problem. Uniqueness of x^* can be tested by the M-Pareto optimality test which is given below:

$Maximize \sum_{n=1}^{N}\xi_n$
subject to
$\mu_{Z_l}(x)-\xi_n=\mu_{Z_l}(x^*)$
$x\in X,\ \bar{\xi}=(\xi_1,\xi_2,\xi_3,\ldots,\xi_n)^T\geq 0$
For the optimal solution $\bar{x}$, $\bar{\xi}$ to problem:

(i) If $\bar{\xi}=0$, then x^* is a M-Pareto optimal solution of the problem.
(ii) If $\bar{\xi}\neq 0$, then $\bar{x}$ is a M-Pareto optimal solution of the problem.

M-Pareto optimal solution: $x^*\in X$ is said to be an M-Pareto optimal solution if and only if there does not exist another $x\in X$ such that $\mu_i(z_i(x))\geq\mu_i(z_i(x^*))\ \forall\ i$ and $\mu_j(z_j(x))\geq\mu_j(z_j(x^*))$ at least one j.

The solution methodology is explained with diagrammatic representation which is displayed in Fig. 2.

7. Computational studies

The model is explained with a numerical example. The input of the numerical data are considered artificially. Artificial data are used in the literature for explaining the functioning of the model [24]. In the mathematical model developed in this research work, supposed that there are two CDCs, four RCs, two types of conveyance, two types of humanitarian items. After the strike of disaster the CDCs are active and delivered the resources in the RCs which are assigned to serve AAs. After some days it has been noticed that the consumption of resources in some RCs are decreased due to lower effect of calamity. Whereas some areas are still being faced the higher impact of disaster and require large amount of resources to survive. Moreover, the RCs established to serve AAs are more near to each other than the CDCs and are connected. Therefore, the total cost and time for redistribution of resources from the RCs where it is available to the RCs where it is required are less than that of CDCs. In this regard, redistribution phase is initiated by the govern authority to give quick response with lowest cost. The certain period of time interval is specified as 8 days for this model to start redistribution phase.

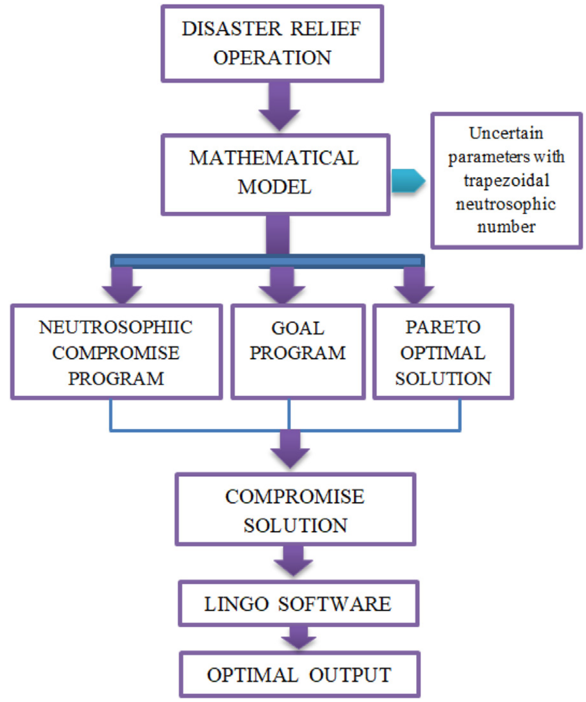

Fig. 2. Diagrammatic representation of solution methodology.

7.1. Input for the model

The mathematical model proposed in the paper is nothing but a MOSTP for humanitarian logistic. It consists of two objective functions

- Objective function for minimization of total cost (Z_1): The total cost is equal to total cost required to execute humanitarian logistic operation in which first phase of delivery is started with conveying of resources from CDCs to RCs and redistribution phase to redistribute among the RCs with their necessity. The first term of the this objective function is the total cost including transportation cost ($\tilde{c}_{ijk}^p$) and processing cost (s_i^p) multiplied by the transported amount of resources from CDCs to RCs (x_{ijk}^p). The second term relate with the total cost of redistribution if started including the transportation cost ($\tilde{q}_{jj'k}^p$) and processing cost (s_j^p) multiplied by the redistributed amount of resources ($y_{jj'k}^p$).
- Objective function for minimization of total time for redistribution (Z_2): Total time for the humanitarian logistic operation in the phase of redistribution is equal to the time required for the redistributed resources ($t_{jj'k}^p$) among the RCs and the service time (τ_j^p) transporting the resources ($y_{jj'k}^p$) from one RC according to their availability to another RCs where it is required.

The input for objective functions and the constraints are given in Tables (1)–(3). The uncertain parameter are taken in the form of symmetric trapezoidal Neutrosophic number as in [53].

8. Result discussion

The objective functions of the mathematical model in Section 5.4 is solved through three different techniques mentioned in Section 6. To obtain the optimal compromise solution of the

Table 1
Input of the objective function-1 for the model in INR.

Transportation cost of humanitarian items from CDCs to RCs.

j	$i=1$		$i=2$	
	$p=1$	$p=2$	$p=1$	$p=2$
		$k=1$		
1	(5,16,2,2;0.9,0.3,0.1)	(4,18,3,3;0.7,0.3,0.1)	(5,16,2,2;0.9,0.3,0.1)	(6,17,2,2,0.95,0.1,0.05)
2	(7,18,2,2;0.9,0.25,0.15)	(6,18,2,2;0.9,0.3,0.1)	(5,24,3,3;0.7,0.3,0.1)	(5,24,3,3;0.9,0.5,0.3)
3	(6,17,2,2,0.85,0.15,0.1)	(6,18,2,2,0.8,0.25,0.15)	(6,17,2,2;0.85,0.25,0.1)	(5,16,2,2;0.95,0.1,0.05)
4	(6,25,3,3;0.75,0.35,0.1)	(6,25,3,3;0.9,0.35,0.15)	(5,24,3,3;0.8,0.35,0.25)	(7,18,2,2;0.9,0.15,0.05)
		$k=2$		
1	(5,24,3,3;0.7,0.3,0.1)	(6,17,2,2;0.85,0.25,0.1)	(6,18,2,2;0.8,0.25,0.15)	(5,24,3,3;0.7,0.2,0.1)
2	(6,25,3,3;0.75,0.35,0.1)	(5,24,3,3;0.7,0.2,0.1)	(5,24,3,3;0.7,0.2,0.1)	(5,24,3,3;0.9,0.5,0.3)
3	(6,17,2,2;0.9,0.15,0.1)	(4,18,2,2;0.9,0.25,0.15)	(5,16,2,2;0.85,0.35,0.1)	(5,24,3,3;0.9,05,0.3)
4	(6,25,3,3;0.75;0.35,0.1)	(6,25,3,3;0.9,0.35,0.15)	(5,16,2,2;0.85,0.35,0.1)	(6,17,2,2;0.9,0.15,0.1)

Processing cost for CDCs

i	$p=1$	$p=2$
1	12	14
2	12	10

Transportation cost for the redistribution phase

j	j'=1	j'=2	j'=3	j'=4
		$k=1$, $p=1$		
1		(3,14,2,2;0.9,0.3,0.1)	(4,15,2,2;0.85,0.25,0.1)	(3,16,2,2;0.85,0.35,0.1)
2	(3,22,3,3;0.8,0.35,0.25)		(4,15,2,2;0.95,0.1,0.05)	(3,22,3,3;0.7,0.3,0.1)
3	(4,15,2,2;0.95,0.15,0.05)	(4,15,2,2;0.9,0.15,0.05)		(3,22,3,3;0.7,0.3,0.1)
4	(4,22,3,3;0.8,0.35,0.25)	(3,14,3,3;0.9,0.5,0.3)	(3,14,3,3;0.9,0.5,0.3)	
		$k=1$, $p=2$		
1		(3,15,2,2;0.9,0.25,0.15)	(4,15,2,2;0.9,0.15,0.05)	(4,15,2,2;0.9,0.15,0.05)
2	(5,16,2,2;0.9,0.3,0.1)		(4,15,2,2;0.9,0.15,0.05)	(3,14,2,2;0.9,0.15,0.05)
3	(4,15,2,2;0.95,0.1,0.05)	(4,15,2,2;0.9,0.15,0.05)		(4,15,2,2;0.95,0.1,0.01)
4	(5,16,2,2;0.9,0.3,0.1)	(3,15,2,2,;0.9,0.15,0.05)	(3,14,2,2;0.95,0.1,0.05)	
		$k=2$, $p=1$		
1		(4,15,2,2;0.85,0.35,0.1)	(4,16,2,2;0.9,0.25,0.15)	(3,14,2,2;0.9,0.15,0.05)
2	(4,15,3,3;0.9,0.5,0.3)		(4,15,2,2;0.95,0.1,0.05)	(2,15,2,2;0.85,0.35,0.1)
3	(4,23,3,3;0.7,0.3,0.1)	(3,15,2,2;0.8,0.25,0.1)		(4,16,2,2;0.9,0.25,0.15)
4	(4,15,3,3;0.9,0.1,0.05)	(3,22,3,3;0.8,0.35,0.25)	(3,15,2,;0.9,0.15,0.05)	
		$k=2$, $p=2$		
1		(3,22,3,3;0.8,0.35,0.25)	(3,14,3,3;0.9,0.5,0.3)	(3,14,2,2;0.95,0.1,0.05)
2	(5,16,2,2;0.9,0.15,0.05)		(3,14,3,3;0.9,0.5,0.3)	(3,15,2,2;0.9,0.25,0.15)
3	(4,16,2,2;0.9,0.25,0.15)	(2,15,2,2;0.85,0.35,0.1)		(4,22,3,3;0.8,0.35,0.25)
4	(4,22.3,3;0.8,0.35,0.25)	(3,15,2,2;0.8,0.35,0.1)	(3,14,3,3;0.9,0.5,0.3)	

Processing cost for redistribution phase

p	$j=1$	$j=2$	$j=3$	$j=4$
1	8	8	6	8
2	7	9	7	10

In table, index j indicates the number of RCs, i for CDCs, k for conveyances used, p for humanitarian item, j' for empty RCs.

mathematical model we have coded it through LINGO optimization solver and run using Intel core i5 of 4 gigabyte. The following sections briefly analysis about the result. The allocation of the resources and redistributed amounts are also shown below in Table (5).

8.1. Optimal result

The optimal result obtained by the three techniques are shown in Table (4). The optimal cost and time obtained by different methods used in this paper are varied. The Neutrosophic compromise approach gives the more perfect result in comparison of goal programming approach and Pareto optimal solution approach. The variation of the results for minimization of cost and minimization of redistributing time are portrait through Fig. 3 and 4 respectively.

8.2. Analytical view of result

The allocated amount of humanitarian items from the CDCs to the RCs arranged at the AAs are shown in Table (5). The allocated amount of humanitarian items are exhibited through Fig. 5. From the figure we can assure that through this model demand of RCs are fulfilled by CDCs. The distribution of items from two different CDCs are displayed through Figs. 6 and 7. The effect of catastrophe varies with time. This change leads to the fact that lower the effect of disaster lowers the consumption of resources. Again, when high intensive disaster strikes it creates more injury and demands of

Table 2
Input of the objective function-2 for the model in hour.

Transportation time for the redistribution phase								
j	j'=1	j'=2	j'=3	j'=4	j'=1	j'=2	j'=3	j'=4
	k = 1, p = 1				k = 1, p = 2			
1		2	3	3.9		3.5	2.2	2.2
2	2.7		2.3	3.8	3		3.2	3.7
3	2.2	3.2		3.8	2.3	3.2		2.3
4	2.7	3.2	3.2		2.5	3.5	3.3	
	k = 2, p = 1				k = 2, p = 2			
1		3.9	2.5	3.2		3.7	3.6	3.3
2	2.6		2.3	2.9	2.2		3.6	2.7
3	2.8	3.4		2.5	2.5	2.9		2.7
4	2.6	3.7	3.5		2.7	3.4	3.6	

Service time for redistribution phase				
p	j'=1	j'=2	j'=3	j'=4
1	4	3	3	4.5
2	3	4	4	3.5

In table, index j indicates the number of RCs, i for CDCs, k for conveyances used, p for humanitarian item, j' for empty RCs.

Table 4
Optimal result for the mathematical model.

Optimal result		
Method	Optimal cost (INR)	Optimal time (h)
Neutrosophic compromise approach	3497.815	62.4
Goal programming approach	3536.9	64.7
Pareto optimal solution approach	4299.2	82.5

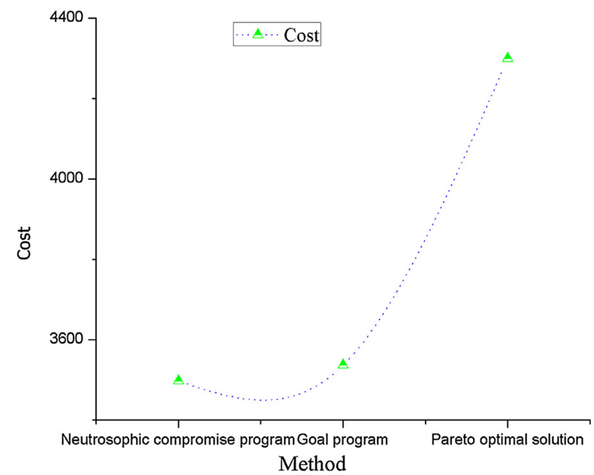

Fig. 3. Variation of cost with different techniques.

first aid service more than the food. Whereas more food will be required after the recovery from the injurious stage. Regarding this fact, the decision has been made to redistribute the items among RCs according to the their needs. According to the decision, flow of humanitarian items from CDCs to RCs are successfully done for 8 days. Concern authority has noticed that after 8 days, RC-3 have excess amount of humanitarian items-1. At the same time, RC-1 and RC-4 is unavailable with the same item. So RC-3 dispatch the humanitarian item-1 to the RC-1 and RC-4. As RC-3 sent its excess amount, therefore the amount may be more than the requirement of the RC-1 and RC-4. But it is observed by the authority that RC-1 does not consume the all amount dispatched from RC-3. RC-1 again redistribute the item-1 to RC-2 as it has urgently required it. On the other hand, RC-1 is available with humanitarian item-2 as it is consumed less in the RC-1. So item-2 is redistributed to the RC-2 and RC-3 as per its urgency from RC-1. The phenomena of redistribution is shown in Table (5). The redistributed amount of humanitarian items from RC-3 to RC-1 and RC-4 is displayed through Fig. 8. Again the redistributed amount from RC-1 to RC-2 and RC-3 can be measure by the graphical representation portrait in Fig. 9 (Table 6).

8.2.1. A particular case considering no excess amount of humanitarian items in response centers

Suppose, there is no excess amount of resources in the RCs then redistribution is not started. So, in this mathematical model second phase has not initiated. Then only first phase occurs which is the normal distribution of the resources. Total cost of the emergency

Table 3
Input of the constraints for the model.

Capacity of CDC (quintal)		
i	p = 1	p = 2
1	(98,111,5,5;0.9,0.35,0.05)	(85,90,4,4;0.85,0.25,0.1)
2	(95,114,5,5;0.9,0.3,0.1)	(108,123,6,6;0.9,0.3,0.1)

Conveyance capacity (quintal)		
k	p = 1	p = 2
1	50	55
2	90	98

Demand of RCs (quintal)				
p	j=1	j=2	j=3	j=4
1	(29,38,2,2;0.9,0.3,0.1)	(25,30,2,2;0.9,0.25,0.15)	(25,30,2,2;0.9,0.25,0.15)	(29,38,2,2;0.9,0.3,0.1)
2	(30,46,4.5,4.5;0.85,0.2,0.15)	(30,48,4.5,4.5;0.85,0.2,0.15)	(25,30,2,2;0.9,0.25,0.15)	(30,46,4.5,4.5;0.85,0.2,0.15)

Demand of RCs after a certain period of interval (quintal)				
p	j'=1	j'=2	j'=3	j'=4
1	4	2	–	4
2	–	3	3	–

Budget for redistribution: 5000 INR

In table, index j indicates the number of RCs, i for CDCs, k for conveyances used, p for humanitarian item, j' for empty RCs.

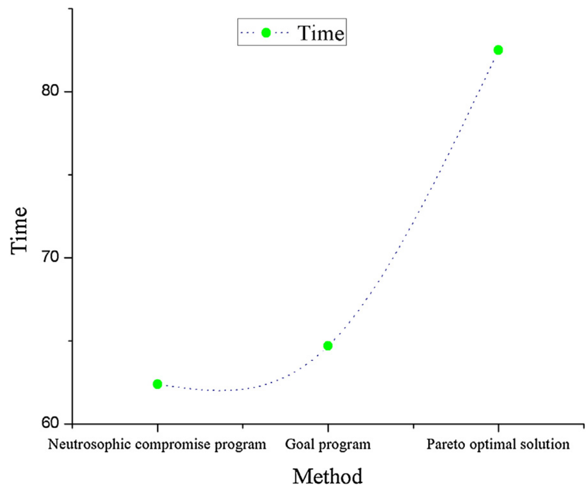

Fig. 4. Variation of time with different techniques.

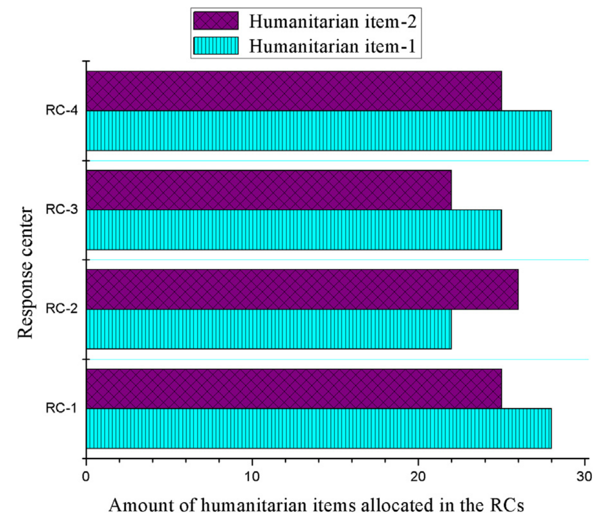

Fig. 5. Allocation of humanitarian items to fulfill the demand from CDC to RCs.

response plan is only transportation cost and processing cost for shipping humanitarian items. Therefore, cost for redistribution phase is zero. Consequently, the second objective function in the mathematical model is vanished. In this context, the total optimal result for minimization of cost of disaster response is $Z_1 = 3303.00$ INR. But in this case, long termed delivery would be required by the CDCs to fulfill the all demand of RCs after 8 days also as humanitarian items are required in all RCs but no RCs carries the excess amount which implies CDCs are the only source to fulfill the demand. As the transportation cost from CDCs to RCs is more than the transportation cost for redistribution among RCs, so total cost is increased. Therefore to fulfill the demand after 8 days convey of humanitarian items are required from CDCs with more cost compared to the redistribution-phase and cost is $Z_1 = 4113.90$ INR, as those RCs are visited by the vehicles carrying humanitarian items.

8.2.2. Limitation of the model when all response centers are available with the humanitarian items

After a certain time, when the effect of disaster is diminished and almost all areas are recovered, then the RCs are available with sufficient humanitarian items. Since the redistribution fact is defined through a constraint so by this mathematical model extra

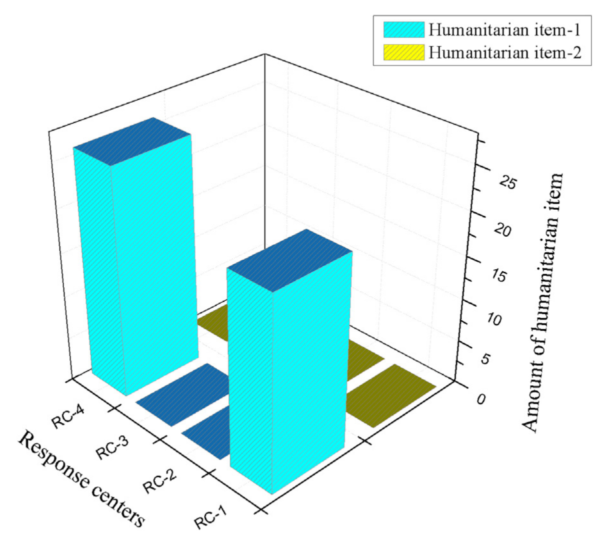

Fig. 6. Allocation of humanitarian items from CDC-1 to RCs.

Table 5
Allocation of humanitarian items.

Distribution of humaniatarian items from CDCs to AAs for neutrosophic compromise approach in quintal								
$k=1$					$k=2$			
j	$i=1$		$i=2$		$i=1$		$i=2$	
	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$
1	21.66727	6.7375	6.145546	2.0	0.1871847	–	–	23.0
2	–	–	22.0	26.0	–	–	–	–
3	–	–	–	22.0	–	–	25.0	–
4	0.1156353	–	–	–	25.96729	–	1.917075	25.0

Redistribution of humanitarian items								
j	$j'=1$		$j'=2$		$j'=3$		$j'=4$	
	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$
1			2.0	3.0		3.0	–	–
2	–	–			–	–	–	–
3	4	–	–	–			–	–
4	–	–	–	–	4	–		

In table, index j indicates the number of RCs, i for CDCs, k for conveyances used, p for humanitarian item, j' for empty RCs.

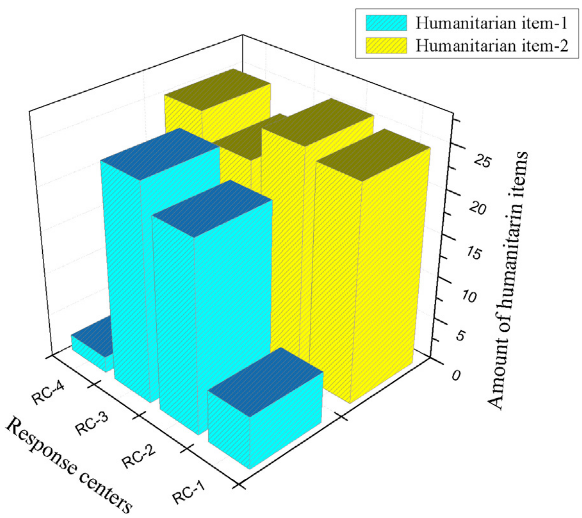

Fig. 7. Allocation of humanitarian items from CDC-2 to RCs.

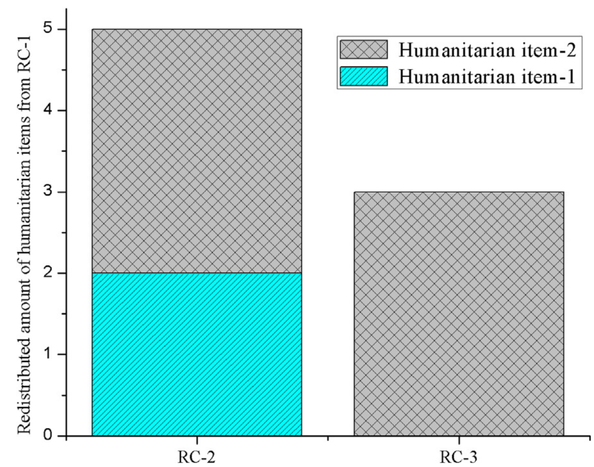

Fig. 9. Redistribution of humanitarian items to fulfill the demand from RC-2 and RC-3 by RC-1.

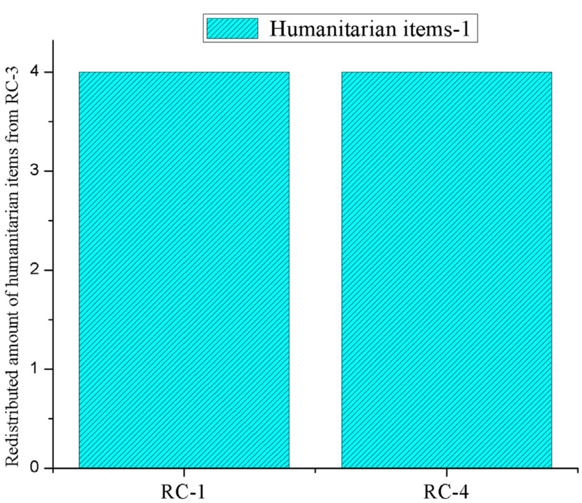

Fig. 8. Redistribution of humanitarian items to fulfill the demand from RC-1 and RC-4 by RC-3.

amount is redistributed among the RCs. In this research, as there is no stopping criteria for redistribution is defined in the mathematical model, so after a particular time horizon it is redistributed among the RCs causes higher cost and time. But when all the AAs are recovered, then concern authority stop to redistribute the humanitarian items after a particular time period. The result for the objective functions in this respect $Z_1 = 3749.1$ INR and $Z_2 = 152.9$ h. The time shows that it is continuously running for an unnecessarily long term. So, authority should concern in this prospect to stop their delivery when RCs are available with extra amount of humanitarian items.

9. Managerial insights with logical comments

The overall research performed in this paper focuses on distribution of relief aid in order to response disaster. An emergency response plan is provided through a mathematical model regarding the quick arrangement of resource in such calamitous event like flood, Tsunami, earthquake, terrorist attack, etc. The plan is helpful to influence the DM for taking decision in case of emergency environment as there is a new concept of

Table 6
Allocation of humanitarian items in different method.

Distribution of humaniatarian items from CDCs to AAs for goal programming in quintal								
	$k=1$				$k=2$			
j	$i=1$		$i=2$		$i=1$		$i=2$	
	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$
1	13.0	–	15.0	2.0	–	–	–	23.0
2	–	–	22.0	26.0	–	–	–	–
3	–	–	–	22.0	–	–	25.0	–
4	–	–	–	–	–	–	28.0	25.0
Distribution of humaniatarian items from CDCs to AAs for Pareto optimal solution in quintal.								
	$k=1$				$k=2$			
j	$i=1$		$i=2$		$i=1$		$i=2$	
	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$	$p=1$	$p=2$
1	–	–	–	10.0	–	–	28.0	15.0
2	–	23.0	–	–	–	–	29.0	3.0
3	22.0	22.0	–	–	3.0	–	–	–
4	28.0	–	–	–	–	30.0	–	–

In table, index j indicates the number of RCs, i for CDCs, k for conveyances used, p for humanitarian item, j' for empty RCs.

redistribution of resources is defined through this model. The mathematical model is a MOSTP which optimizes the total cost and total redistribution time in the emergency operation so as to quick delivery of humanitarian items to the victims. After finding the solution through three different methods mentioned in Section 6 optimal results are obtained for the total cost and redistribution time. Moreover, optimal allocation from CDCs to RCs and the amount of redistribution among the RCs are also measured for the model. Fig. 3 and 4 have shown the variation of cost and time w.r.t the different solution techniques. This can help DM to choose the best approach for finding optimal decision to quick response. The concept of redistribution is in the emergency response through this model. As the transportation cost is required more when the humanitarian items are shipped from the CDCs to RCs than RC to RC, therefore the decision of redistribution causes lowest cost to operate the emergency plan. Through this model it is cleared when we have analyzed the computational study by considering no excess amount of humanitarian items for all RCs after 8 days, which directly implies redistribution phase cannot operate. Again, limitation of the mathematical model is also analyzed by applying the condition of excess amount of humanitarian items in all the RCs.

10. Conclusion and future scopes

In this research investigation, a new mathematical model for MOSTP with two objective functions namely minimization of cost and minimization of time have been introduced. MOSTP is considered in mixed uncertain environment as some of the parameter are in crisp form and some others are in uncertain form. The uncertainty of those parameters are described in terms of trapezoidal neutrosophic number. Three different techniques are used to solve the MOSTP with two objective functions viz. (1) Neutrosophic compromise programing approach, (2) goal programming approach and (3) Pareto optimal solution method. A new concept of redistribution of resource among the affected areas in emergency management is defined through the mathematical model which is useful for decision making process in disaster response operation. A comparative study is also performed among these three techniques mention above. The performance measure of the model has been derived by computing a numerical study and solved using LINGO optimization solver.

In this manuscript, MOSTP for humanitarian logistic is defined in mixed uncertain environment. Demand of the AAs for the normal distribution phase is considered as the uncertain measure. But the requirements of the AAs for redistribution phase is in crisp form. For future extension it can be taken in uncertain measure. As calamitous events bring misery to the society and regarding the critical condition many more organization collected money as donation and total budget may not always fixed for the disaster operation. So, for further research the budget can be considered in uncertain measure. Through this research redistribution of relief materials are assumed. But one can extend it in medical emergency care with limited service in disaster after initial treatment of wounded, the most sever one is admitted for proper care and recovered are shifted to shelter point. The model defined in this paper can also solved by adopting different heuristic techniques as in [45]. Since, the limitation of the model is mentioned in Section 8.2.2, one can extent the model by defining stopping criteria for further research.

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