Chapter 6

Multi-objective solid transportation -location problem in inventory management[1]

This chapter acquaints a streamlining model that incorporates FLP, STP, and inventory management under a multi-objective environment. The aims of the stated formulation are multi-fold: *(i)* seek the optimum locations for potential facilities in Euclidean plane; *(ii)* find the amount of distributed commodities; and *(iii)* reduce the overall transportation cost, transportation time, and inventory cost along with the carbon emission cost. Here, variable carbon emission cost is taken into consideration because of the variable locations of facilities and the amount of distributed products. After that, a new hybrid approach is introduced dependent on an alternating locate-allocate heuristic and the intuitionistic fuzzy programming to get the Pareto-optimal solution of the proposed formulation. In fact, the performances of our findings are discussed with a numerical example. Sensitivity analysis is executed to check the resiliency of the parameters. Ultimately, managerial insights and conclusions are offered at the end of this study.

6.1 Introduction

FLP, STP and inventory management are the core components of supply chain management. Deciding the optimal locations for the facilities such as retailer-outlets, plants, terminals, workplaces, fire stations, railroad stations, and so forth and optimizing the overall logistics cost, transportation time and inventory cost by different transportation modes can significantly affect the management system. Therefore, the significance of the integrated model helps an organization to increase efficiency and decrease the wastage. The primary level of the integrated model consists of location cost, inventory cost, and transportation cost. Therefore, the trade-off between these cost factors is the major component of this model.

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Nowadays, due to enormous transportation systems, huge quantities of carbon dioxide emit into the atmosphere, which is the crucial clarification for an unnatural climate change. To reduce carbon discharge, the government endorses a couple of strategies wherein carbon tax policy is commonly acquired. According to this policy, the carbon discharge holders have to pay the carbon tax for each unit of carbon emission to the government. Here, an unprecedented mathematical model is introduced by incorporating FLP, inventory management, and STP under multi-objective decision making environment. Consequently, the stated model is referred as *multi-objective solid transportation-location problem* (MOST-LP). In MOST-LP, the DM asks for the best positions of potential facilities in the Euclidean plane and quantities of distributed items by different modes of transportation simultaneously with minimizing the stated goals. It is believed that the above mathematical model will be more relevant than conventional FLP, inventory management, and MOSTP. It is also evident that several uncertainties occur in a transportation system because of insufficient information from the market situation. For that reason, IFS is introduced dependent on an assumption wherein member is expressed by two degrees, namely, membership and non-membership. For more explanations of the intuitionistic fuzzy environment, we suggest to the Chapter 1.

The major contributions of this chapter are highlighted as:

- An unprecedented non-linear mathematical formulation based on FLP, inventory management, and MOSTP is presented.
- The formulation provides a decision regarding the assignment from numerous existing sites to several potential sites in the Euclidean plane with a distance function.
- The overall logistics cost and time, and inventory cost by different modes of transportation are also considered.
- Variable carbon emission cost is incorporated which is a significant issue in the modern time.
- A hybrid approach is described to get the Pareto-optimal solution of MOST-LP.
- The characteristic of the derived compromise solution is also discussed.

6.2 Modeling framework

In this section, we initially delineate the stated problem, that is, the multi-objective solid transportation-location problem within an inventory management framework. In this regard, we incorporate the notations and state the assumptions to formulate the mathematical model. Eventually, the coordination between MOST-LP and MOSTP is discussed. Finally, some basic definitions are defined for the development of the study.

6.2.1 Problem description

Herein, an unprecedented strategic formulation is investigated from an environmental and economical frame of reference. This study deals with a solid logistics framework, which comprises of multiple suppliers treated as existing facilities, retail outlets addressed as potential facilities, and commodities are distributed from some suppliers to certain retail outlets through warehouses considered as existing facilities. The important goal is to reduce the overall conveyance cost, time, and inventory cost along with the carbon discharge cost of finding the potential sites simultaneously. Apart from the logistics cost and delivery time, the following postures are also taken into consideration: *(i)* the weights of the conveyances which affect the logistics cost, delivery time and carbon emission cost, *(ii)* weights of the obstacles in the way which are considered in conveyance time, *(iii)* variable carbon emission cost, *(iv)* fixed cost for opening the warehouses, *(v)* each of the warehouses pursues a continuous review policy, that is, a fixed quantity is ordered from the suppliers when the inventory level at warehouses gets below the reorder point and preserves it for future uses, *(vi)* before preserving, a screening process is performed at the warehouses for selecting the defective items and it is backed for changing to the producer at the next slot of order, *(vii)* when there is a requirement for the items, the warehouses supply the items according to their requirement, *(viii)* deterioration occurs in the warehouses if the items are deteriorating in nature, and *(ix)* shortages are not allowed in the warehouses because the DM always preserves a safety stock, as this is a continuous review inventory policy. Therefore, the total inventory cost of the system consists of ordering cost, holding cost, fixed cost, screening cost, deterioration cost, purchasing cost and carbon emission cost. Fig. 6.1 illustrates the

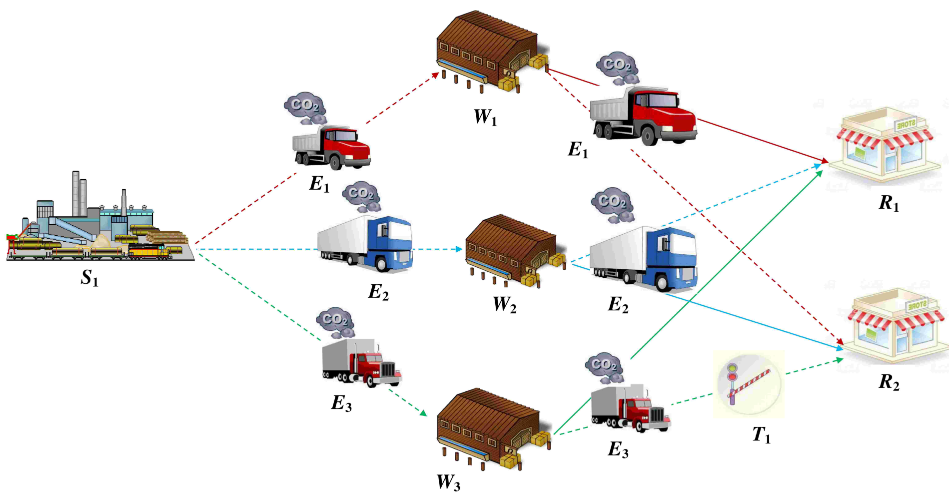

Fig. 6.1: Pictorial representation of MOST-LP.

structure of MOST-LP network. Assume that there is one supplier S_1, three warehouses W_1, W_2 and W_3, and two retail outlets R_1 and R_2. The supply and demand of the relating facilities are provided. Furthermore, the locations of S_1, W_1, W_2, and W_3 are given. But, the locations of R_1 and R_2 are not known in the two-dimensional space. In fact, the dotted paths indicate the product flow by three different transportation modes such as E_1, E_2, and

E_3 from S_1 to R_1 and R_2 through W_1, W_2, and W_3, respectively. Moreover, the obstacle is assigned as T_1. In this circumstance, we have to find the optimum positions of the potential facilities with the stated goals.

6.2.2 Notations & Assumptions

This subsection describes the notations and assumptions corresponding to the stated model:

I: Set of suppliers indexed by i.

J: Set of retailers indexed by j.

K: Set of warehouses indexed by k.

L: Set of transportation modes indexed by l.

d_{1j}: Average demand rate for the product from j^{th} retailer.

d_{2k}: Average demand rate for the product from k^{th} warehouse.

f_k: Fixed cost for opening k^{th} warehouse.

B_i: Unit purchasing cost of an item from i^{th} supplier.

A_{ik}: Unit ordering cost from i^{th} supplier to k^{th} warehouse.

G_{kj}: Unit ordering cost from k^{th} warehouse to j^{th} retailer.

g_k: Unit screening cost at k^{th} warehouse.

H_k: Unit holding cost at k^{th} warehouse is time-dependent (t) and it also depends on the location of the warehouse and it is represented by $H_k = th_{1k} + h_{2k}\sqrt{{r_k}^2 + {s_k}^2}$, where h_{1k} and h_{2k} are constants.

D_k: Unit deterioration cost at k^{th} warehouse.

m: Number of suppliers.

n: Number of warehouses.

p: Number of retailers.

q: Number of transportation modes.

q': Number of objective functions.

w^l_{ikj}: Unknown amount to be distributed from i^{th} supplier to j^{th} retailer through k^{th} warehouse by l^{th} different transportation modes.

W: $\{(w^l_{ikj}) : \forall\, i, j, k, l\}$: the feasible space.

W^B: $\{(w_{ikj}^{lB}) : \forall\, i,j,k,l\}$: the optimal feasible set.

(u_i, v_i): Coordinate of the i^{th} supplier $(i = 1,2,\ldots,m)$.

(r_k, s_k): Coordinate of the k^{th} warehouse $(k = 1,2,\ldots,n)$.

(x_j, y_j): Coordinate of the j^{th} retailer $(j = 1,2,\ldots,p)$.

F: $\mathbb{R}^{2p} \times W$, where $(x,y) \in \mathbb{R}^{2p}$ and $w \in W$, the feasible set.

a_k: Availability in the k^{th} warehouse $(k = 1,2,\ldots,n)$.

b_j: Demand at the j^{th} retailer $(j = 1,2,\ldots,p)$.

c_l: Capacity of the l^{th} transportation mode $(l = 1,2,\ldots,q)$.

α_i: In a location problem, the DM may put more important of the supplier with respect to transportation cost, expressed as weight. Therefore, with each i^{th} supplier, we associate a weight α_i.

α'_k: Nonnegative weight of the k^{th} warehouse with respect to transportation cost $(k = 1,2,\ldots,n)$.

β_i: Nonnegative weight of the i^{th} supplier with respect to transportation time $(i = 1,2,\ldots,m)$.

β'_k: Nonnegative weight of the k^{th} warehouse with respect to transportation time $(k = 1,2,\ldots,n)$.

ε_l: Nonnegative weight of the l^{th} transportation mode cost a unit measure of goods $(l = 1,2,\ldots,q)$.

δ_{ik}: There might be utilized an alternate kind of transportation modes to distribute the products from the i^{th} site to the k^{th} site. Based on their machine execution, a weight δ_{ik} is designated.

δ_{kj}: Nonnegative weight (machine performance) of conveyances to transfer the assignment from the k^{th} site to the j^{th} site.

ε'_l: Nonnegative weight of the l^{th} conveyance time a unit measure of goods $(l = 1,2,\ldots,q)$.

t_{ik}: There might be a few barriers (e.g., bridge crossing, broken-down, railway level crossing, and so on) of the way from the i^{th} supplier to the k^{th} warehouse which is influenced the conveyance time. These will be assigned as t_{ik}.

t_{kj}: Nonnegative weight (obstacle) of paths from the k^{th} warehouse to the j^{th} retailer.

γ: Tax for per unit item that emits carbon dioxide.

ε_l'': Nonnegative weight of the l^{th} conveyance carbon emission a unit measure of commodity $(l = 1, 2, \ldots, q)$.

$\mathbf{Z}$: Objective function vector.

M: Membership function.

N_o: Non-membership function.

$U'_{q'}$: Upper bound of the q'^{th} objective function.

$L'_{q'}$: Lower bound of the q'^{th} objective function.

There are the following functions and assumptions:

- $\phi_l(u_i, v_i; r_k, s_k) = \varepsilon_l \varphi(u_i, v_i; r_k, s_k)$: transportation cost function a unit measure of goods from i^{th} supplier to k^{th} warehouse by l^{th} conveyance, where $\varphi(u_i, v_i; r_k, s_k)$ is a hyperbolic approximation of Euclidean distance in two-dimensional space $\left(\varphi(u_i, v_i; r_k, s_k) = \sqrt{(u_i - r_k)^2 + (v_i - s_k)^2 + \delta_{ik}}\right)$.
- $\phi_l(r_k, s_k; x_j, y_j) = \varepsilon_l \varphi(r_k, s_k; x_j, y_j)$: transportation cost function per unit item from k^{th} warehouse to j^{th} retailer by l^{th} conveyance, where $\varphi(r_k, s_k; x_j, y_j) = \sqrt{(x_j - r_k)^2 + (y_j - s_k)^2 + \delta_{kj}}$.
- $\psi_l(u_i, v_i; r_k, s_k) = \varepsilon_l' \tau(u_i, v_i; r_k, s_k)$: transportation time function per unit product from i^{th} supplier to k^{th} warehouse by l^{th} conveyance, where $\tau(u_i, v_i; r_k, s_k) = \sqrt{(u_i - r_k)^2 + (v_i - s_k)^2 + t_{ik} + \delta_{ik}}$.
- $\psi_l(r_k, s_k; x_j, y_j) = \varepsilon_l' \tau(r_k, s_k; x_j, y_j)$: transportation time function per unit flow from k^{th} warehouse to j^{th} retailer by l^{th} conveyance, where $\tau(r_k, s_k; x_j, y_j) = \sqrt{(x_j - r_k)^2 + (y_j - s_k)^2 + t_{kj} + \delta_{kj}}$.
- $\rho_l(u_i, v_i; r_k, s_k) = \varepsilon_l'' \rho(u_i, v_i; r_k, s_k)$: carbon emission function per unit transported item from i^{th} supplier to k^{th} warehouse by l^{th} conveyance, where $\rho(u_i, v_i; r_k, s_k) = \sqrt{(u_i - r_k)^2 + (v_i - s_k)^2 + \delta_{ik}}$.
- $\rho_l(r_k, s_k; x_j, y_j) = \varepsilon_l'' \rho(r_k, s_k; x_j, y_j)$: carbon emission function per unit transported good from k^{th} warehouse to j^{th} retailer by l^{th} conveyance, where $\rho(r_k, s_k; x_j, y_j) = \sqrt{(x_j - r_k)^2 + (y_j - s_k)^2 + \delta_{kj}}$.
- The solution space where the facilities are situated is the continuous planner surface. Furthermore, the facility plants are considered as Euclidean points.
- The facility sites have some capacity. The nature of the parameters is deterministic. The distances are assumed as a hyperbolic approximation of Euclidean metric in the Euclidean plane.

- The distributed commodity is the homogeneous type. The nature of transportation modes is heterogeneous. Logistics cost, deliver time, and carbon emission are directly proportional to the unit of shipped commodities.
- There does not exist any connection between the potential facilities. The installation costs of potential facilities are also overlooked.
- The supplier has a limited capacity, so, warehouses are established. Shortages are not allowed in this model. The lead time is 0 and the replenishment rate is finite.
- There are no replacements of the deteriorated commodities during transportation. Deterioration cost is calculated because the supplied items are deteriorating in nature. There are fixed opening costs for opening warehouses.
- Holding cost is time-dependent as with time the rate of deterioration increases simultaneously. The holding cost is also dependent on the locations of the warehouse as the holding cost for a warehouse which is located at a far distance from town will be less.

6.2.3 Model formulation

Here, a mathematical model is introduced in the light of FLP, inventory management, and MOSTP. Indeed, this formulation finds distributed commodities and optimum locations for the potential facilities at the same time. The mathematical model of MOST-LP along with carbon emission cost can be stated as follows:

Model 6.1

$$\text{minimize} \quad Z_{1(x,y,w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(\alpha_i\phi_l(u_i,v_i;r_k,s_k)+\alpha'_k\phi_l(r_k,s_k;x_j,y_j)\right)w^l_{ikj} \tag{6.1}$$

$$\text{minimize} \quad Z_{2(x,y,w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(\beta_i\psi_l(u_i,v_i;r_k,s_k)+\beta'_k\psi_l(r_k,s_k;x_j,y_j)\right)w^l_{ikj} \tag{6.2}$$

$$\begin{aligned}\text{minimize} \quad Z_{3(x,y,w)} = &\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(d_{2k}A_{ik}+d_{1j}G_{kj}\right)w^l_{ikj}+\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}H_k w^l_{ikj}\\ &+\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}D_k w^l_{ikj}+\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}B_i w^l_{ikj}\\ &+\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}g_k w^l_{ikj}+\sum_{k\in K}f_k\\ &+\gamma\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(\rho_l(u_i,v_i;r_k,s_k)+\rho_l(r_k,s_k;x_j,y_j)\right)w^l_{ikj}\end{aligned} \tag{6.3}$$

$$\text{subject to} \quad \sum_{i\in I}\sum_{j\in J}\sum_{l\in L}w^l_{ikj}\le a_k \quad \forall\ k, \tag{6.4}$$

$$\sum_{i\in I}\sum_{k\in K}\sum_{l\in L}w^l_{ikj}\ge b_j \quad \forall\ j, \tag{6.5}$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}w^l_{ikj}\le c_l \quad \forall\ l, \tag{6.6}$$

$$w^l_{ijk}\ge 0\ \forall\ i,j,k,l, \tag{6.7}$$

$$\sum_{k\in K}a_k\ge\sum_{j\in J}b_j \text{ and } \sum_{l\in L}c_l\ge\sum_{j\in J}b_j. \tag{6.8}$$

The objective function (6.1) objects to determine the optimum positions for p-facilities which minimize the overall logistics cost. Terms 1 and 2 of (6.1) represent the transportation cost from i^{th} supplier to k^{th} warehouse, and k^{th} warehouse to j^{th} retailer by l^{th} conveyance, respectively. The objective function (6.2) intents to reduce the overall conveyance time from i^{th} supplier to j^{th} retailer through k^{th} warehouse by l^{th} conveyance, seeking the optimum positions for p-facilities. The objective function (6.3) indicates to optimize the total inventory cost along with carbon emission cost by determining the optimum locations for the p-facilities. Terms 1-6 of (6.3) express the inventory related costs such as ordering cost from warehouses to suppliers and retailers to warehouses, holding cost of storage and maintenance of items in the warehouses, deterioration cost of the deteriorating items in the warehouses, purchasing cost of all items from suppliers, screening cost for selecting the imperfect units from the items delivered by the suppliers and the imperfect units are returned back to the suppliers at next slot, fixed cost for opening the warehouses. Term 7 of (6.3) displays the total carbon emission cost for transporting the goods from i^{th} supplier to k^{th} warehouse, and k^{th} warehouse to j^{th} retailer by l^{th} transportation mode. Constraints (6.4) enforce that the overall distributed quantity of each warehouse must be less or equal to its capacity. Constraints (6.5) impose that the overall shipped units of each retailer fulfill the demand. Constraints (6.6) demonstrate that the overall transported flows of each transportation mode cannot surpass its ability. Constraints (6.7) are the nonnegativity condition. Ultimately, Constraints (6.8) refer to the feasibility criterion of the problem.

6.2.4 Connection between MOST-LP and MOSTP

The functions (i.e., ϕ_l, ψ_l and ρ_l) rely upon the locations of the potential facilities. In this regard, we determine the best locations of the potential facilities, then the functions must be converted into constant functions. Hence, we address (x_j^*, y_j^*) for optimal facilities, $\big(\alpha_i\phi_l(u_i,v_i;r_k,s_k)+\alpha_k'\phi_l(r_k,s_k;x_j^*,y_j^*)\big)=c_{ikj}'^{l}$ for unit conveyance cost from i^{th} supplier to j^{th} retailer through k^{th} warehouse by mode of l^{th} conveyance, $\big(\beta_i\psi_l(u_i,v_i;r_k,s_k)+\beta_k'\psi_l(r_k,s_k;x_j^*,y_j^*)\big)=t_{ikj}'^{l}$ as unit delivery time from i^{th} supplier to j^{th} retailer through k^{th} warehouse by mode of l^{th} conveyance, and $\gamma\big(\rho_l(u_i,v_i;r_k,s_k)+\rho_l(r_k,s_k;x_j,y_j)\big)=d_{ikj}'^{l}$ for unit carbon emission cost due to transport the product from i^{th} supplier to j^{th} retailer through k^{th} warehouse by mode of l^{th} conveyance. Henceforth, Model 6.1 is rewritten as the following Model 6.2:

Model 6.2

$$\text{minimize} \quad Z_{1(w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} c'^{l}_{ikj} w^{l}_{ikj}$$

$$\text{minimize} \quad Z_{2(w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} t'^{l}_{ikj} w^{l}_{ikj}$$

$$\begin{aligned}\text{minimize} \quad Z_{3(w)} = & \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} \left(d_{2k}A_{ik} + d_{1j}G_{kj}\right) w^{l}_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} H_k w^{l}_{ikj} \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} D_k w^{l}_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} B_i w^{l}_{ikj} \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} g_k w^{l}_{ikj} + \sum_{k\in K} f_k + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} d'^{l}_{ikj} w^{l}_{ikj}\end{aligned}$$

subject to the constraints (6.4) to (6.8),

which is the well-known form of an MOSTP along with total inventory cost.

6.2.5 Basic concept of a multi-objective problem

In this subsection, we discuss a few basic definitions which are related to the proposed hybrid approach of MOST-LP.

Definition 6.1 ***(Intuitionistic fuzzy set [8])***: *Let U be a universal set and $s \in U$. An intuitionistic fuzzy set S in U is defined by a membership function $M(s)$ and a non-membership function $N_o(s)$, respectively, and denoted by $S = \{(s, M(s), N_o(s)) : s \in U\}$, where*

1. *$M(s) : U \to [0,1]$ and $N_o(s) : U \to [0,1]$,*
2. *$0 \leq M(s) + N_o(s) \leq 1$.*

Definition 6.2 ***(Ideal solution)***: *An ideal solution of MOST-LP is the one which reduces each of the goal independently, i.e., $Z_{q'}(x^*, y^*, w^*) = \min_{(x,y,w)\in F} Z_{q'}(x,y,w)$, $q' = 1,2,3$.*

Definition 6.3 ***(Anti-ideal solution)***: *The anti-ideal solution of MOST-LP is $Z_{q'}(x^A, y^A, w^A) = \max_{(x,y,w)\in F} Z_{q'}(x,y,w)$, $q' = 1,2,3$.*

Definition 6.4 ***(Pareto-optimal solution):*** *A solution $(x^N, y^N, w^N) \in F$ is said to be a Pareto-optimal solution (otherwise called non-dominated solution, non-inferior or efficient solution) of Model 6.1 if and only if there is no other solution $(x,y,w) \in F$ such that*

$$Z_{q'}(x,y,w) \leq Z_{q'}(x^N, y^N, w^N) \;\; \text{for } q' = 1,2,3, \text{and}$$
$$Z_{q'}(x,y,w) < Z_{q'}(x^N, y^N, w^N) \;\; \text{for at least one } q'.$$

Definition 6.5 ***(Compromise solution):*** *A Pareto-optimal solution $(x^N, y^N, w^N) \in F$ yields a compromise solution of MOST-LP if and only if $\mathbf{Z}(x^N, y^N, w^N) \leq \wedge_{(x,y,w)\in F} \mathbf{Z}(x,y,w)$, whereas $\wedge$ designates the minimum.*

The pictorial representation of ideal, anti-ideal, Pareto-optimal solutions and Pareto front (BC) are delineated in Fig. 6.2.

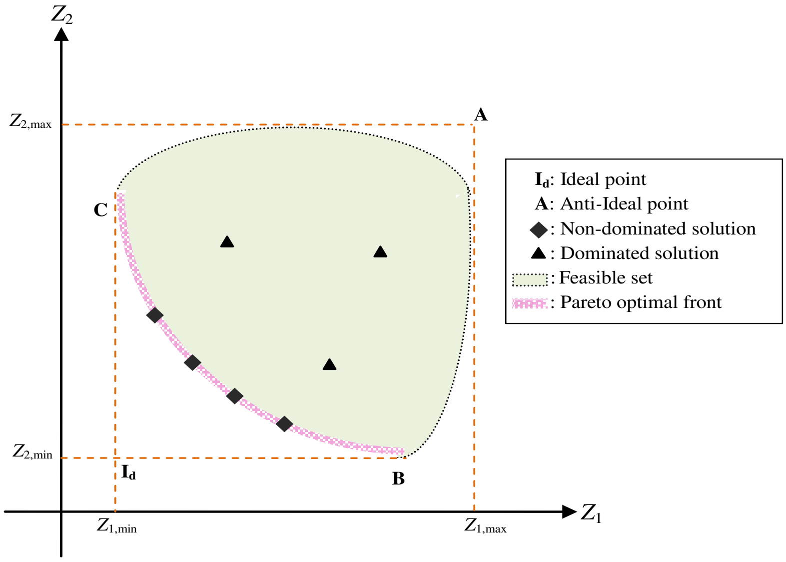

Fig. 6.2: The solution procedure of a multi-objective decision making problem.

6.3 Solution methodology

Herein, a hybrid solution procedure is introduced to solve the stated MOST-LP. Afterwards, the pros and cons of the proposed procedure are also discussed.

6.3.1 Hybrid approach

In this subsection, a hybrid approach is presented based on an alternating Loc-Alloc heuristic (Cooper [29]) and an IFP (Roy et al. [134]). The mentioned procedure is divided into two parts. In the first part, three single objective *solid transportation-location problems* (ST-LPs) are solved by the heuristic, and in the subsequent part, the Pareto-optimal solution for MOST-LP is derived by IFP.

Alternating Loc-Alloc heuristic: The Loc-Alloc heuristic consists of two steps. In the first step, the heuristic looks for the initial positions of p-outlets, and in the second step, it determines the optimum positions of the outlets. Here, at first, the locations are chosen for p-outlets from n-warehouses. If $p < n$, then all possible combinations of the n-warehouses are generated taken p at once, i.e., $\binom{n}{p}$. For each combination, the existing facilities are to be assumed as potential facilities, and other existing facilities are assigned relying upon which potential facilities have the minimum distance. Ultimately, all assigned distances are summed up. Therefore, this fact is repeated for all combinations. In this way, the final initial potential sites for three distance functions are the combinations with the minimum sum of distances. With these final allocations, the distances between p-outlets and n-warehouses for three distance functions are computed. If $p = n$, the case is trivial and we easily get the distances between them. Nevertheless, if $p > n$, then there is a problem to find the initial locations for outlets. For that reason, here, we incorporate a new heuristic idea. At first, we select the n allocations as n warehouses randomly and locate the remaining

$(p-n)$ outlets in some large Euclidean coordinates in such a way that the distances of those coordinates become very large numbers from warehouses. Thereafter, the distances between p-outlets and n-warehouses are calculated and a large positive number is allocated for such distances which cannot be computed. In fact, we already consider that the distance metrics are treated as logistics cost, delivery time and carbon discharge functions per unit item. Then, these distances are taken as the cost, time and carbon discharge coefficients. Hence, the three single objective ST-LPs turn into three traditional STPs. Utilizing the initial potential location (x_j^I, y_j^I), we solve the following problems:

Model 6.3

$$\begin{aligned} \text{minimize} \quad & Z_{1(w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\big(\alpha_i\phi_l(u_i,v_i;r_k,s_k) + \alpha'_k\phi_l(r_k,s_k;x_j^I,y_j^I)\big)w_{ikj}^l \\ \text{subject to} \quad & \text{the constraints (6.4) to (6.8).} \end{aligned}$$

Model 6.4

$$\begin{aligned} \text{minimize} \quad & Z_{2(w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\big(\beta_i\psi_l(u_i,v_i;r_k,s_k) + \beta'_k\psi_l(r_k,s_k;x_j^I,y_j^I)\big)w_{ikj}^l \\ \text{subject to} \quad & \text{the constraints (6.4) to (6.8).} \end{aligned}$$

Model 6.5

$$\begin{aligned} \text{minimize} \quad & Z_{3(w)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\big(d_{2k}A_{ik} + d_{1j}G_{kj}\big)w_{ikj}^l + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}H_k w_{ikj}^l \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}D_k w_{ikj}^l + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}B_i w_{ikj}^l \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}g_k w_{ikj}^l + \sum_{k\in K} f_k \\ & + \gamma\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\big(\rho_l(u_i,v_i;r_k,s_k) + \rho_l(r_k,s_k;x_j^I,y_j^I)\big)w_{ikj}^l \\ \text{subject to} \quad & \text{the constraints (6.4) to (6.8).} \end{aligned}$$

From the Models 6.3 to 6.5, the optimal feasible solutions (w^B) are derived. Employing these (w^B), the objective functions are minimized. The iterations (see Appendix A.4) are utilized to optimize the objective functions. Thereafter, $(x,y,w)^{(p')}$ is the local optimal (ideal) solution for the p'-th single objective ST-LP, where $p' = 1,2,3$.

IFP: Here, a payoff table with entries $Z_{p'q'} := Z_{q'}\big((x,y,w)^{(p')}\big)$, $p',q' = 1,2,3$ are computed for Pareto-optimal solution of MOST-LP. Afterwards, the upper $(U'_{q'})$ and lower $(L'_{q'})$ bound for each goal are evaluated as $U'_{q'} = \max\{Z_{1q'}, Z_{2q'}, Z_{3q'}\}$ and $L'_{q'} = Z_{q'q'}$, $q' = 1,2,3$. Thus, the membership and non-membership functions for the intuitionistic fuzzy environment are calculated as:

$$M\big(Z_{q'}(x,y,w)\big) = \begin{cases} 1 & Z_{q'}(x,y,w) \le L'_{q'}, \\ \frac{U'_{q'} - Z_{q'}(x,y,w)}{U'_{q'} - L'_{q'}} & L'_{q'} \le Z_q(x,y,w) \le U'_{q'}, \\ 0 & Z_{q'}(x,y,w) \ge U'_{q'}. \end{cases}$$

$$N_o\big(Z_{q'}(x,y,w)\big) = \begin{cases} 0 & Z_{q'}(x,y,w) \leq L'_{q'}, \\ \frac{Z_{q'}(x,y,w)-L'_{q'}}{U'_{q'}-L'_{q'}} & L'_{q'} \leq Z_{q'}(x,y,w) \leq U'_{q'}, \\ 1 & Z_{q'}(x,y,w) \geq U'_{q'}. \end{cases}$$

As the objective functions are conflicting in nature, thus, $U'_{q'} = L'_{q'}$ is not possible for any $(x^*_{q'}, y^*_{q'}, w^*_{q'})$ $(q' = 1,2,3)$. The intuitionistic optimization model for MOST-LP can be expressed as follows:

Model 6.6

$$\begin{array}{ll} \text{maximize} & \theta \\ \text{minimize} & \mu \\ \text{subject to} & M\big(Z_{q'}(x,y,w)\big) \geq \theta,\ N_o\big(Z_{q'}(x,y,w)\big) \leq \mu,\ q' = 1,2,3, \\ & \text{the constraints (6.4) to (6.8)}, \\ & \theta \geq \mu,\ \theta + \mu \leq 1,\ \theta, \mu \in [0,1]. \end{array}$$

Here, θ and μ are the level of satisfaction and dissatisfaction of a solution, respectively. Thereafter, the simplified intuitionistic fuzzy optimization model of MOST-LP is as follows:

Model 6.7

$$\begin{array}{ll} \text{maximize} & \theta - \mu \\ \text{subject to} & Z_{q'}(x,y,w) + \theta(U'_{q'} - L'_{q'}) \leq U'_{q'},\ q' = 1,2,3, \\ & Z_{q'}(x,y,w) - \mu(U'_{q'} - L'_{q'}) \leq L'_{q'},\ q' = 1,2,3, \\ & \text{the constraints (6.4) to (6.8)}, \\ & \theta \geq \mu,\ \theta + \mu \leq 1,\ \theta, \mu \in [0,1]. \end{array}$$

6.3.2 Advantages of the hybrid approach

Herein, the crucial advantages of the stated solution procedure are investigated.

- The major advantage of the aforementioned procedure is to provide a general structure for handling the membership and non-membership concept in available information. Besides, it doesn't need trade-offs, complicated parameters or any other reference directions from the DM. Indeed, employing this ensures a solution that maximizes the satisfaction level and reduces the dissatisfaction level.

- The facts about the available data of MOST-LP are not exactly characterized, the model of the stated procedure has the potentiality to handle fuzzy concepts such as the number of objective functions and restrictions.

- The stated procedure gives a basic numerical structure which makes it simpler for comprehension and utilizing. Moreover, it generally provides a Pareto-optimal solution with a less computational burden.

6.3.3 Disadvantages of the proposed approach

The main disadvantage of our procedure is that it cannot deal with the fixed-charge cost for route selection (represent toll charges on the expressway, landing expenses at air terminals, etc.). If the fixed-charge cost is included, then the continuous nature of the model will be lost. Additionally, the iterations (see Appendix A.4) are coded in C++ programming for and the IFP model is solved using LINGO optimization tool. Thus, if an algorithm is specially delineated for the complex problem, then this may yield result faster for large-scale entries.

6.4 Analysis of Pareto-optimal solution

In this section, we initially show that if (x^*, y^*, w^*) is a Pareto-optimal solution of MOST-LP, then (x^*, y^*) is a Pareto-optimal solution of the unconstrained multi-objective FLPs of Eqs. (6.1), (6.2) and (6.3), whereas $w = w^*$.

Proposition 6.1 *Let us consider that (x^*, y^*, w^*) is a Pareto-optimal solution of MOST-LP of Eqs. (6.1), (6.2) and (6.3). Then (x^*, y^*) is a Pareto-optimal solution of the multi-objective FLP:*

$$\begin{aligned}
\textit{minimize} \quad & Z_{1(x,y)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(\alpha_i\phi_l(u_i,v_i;r_k,s_k) + \alpha'_k\phi_l(r_k,s_k;x_j,y_j)\right)w^{l*}_{ikj}\\
\textit{minimize} \quad & Z_{2(x,y)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(\beta_i\psi_l(u_i,v_i;r_k,s_k) + \beta'_k\psi_l(r_k,s_k;x_j,y_j)\right)w^{l*}_{ikj}\\
\textit{minimize} \quad & Z_{3(x,y)} = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}(d_{2k}A_{ik} + d_{1j}G_{kj})w^{l*}_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}H_k w^{l*}_{ikj}\\
& \quad + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}D_k w^{l*}_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}B_i w^{l*}_{ikj}\\
& \quad + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}g_k w^{l*}_{ikj} + \sum_{k\in K} f_k\\
& \quad + \gamma\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L}\left(\rho_l(u_i,v_i;r_k,s_k) + \rho_l(r_k,s_k;x_j,y_j)\right)w^{l*}_{ikj}
\end{aligned}$$

Proof. The proposition can be demonstrated by contradiction logic. At first, we assume that $(\bar{x}, \bar{y})$ is a solution which satisfies the criteria $Z_{q'}(\bar{x}, \bar{y}, w^*) \leq Z_{q'}(x^*, y^*, w^*)$ for $q'(=1,2,3)$, and $Z_{q'}(\bar{x}, \bar{y}, w^*) < Z_{q'}(x^*, y^*, w^*)$ for at least one $q'(=1,2,3)$. Once more $(\bar{x}, \bar{y}, w^*)$ is a feasible solution of the problem; then there is a contradiction to Pareto-optimal solution of (x^*, y^*, w^*). □

Proposition 6.2 *Let us assume that $(x^*, y^*, w^*, \theta^*, \mu^*)$ be an optimal solution of Model 6.7, then it should be also a Pareto-optimal solution (x^*, y^*, w^*) of Model 6.1.*

Proof. Let the contradictory be true. Thus, there is a solution $(\bar{x}, \bar{y}, \bar{w}) \in F$ like $Z_{q'}(\bar{x}, \bar{y}, \bar{w}) < Z_{q'}(x^*, y^*, w^*)$ for $q' = 1,2,3$. Again, θ^* and μ^* are the optimum values of Model 6.7; subsequently:

$$\begin{aligned}
\theta^*(U'_{q'} - L'_{q'}) &< Z_{q'}(x^*, y^*, w^*) + \theta^*(U'_{q'} - L'_{q'}) \leq U'_{q'}, \quad q' = 1,2,3,\\
\mu^*(U'_{q'} - L'_{q'}) &< Z_{q'}(x^*, y^*, w^*) - \mu^*(U'_{q'} - L'_{q'}) \leq L'_{q'}, \quad q' = 1,2,3.
\end{aligned}$$

Hereafter, there exist $\theta > \theta^*$, $\mu > \mu^*$ and a $q'' \in \{1,2,3\}$ like

$$Z_{q''}(\bar{x},\bar{y},\bar{w}) + \theta(U'_{q''} - L'_{q''}) = U'_{q''},$$
$$Z_{q'}(\bar{x},\bar{y},\bar{w}) + \theta(U'_{q'} - L'_{q'}) \leq U'_{q'}, q' \neq q'',$$
$$Z_{q''}(\bar{x},\bar{y},\bar{w}) - \mu(U'_{q''} - L'_{q''}) = L'_{q''},$$
$$Z_{q'}(\bar{x},\bar{y},\bar{w}) - \mu(U'_{q'} - L'_{q'}) \leq L'_{q'}, q' \neq q'',$$

which contradicts with that $(x^*, y^*, w^*, \theta^*, \mu^*)$ is an optimal solution of Model 6.7. □

6.5 Numerical experiment

An extensive numerical effort has been put and a suitable numerical example has been studied in order to validate the objective of this study. Here, we consider that an industrial organization wishes to begin a couple of new firms with the goal of reducing the overall logistics cost, delivery time and inventory cost along with carbon emission cost. The association has 3 supplier firms: S_1, S_2 and S_3; 4 warehouses: W_1, W_2, W_3 and W_4, and they want to establish 3 new retail outlets: R_1, R_2 and R_3. They transport the goods from suppliers to retail outlets through warehouses by mode of conveyances. Products are transported by 3 different conveyances E_1, E_2 and E_3. For that reason, the non-negative weights of conveyances for transportation cost, time and carbon emission are also taken into account. Supportive hypothetical data of this phenomenon are designed. The availability at S_1, S_2 and S_3, and the demand of the firms R_1, R_2 and R_3, are given. Further, the positions and weights of the firms S_1, S_2 and S_3, and W_1, W_2, W_3 and W_4 are also provided. Tables 6.1 and 6.2 represent the locations and weights of the supplier firms and warehouses, respectively. The supply and demand of a product and their corresponding weights are given in Tables 6.3 and 6.4. Thereafter, Table 6.5 displays the weights and capacity of conveyances. Furthermore, Tables 6.6 and 6.7 depict the parametric values of ordering cost.

Table 6.1: Positions and weights of the supplier firms.

	Position (u_i, v_i)	Weight (α_i)	Weight (β_i)
S_1	$(2,16)$	15	10
S_2	$(3,6)$	13	13
S_3	$(14,24)$	12	15

Table 6.2: Locations and weights of the warehouses.

	Position (r_k, s_k)	Weight (α'_k)	Weight (β'_k)
W_1	$(7,12)$	14	16
W_2	$(4,27)$	13	12
W_3	$(19,27)$	12	10
W_4	$(22,7)$	20	14

Table 6.3: Pay-off table (t_{kj}, δ_{kj}).

	R_1	R_2	R_3	Supply (a_k)
S_1	$(0.0, 0.2)$	$(0.7, 0.3)$	$(0.3, 0.5)$	20
S_2	$(0.1, 0.3)$	$(0.2, 0.4)$	$(0.7, 0.3)$	85
S_3	$(0.1, 0.5)$	$(0.5, 0.4)$	$(0.4, 0.1)$	30
S_4	$(0.0, 0.3)$	$(0.6, 0.6)$	$(0.4, 0.1)$	50
Demand (b_j)	40	75	60	

Table 6.4: Pay-off table (t_{ik}, δ_{ik}).

$(0.1, 0.5)$	$(0.4, 0.4)$	$(0.5, 0.1)$	$(0.4, 0.2)$
$(0.6, 0.2)$	$(0.0, 0.4)$	$(0.4, 0.4)$	$(0.5, 0.1)$
$(0.0, 0.5)$	$(0.3, 0.3)$	$(0.7, 0.2)$	$(0.1, 0.5)$

Table 6.5: Capacity & weight of conveyance.

Capacity (c_l)	Weight (ε_l)	Weight (ε'_l)	Weight (ε''_l)
30	0.6	0.1	0.2
70	0.3	0.4	0.3
75	0.1	0.5	0.5

Table 6.6: Pay-off table for parameters (A_{ik}).

5	4	5	2
2	2	6	3
4	4	8	5

Table 6.7: Pay-off table for parameters (G_{kj}).

3	2	4
5	7	9
3	2	4
2	4	5

Here, the other input parameters are taken as follows:
Carbon emission tax $\gamma = 0.4$; purchasing costs as $B_1 = 15$, $B_2 = 20$, $B_3 = 10$; holding costs like $t = 5$, $h_{11} = 2$, $h_{12} = 4$, $h_{13} = 5$, $h_{14} = 7$, $h_{21} = 8$, $h_{22} = 9$, $h_{23} = 11$, $h_{24} = 15$; deterioration costs such as $D_1 = 3$, $D_2 = 2$, $D_3 = 4$, $D_4 = 5$; screening costs as $g_1 = 5$, $g_2 = 6$, $g_3 = 3$, $g_4 = 4$; demand rates for the goods like $d_{11} = 10$, $d_{12} = 2$, $d_{13} = 4$, $d_{21} = 2$, $d_{22} = 2$, $d_{23} = 4$, $d_{24} = 6$, $f_1 = 10$; fixed cost as $f_1 = 15$, $f_1 = 20$, $f_1 = 20$.

6.5.1 Performance of the proposed procedure

The steps are required to solve MOST-LP:

Step 1: Initially, we choose three potential sites from Table 2 for three retail outlets. Therefore, four possible *cases* appear which are displayed in Tables 6.8- 6.11.

Table 6.8: Case 6.1.

	Position (x_j, y_j)
R_1	$(7, 12)$
R_2	$(4, 27)$
R_3	$(19, 27)$

Table 6.9: Case 6.2.

	Position (x_j, y_j)
R_1	$(4, 27)$
R_2	$(19, 27)$
R_3	$(22, 7)$

Table 6.10: Case 6.3.

	Position (x_j, y_j)
R_1	$(19, 27)$
R_2	$(22, 7)$
R_3	$(7, 12)$

Table 6.11: Case 6.4.

	Position (x_j, y_j)
R_1	$(22, 7)$
R_2	$(7, 12)$
R_3	$(4, 27)$

Step 2: The distances (that is, for each individual Euclidean function) are calculated among the allocated outlets and the rest firm site for each possible case. Then, the smallest distance is picked up for each individual Euclidean function from the mentioned possible cases. Thus, the initial potential sites of the retail outlets are as follows: Case 6.4 for the transportation cost function, Case 6.3 for the transportation time function, and Case 6.4 for the carbon emission function.

Step 3: Now, the distances among suppliers, warehouses and initially allocated outlets are calculated, and then these are taken as a logistics cost, delivery time and carbon emission coefficients. Thereafter, LINGO 17.0 software is utilized to get the individual feasible solution:

For **Model 6.3:**
$w^1_{341} = 30$, $w^2_{341} = 10$, $w^2_{342} = 10$, $w^2_{312} = 20$, $w^2_{323} = 30$, $w^3_{123} = 30$, $w^3_{322} = 45$ with all other $w^l_{ikj} = 0$.

For **Model 6.4:**
$w^1_{122} = 25$, $w^1_{123} = 5$, $w^2_{121} = 10$, $w^2_{123} = 35$, $w^2_{342} = 5$, $w^2_{313} = 20$, $w^3_{131} = 30$, $w^3_{342} = 45$ with all other $w^l_{ikj} = 0$.

For **Model 6.5:**
$w^1_{322} = 30$, $w^2_{322} = 45$, $w^2_{133} = 25$, $w^3_{123} = 10$, $w^3_{141} = 40$, $w^3_{313} = 20$, $w^3_{323} = 5$ with all other $w^l_{ikj} = 0$.

Step 4: The C++ programming language is executed to obtain the individual optimal locations for the outlets and they are as follows:
$(x_1, y_1)^{(1)} = (22.000, 7.000)$, $(x_2, y_2)^{(1)} = (7.421, 12.355)$, $(x_3, y_3)^{(1)} = (4.000, 27.000)$, $(x_1, y_1)^{(2)} = (18.736, 27.000)$, $(x_2, y_2)^{(2)} = (21.936, 7.072)$, $(x_3, y_3)^{(2)} = (4.330, 25.350)$, $(x_1, y_1)^{(3)} = (22.000, 7.000)$, $(x_2, y_2)^{(3)} = (4.000, 27.000)$ and $(x_3, y_3)^{(3)} = (8.713, 20.867)$.

Step 5: Employing the aforementioned solutions (i.e., Steps 3 and 4), a payoff table (for details see the IFP methodology) are computed, and the entries are:
$U'_1 = \max\{9998.322, 14971.328, 23372.049\}$, $L'_1 = 9998.322$;

$U'_2 = \max\{22823.112, 13925.662, 21140.882\}$, $L'_2 = 13925.662$;
$U'_3 = \max\{19528.219, 19895.936, 18851.763\}$, $L'_3 = 18851.763$.

Step 6: Therefore, the upper and lower values depend on IFP are estimated which are as follows:
For $Z_1(x,y,w)$: $U'_1 = 23372.049$, $L'_1 = 9998.322$,
For $Z_2(x,y,w)$: $U'_2 = 22823.112$, $L'_2 = 13925.662$,
For $Z_3(x,y,w)$: $U'_3 = 19895.936$, $L'_3 = 18851.763$.

Step 7: Using LINGO 17.0 software, the simplified intuitionistic fuzzy optimization model (i.e., Model 6.7) is solved. The compromise solution of MOST-LP are as follows: $w^2_{111} = 19.106$, $w^3_{111} = 0.336$, $w^3_{121} = 8.926$, $w^2_{122} = 10.550$, $w^3_{122} = 5.459$, $w^1_{123} = 30.000$, $w^3_{123} = 29.238$, $w^2_{133} = 0.305$, $w^2_{131} = 7.457$, $w^3_{131} = 3.246$, $w^2_{132} = 1.897$, $w^3_{132} = 7.094$, $w^2_{142} = 19.165$, $w^3_{142} = 1.086$, $w^2_{223} = 0.456$, $w^3_{221} = 0.370$, $w^2_{211} = 0.558$, $w^2_{242} = 0.513$, $w^3_{242} = 0.845$, $w^2_{342} = 9.991$, $w^3_{342} = 18.391$ with all other $w^l_{ikj} = 0$, $\theta = 0.9$, $\mu = 0.1$, $(x_1, y_1) = (7.091, 12.352)$, $(x_2, y_2) = (121.884, 7.167)$, $(x_3, y_3) = (3.936, 27.018)$, $Z_1 = 11315.716$, $Z_2 = 147779.317$, $Z_3 = 19757.347$.

6.6 Experimental result and discussion

A numerical study is presented for analyzing the stated problem and solution procedure. In this procedure, we first find the initial allocations, optimal feasible solutions, optimum locations, ideal solutions (individual minimum), and anti-ideal solutions (individual maximum), and then we calculate the upper and lower bounds for membership and non-membership functions. Subsequently, the intuitionistic fuzzy optimization model for MOST-LP is designed to get the Pareto-optimal solution. The derived result of the numerical experiment shows that the overall conveyance cost and time, and inventory cost along with carbon discharge cost are minimized, and the best locations of the retail outlets are established with a global degree of satisfaction; here it is 0.9, and dissatisfaction level is 0.1. In fact, when the carbon emission cost increases (decreases), the profit of firms will be less (more). For that reason, the industrial organization will always be concerned about carbon emission due to the transportation of goods. In this way, the stated formulation can control the effusions which also directly affect the environment to reduce pollution. The optimal positions of outlets for this numerical study are shown in Fig. 6.3. The heuristic is coded in C++, the IFP is coded in the LINGO optimization tool (version 17.0), and the experiment is performed on a computer with Intel Core i5-3210M CPU @2.50 GHz and 4 GB RAM. In contrast, the obtained result is also verified with Mac terminal on a personal computer (1.8 GHz Intel Core i5 with 8 GB 1600 MHz DDR3 RAM).

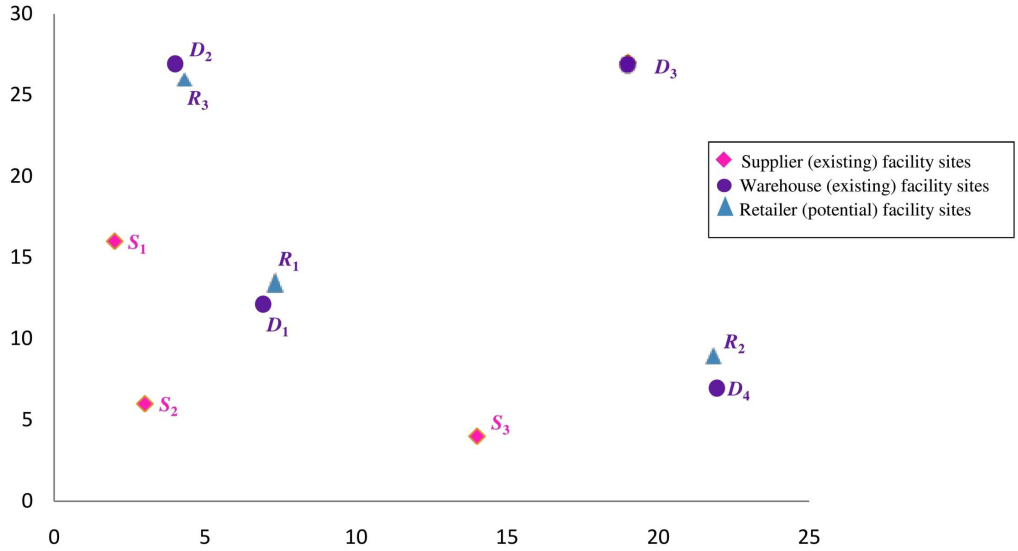

Fig. 6.3: The locations of existing and potential facilities in the example.

6.7 Sensitivity analysis

Here, we check the sensibility of a Pareto-optimal solution in MOST-LP by varying the parameters. For MOST-LP, the complexity occurs when the ranges are calculated after parametric changes to the object that the obtained compromise solution still remains the same. Indeed, the difficulty enlarges when the decision variables and restrictions are large in number. Because of that, a simple procedure is already carried out in Chapter 3 (see Section 3.5) to analyze the sensitivity of parameters. Here, the same steps (Steps 1- 4) are repeated to obtain the validity ranges of the parameters in MOST-LP .

Sensitivity analysis for supply, demand and capacity parameters:
Let us consider that a_k be converted to a_k^* $(k = 1,2,3,4)$, b_j be changed to b_j^* $(j = 1,2,3)$ and c_l be changed to c_l^* $(l = 1,2,3)$. Using the above steps, the values of a_k^*, b_j^* and c_l^* are easily computed, which is displayed in Table 6.12. In fact, the ranges of the alternate parameters in MOST-LP are likewise achieved comparably.

Table 6.12: The range of supply, demand and capacity parameters for the example..

Real values of a_k, b_j and c_l	Changing values of a_k, b_j and c_l
$a_1 = 20$	$20 \leq a_1^* \leq 35.5$
$a_2 = 85$	$85 \leq a_2^* \leq 116.3$
$a_3 = 30$	$30 \leq a_3^* \leq 44$
$a_4 = 50$	$50 \leq a_4^* < \infty$
$b_1 = 40$	$15 \leq b_1^* \leq 40$
$b_2 = 75$	$31 \leq b_2^* \leq 75$
$b_3 = 60$	$15 \leq b_3^* \leq 60$
$c_1 = 30$	$30 \leq c_1^* < \infty$
$c_2 = 70$	$70 \leq c_2^* \leq 95$
$c_3 = 75$	$75 \leq c_3^* \leq 100$

6.8 Managerial insights

The fact that MOST-LP is a decision making application-based study, makes it essential to get deep insights into the attributes of the compromise solution. Here, we gather information about the compromise solution obtained when utilizing Model 6.1 into Model 6.7. From the outcome, the DM can choose the Pareto-optimal solution from Model 6.7. A brief discussion of the logistics cost, delivery time and inventory cost along with carbon emission are displayed. From that discourse, the DM can determine the best potential sites so that he/she can easily distribute the commodities with the least expense and time just as the carbon discharge. On the other hand, there is an inspection of carbon tax policy, from that the DM can choose when their profit will be less (more). As a result, he/she can balance their profits, and environmental issues, which may lead to a gain of reputation in the worldwide market. Again, the machine execution of the vehicles is displayed in conveyance cost and discharge. In case the machine execution is good, then the overall logistics cost along with carbon discharge will be reduced. Hence, the DM can easily select which kinds of vehicles are better for distributing products. Once more, the time for the barriers of the paths is also incorporated in conveyance time, so that the DM can calculate a more accurate delivery time which improves his/her services to the customers. Now, the following are the deep insights for the organization which significantly defined in our model:

- The model works as a trade-off between locations problems and inventory management. As inventory is fundamental for the development of a company, therefore, the model ensures a strong economic investment for maximizing the profit of a company.
- When the probability of total inventory cost and fixed set up cost increases, the number of constructed facilities are also increasing.
- This integrated model leads to significant economic savings which indirectly drive us to reinvest in another aspect of the model.
- If one spread customer's demand in more facilities, it will help to reduce the number of the shipment and the total transportation cost.
- The model gives a full understanding of the relationship between the decisions associated with facility locations, inventory, transportation cost and time.
- The model adds a managerial insight which helps the industry to obtain a financial surplus at an optimal level.

Ultimately, we can say that this study will be operative for the DM to make the decisions about the best potential sites and distribute the commodities simultaneously.

6.9 Conclusion

In this research work, we have introduced an unprecedented formulation of integrated supply chain management and location decisions with the objects of reducing the overall logistics cost, shipping time and inventory cost along with carbon emission cost in a solid transportation network. At the same time, it also asks the optimal locations for the potential facilities as well as the amounts of distributed goods by different transportation modes simultaneously. To the best of the authors' knowledge, there is no research so far integrating by the FLP, inventory management and STP in a multi-objective environment. In addition, a hybrid approach is introduced to solve the stated formulation in a successful way. Thereafter, the aforementioned model and solution procedure have been validated by a numerical example. Therefore, the decisions regarding reducing carbon dioxide due to transportation systems are also discussed. The characteristic of the optimal compromise solution is described by two propositions. In fact, this study of decision making will definitely help the DMs to deal with the other multi-objective decision making applications such as production-inventory system, green supply chain model, financial and further applications.