The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0263-5577.htm

Received 24 March 2019
Revised 9 June 2019
Accepted 26 July 2019

A model for the selection of transportation modes in the context of sustainable freight transportation

Vijayta Fulzele
Department of Decision Sciences, Operations Management, and Information Systems, School of Management and Entrepreneurship, Shiv Nadar University, Greater Noida, India
Ravi Shankar
Department of Management Studies, Indian Institute of Technology Delhi, New Delhi, India, and
Divya Choudhary
Indian Institute of Management Sambhalpur, Burla, India

Abstract

Purpose – A sustainable freight transportation system involves freight processes that are economically efficient, socially inclusive and environment friendly. For enhancing sustainability in the freight operations, mode selection is a crucial strategic decision. Therefore, the purpose of this paper is selecting the best mode, or a combination of modes based on various criteria to carry shipments from origin to destination.

Design/methodology/approach – This study has used an integrated grey relational analysis based intuitionistic fuzzy multi-criteria decision-making process (GRA–IFP) and fuzzy multi-objective linear programming model. Three scenarios have been developed for analyzing sensitivity of decision variables with the variations in parameters under relevant conditions. A real case of Indian third-party logistics service provider has been used to demonstrate the effectiveness of the model.

Findings – The most relevant criterion emerged out in this study for multi-mode selection problem is costs. It can be concluded from the study that multi-modal freight transportation has the potential to improve the sustainability of freight transportation by reducing the costs, damages, emissions, traffic congestion and by increasing the speed of delivering the shipment. The sensitivity analysis further shows that road is the economical mode, whereas sea and rail together are the greenest as well as socially responsible modes of transportation.

Originality/value – This study provides an integrated tool, which can be used by freight transporters to decide upon the sustainable modes of transportation for their various shipments.

Keywords Fuzzy multi-objective linear programming, Intuitionistic fuzzy numbers, Multi-mode freight transportation, Sustainable freight transportation system

Paper type Research paper

1. Introduction

Freight transportation system (FTS) integrates a number of complex operations in order to fulfill the end-customer's demands worldwide (Muerza *et al.*, 2017). The performance level of freight transportation (FT) is measured through the service time involved to meet customers' demand. One of the key components of FT that has direct impact on the service levels is a "mode" by which freight moves from shipper to receiver. The modes of transportation include road, rail, sea and air, which also determine the transportation costs, environmental emissions and social risks to a large extent (SteadieSeifi *et al.*, 2014). Each transportation mode possesses different characteristics that provide certain benefits as compared to the others. However, these benefits entail a trade-off for some other attribute as shown in Figure 1.

The share of road-based FT has significantly increased during last two decades, which has resulted in various negative externalities on physical environment and society such as

Industrial Management & Data Systems
Vol. 119 No. 8, 2019
pp. 1764-1784

0263-5577
DOI 10.1108/IMDS-03-2019-0169

traffic congestion, noise pollution and increased energy consumption (Vannieuwenhuyse *et al.*, 2003). It has been estimated that road-based FT alone is responsible for 40 percent of CO_2 emissions in cities and this share is continuously increasing (Björklund and Gustafsson, 2015). Thus, there is an urgent need to integrate three dimensions of Triple Bottom Line approach (TBL) into freight operations by shifting to more cost-effective greener modes (Qaiser *et al.*, 2017) as shown in Figure 2.

As FTS is expanding and becoming more integrated, reliance on uni-modal transportation is not much profitable in long term. Accordingly, organizations are adopting multi-modal freight transportation (MMFT) that facilitates the freight movement by well-coordinated and sequential use of two or more than two modes of transportation (Kengpol *et al.*, 2014). MMFT has the potential to curb the negative externalities associated with FT operations while simultaneously providing seamless connectivity to the customers. As shown in Figure 3, a transportation chain comprises of pre-haul (or first mile pick up process), long-haul (freight movement) and end-haul (last mile delivery process). The pre-haul and end-haul transportation is generally carried out using road. On the other hand, long-haul transportation involves combination of road, rail, sea and air modes (SteadieSeifi *et al.*, 2014) (Figure 3).

Within the purview of shipment process planning, optimal selection of transportation modes is a key operational decision to leverage the benefits of MMFT. It has significant influence on the service level, synchronization and system performance of FTSs (SteadieSeifi *et al.*, 2014). Thus, there is a need to encourage modal shifts by developing analytical models that can be

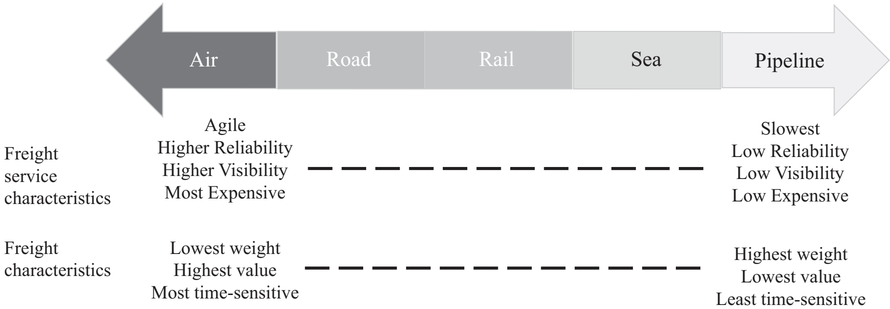
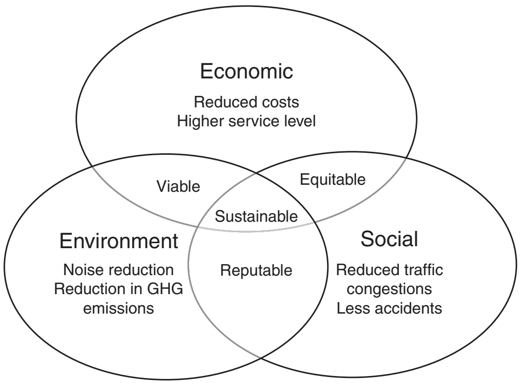


Figure 1. Characteristics of different modes of transportation



Source: Zeimpekis *et al*. (2018)

Figure 2. Sustainable freight transportation system

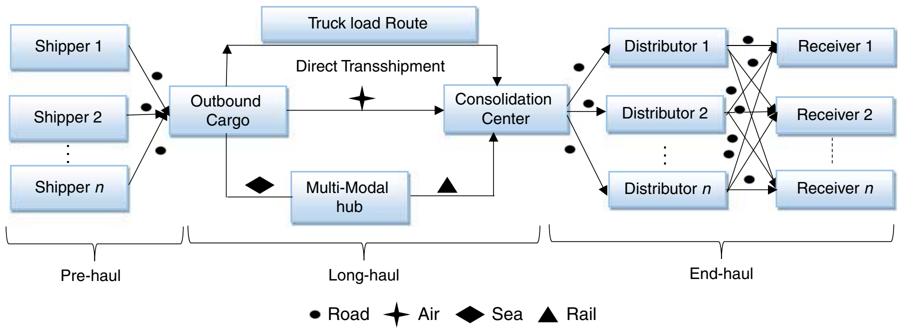


Figure 3.
Multi-modal freight transportation process

used to select best combinations of modes. However, multi-mode selection problem (MMSP) has been considered as a complex process in the literature due to the following reasons:

(1) FT modes need to be evaluated on multiple qualitative and quantitative criteria. Hence, MMSP requires multi-criteria decision making-based evaluation (Tuzkaya and Önüt, 2008).

(2) Individual mode exhibits different performance characteristics on multiple criteria. These criteria are contradictory in nature and can be treated as conflicting goals. Thus, by nature MMSP is a multi-objective problem (Murphy and Farris, 1993).

(3) Capacity shortages, international growth, economies of scale, security concerns, federal policy actions, infrastructural availability, environmental and energy use concerns act as constraints to MMSP that further add complexities in making FT modes choices (Meixell and Norbis, 2008).

(4) MMSP is sensitive to changes in weights of criteria, which makes difficult to estimate demands for FT modes (Baumol and Vinod, 1970).

(5) Perceptual differences among carrier, import shipper and export shipper regarding modes' choice further make MMSP a complex process (Kent and Stephen Parker, 1999).

Therefore, deciding what combinations of modes to be used for shipping consignments is not an easy task and no more a psychic matter. Motivated from the above annotations, the key research question addressed in this study is "which mix of modal investments yields the highest returns to freight transporters?" Thus, this study identifies different criteria that can assist in the assessment and selection of the most optimal combination of transportation modes. These identified parameters aid in determining the performances of individual modes ensuring that the freight operations are efficient and cost effective.

For several years, MMSP decisions were made with a skewed view of cost minimization and operational efficiency maximization. This is due to the fact that in a manufacturing environment, 20 percent of the total product costs are incurred due to transportation of products and characteristic of market demand are dynamic in nature (Meixell and Norbis, 2008). Similarly, in MMSP literature, primary focus is on economic criteria for making modal choices (Foster and Strasser, 1990; De-Jong and Ben-Akiva, 2007). There are limited studies that have considered all three dimensions of sustainability in an integrated manner, which can play an important role in long term (Kahi *et al.*, 2017). This study addresses the abovementioned gaps in existing literature by developing an integrated model to determine the sustainable combination of FT modes. The proposed hybrid model uses a grey relational analysis based intuitionistic fuzzy multi-criteria decision-making process (GRA–IFP) and fuzzy multi-objective linear programming (FMOLP) for FT modes selection. The formulated model has been validated using real-life MMSP handled by a third-party logistics company operating in India.

The uniqueness of this study can be analyzed based on two key aspects (i) focus of the study and (ii) methodology used. This study focuses on the sustainability criteria while selecting best combination of FT modes for a shipment. It uniquely blends GHG emissions and traffic congestion criteria along with other costs and service level-related criteria of MMSP. Under the second aspect, the study has used a novel integrated approach by combining intuitionistic fuzzy numbers (IFNs)-based MCDM and FMOLP. SFT field is characterized with uncertain and incomplete subjective inputs of decision makers (DMs), which can be easily dealt with GRA–IFP-based technique. Another advantage of using this method is that it also considers the importance of various DMs by using intuitionistic fuzzy weighted averaging (IFWA) operator to aggregate the responses of the DMs. Furthermore, the study has uniquely developed FMOLP model specifically to select the modes of FT. To make the model more realistic, distance traveled by different modes of transportation has been considered as fuzzy. Overall, the integrated approach is simple to understand and easy operate while selecting best mode of FT.

This research is based upon literature that include the assessment and selection of modes that are conflicting in nature involving minimization of costs, time, risk and unreliability (Nijkamp *et al.*, 2004). A large number of factors influence the modal choices that are classified into "service related," "consignor related" and "traffic related" (Punakivi and Hinkka, 2006; Roberts, 2012). A brief overview of some of the studies on transportation mode selection and the corresponding sustainability criteria considered are provided in Table I. Various sustainability criteria used for transportation mode selection in this study are diagrammatically shown in Figure 4.

2. Methodology

Fuzzy sets are generally used when the data are characterized with impreciseness and vagueness. Any element belonging to the fuzzy set comprises of a membership value for that fuzzy set. However, in majority of the real-world problems, DMs do not provide complete information due to lack of knowledge or hesitancy. Therefore, the existing concept of fuzzy sets was extended to intuitionistic fuzzy sets introduced by Atanassov (1986) that has the capability to manage impreciseness and hesitancy originating from qualitative information. Thus, an IFN generally comprises of three functions, i.e. a membership degree, a non-membership and a hesitation degree (Li, 2010).

This section provides a detailed step-wise methodology to determine weights of criteria using grey relational analysis based intuitionistic fuzzy multi-criteria decision-making process (GRA–IFP) as proposed by Zhang and Liu (2011).

2.1 Step-wise proposed methodology

Let $C = \{c_1, c_2, \ldots, c_n\}$ be the set of criteria where, $n \geqslant 2$ and $X = \{x_1, x_2, \ldots, x_m\}$ be the set of DMs, where $m \geqslant 2$:

- Step 1: develop the intuitionistic fuzzy decision matrix $M^{(e)}$ as shown in the following equation for each DMs using linguistic variable shown in Table II:

$$B^{(e)} = \left(b_{ij}^{e}\right)_{n\times n} = \begin{bmatrix} b_{11}^{(e)} & \cdots & b_{1n}^{(e)} \\ \vdots & \ddots & \vdots \\ b_{n1}^{(e)} & \cdots & b_{nn}^{(e)} \end{bmatrix}. \tag{1}$$

- Step 2: compute the weights of DMs according to their importance in the study as shown in Table III using the following equation:

$$\delta_e = \frac{\left(\mu_e + \pi_e\left(\mu_e/\left(\mu_e + v_e\right)\right)\right)}{\sum_{e=1}^{m}\left(\mu_e + \pi_e\left(\mu_e/\left(\mu_e + v_e\right)\right)\right)}, \quad \text{where} \quad \sum_{e=1}^{m}\delta_e = 1. \tag{2}$$

Authors	Costs	Damage during transportation	Shipping delays	GHG emissions	Traffic congestion	Speed of delivery	Distance	Techniques used	Optimization considered
Tuzkaya and Önüt (2008)	Yes	Yes	Yes	No	Yes	Yes	Yes	ANP	No
Ozceylan (2010)	Yes	Yes	Yes	Yes	No	No	No	AHP	No
Roberts (2012)	Yes	No	No	Yes	Yes	Yes	No	Qualitative	No
De-Jong and Ben-Akiva (2007)	Yes	Yes	Yes	No	No	Yes	Yes	Simulation	Yes
Foster and Strasser (1990)	Yes	Yes	Yes	No	No	Yes	No	Qualitative	No
McGinnis (1979)	Yes	Yes	Yes	No	No	Yes	No	Qualitative	No
Jeffs and Hills (1990)	No	Yes	Yes	No	No	No	Yes	Qualitative	No
Cullinane and Toy (2000)	Yes	No	Yes	No	No	Yes	Yes	Ranking	No
Hoen *et al.* (2014)	Yes	No	No	Yes	No	No	Yes	Quantitative	No
Punakivi and Hinkka (2006)	Yes	Yes	Yes	No	No	Yes	No	Case study	No

Table I.
Summary of sustainability criteria used for transportation mode selection

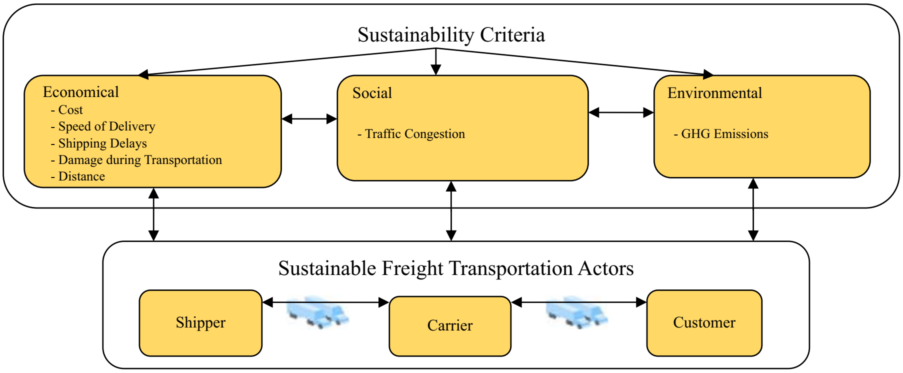


Figure 4. Sustainable framework considered in the study

Linguistic scale for importance	Intuitionistic fuzzy numbers (IFNs)	Linguistic scale for importance	Intuitionistic fuzzy numbers (IFNs)
Extremely low important	(0.05, 0.95, 0)	Medium high important	(0.65, 0.25, 0.1)
Very low important	(0.15, 0.8, 0.05)	High important	(0.75, 0.15, 0.1)
Low important	(0.25, 0.65, 0.1)	Very high important	(0.85, 0.1, 0.05)
Medium low important	(0.35, 0.55, 0.1)	Extremely high important	(0.95, 0.05, 0)
Equally important	(0.5, 0.4, 0.1)		

Table II. Conversion of linguistic variable into intuitionistic fuzzy numbers

Linguistic variables	IFNs	Linguistic variables	IFNs
Very important	(0.9, 0.05, 0.05)	Unimportant	(0.25, 0.6, 0.15)
Important	(0.75, 0.2, 0.05)	Very unimportant	(0.1, 0.8, 0.1)
Medium important	(0.5, 0.4, 0.1)		

Table III. Conversion of linguistic variables into IFNs for the importance of decision makers

- Step 3: an aggregated intuitionistic fuzzy decision matrix is constructed using IFWA operator using the following equation:

$$b_{ij} = \text{IFWA}_\delta\left(b_{ij}^{(1)}, b_{ij}^{(2)}, \ldots, b_{ij}^{(m)}\right) = \delta_1 b_{ij}^{(1)} \oplus \delta_2 b_{ij}^{(2)} \oplus \ldots \oplus \delta_m b_{ij}^{(m)}$$

$$= \left(1-\prod\nolimits_{e=1}^{m}(1-\mu_{ij}^{e})^{\delta_e},\ \prod\nolimits_{e=1}^{m}\left(\left(v_{ij}^{(e)}\right)^{\delta_e}\right),\ \prod\nolimits_{e=1}^{m}\left(1-\mu_{ij}^{(e)}\right)^{\delta_e}-\prod\nolimits_{e=1}^{m}\left(\left(v_{ij}^{e}\right)^{\delta_e}\right)\right). \quad (3)$$

Thus, the aggregated matrix B is represented as shown in the following equation:

$$B = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{n1} & \cdots & b_{nn} \end{bmatrix} \quad (4)$$

where:

$$\mu_{ij} = \left(m_{ij}, v_{ij}, \pi_{ij}\right),$$

$$\mu_{ij} = 1 - \prod_{e=1}^{m} \left(1-\mu_{ij}^{e}\right)^{\delta_e},$$

$$v_{ij} = \prod_{e=1}^{m} \left(\left(v_{ij}^{(e)}\right)^{\delta_e}\right),$$

$$\pi_{ij} = \prod_{e=1}^{m} \left(1-\mu_{ij}^{(e)}\right)^{\delta_e} - \prod_{e=1}^{m} \left(\left(v_{ij}^{e}\right)^{\delta_e}\right) \; i \in N \text{ and } j \in N.$$

- Step 4: compute the entropy weights of each criteria by first determining intuitionistic fuzzy entropy (ρ_j) using the following equation:

$$\rho_j = -\frac{1}{n \ln 2} \sum_{i=1}^{n} \left[\mu_{ij} \ \ln \mu_{ij} + v_{ij} \ \ln v_{ij} - (1-\pi_{ij})\ln(1-\pi_{ij}) - \pi_{ij} \ln 2\right]. \tag{5}$$

Further, the entropy weight (ϖ) for each column is calculated using the following equation:

$$\varpi_j = \frac{1-\rho_j}{n - \sum_{j=1}^{n} \rho_j}, \quad \text{where} \quad \sum_{j=1}^{n} \varpi_j = 1. \tag{6}$$

- Step 5: determine optimal values of criteria known as a reference sequence. Ideally, it is the maximum value of IFN, i.e. $a^{+} = (1, 0, 0)$. The reference sequence s_0 is represented as shown in the following equation:

$$s_0 = \left(s_{0j}\right)_{1\times n} = \left[a^{+} a^{+} \ldots a^{+}\right]. \tag{7}$$

- Step 6: determine the distance between b_{ij} and s_{0j} by calculating the grey relational coefficient (γ) using the following equation:

$$d(a_1, a_2) = \frac{1}{2}\left(\left|\mu_{a_1} - \mu_{a_2}\right| + \left|v_{a_1} - v_{a_2}\right| + \left|\pi_{a_1} - \pi_{a_2}\right|\right), \tag{8}$$

  where $a_1 = (\mu_{a_1}, \ v_{a_1}, \ \pi_{a_1})$ and $a_2 = (\mu_{a_2}, v_{a_2}, \pi_{a_2})$. The grey relational coefficient is calculated using the following equation:

$$\gamma_{ij} = (\beta\_ \min + \varrho\beta\_ \max)/(\beta\_ij + \varrho\beta\_ \max), \ \ i \in N \ \text{ and } \ j \in N, \tag{9}$$

  where γ_{ij} is grey relational coefficient between b_{ij} and s_{0j}; β_ij is distance between b_{ij} and s_{0j}; $\beta\_\text{min} = Min \{\beta\_ij, i \in N; j \in N\}$, $\beta\_\text{max} = Max \{\beta\_ij, i \in N; j \in N\}$ and $\rho \in [0, 1]$ is a distinguishing coefficient. Therefore, the value of ρ is generally considered as 0.5.

- Step 7: finally, calculate the grey relational trade and determine the final weights of each criteria as shown in the following equation. The weights are then normalized such that $\sum_{i=1}^{n} W_i = 1$:

$$W_i = \sum_{i=1}^{n} \left(\varpi_j \gamma_{ij}\right), i \in N. \tag{10}$$

2.2 Fuzzy Multi-objective linear programming

Fuzzy linear programming proposed by Zimmermann (1978) comprises of fuzzy goals and fuzzy constraints. The crisp formulation of fuzzy programming problem can be represented by the following equation comprising of i objectives and n constraints (Shaw *et al.*, 2012):

$$\left.\begin{array}{c} \text{Maximize } \lambda \\ \lambda\left(Z_i^{\max}-Z_i^{\min}\right)+Z_i(x)\leqslant Z_i^{\max} \text{ for all } i \text{ and } i=1,2,\ldots,I \\ \lambda(d_x)+g_n\,(x)\leqslant b_n+d_n \text{ for all } k, k=1,2,\ldots,K \\ Px \leqslant b \text{ for all deterministic constant} \\ x\geqslant 0 \text{ as integers and,} \\ 0 \leqslant \lambda \leqslant 1 \end{array}\right\}. \tag{11}$$

Each objective must be solved for maximization and minimization to obtain optimum upper ($Z_i^{\max}$) and lower bounds ($Z_i^{\min}$), respectively. In such models, the weights of objective functions and constraints are considered to be same. Thus, weighted additive model proposed by Tiwari *et al.* (1987) has been used where each objective function is multiplied by their respective priority weights. Such crisp single-objective linear programming model can be represented as given in the following equation:

$$\left.\begin{array}{c} \text{Maximize } \sum_{i=1}^{I} w_i\lambda_i+\sum_{n=1}^{N}\beta_n\gamma_n \\ \text{subject to} \\ \lambda_i\leqslant\mu_{Z_i}(x),\;\; i=1,2,\ldots,I \\ \gamma_k\leqslant\mu_{g_n}(x),\;\; n=1,2,\ldots,N \\ g_p\leqslant b_p(x), p=1,2,\ldots,M, \text{ where } \lambda_i \text{ and } \gamma_n\in[0,1] \\ \sum_{i=1}^{I} w_i+\sum_{k=1}^{K}\beta_k=1, \text{ where } w_i \text{ and } \beta_k>1 \\ x_i\geqslant 0, \text{ where } i=1,2,\ldots,I \end{array}\right\}, \tag{12}$$

where w_i and β_n are weight coefficients that indicates the relative importance among fuzzy goals and fuzzy constraints.

3. A case illustration

The effectiveness of the model has been illustrated through a case organization, which is a leading India-based logistics service provider (XYZ) with the turnover of approximately INR1,500 crores. It offers a wide range of innovative cutting-edge logistics services including express delivery and supply chain consulting. The firm provides services to various industries ranging from automobile, apparel, healthcare, FMCG and e-commerce. It serves over 610 destinations with more than 1,100 routes linked through hubs and mega hubs that are spread across all over the country.

In the process of shipping consignments of automobile spare parts, the management of XYZ Company required to make strategic decision on the modes of transportation to deliver the shipments faster and efficiently. Further, due to growing awareness of sustainability among shippers or consignor, the company was looking to incorporate sustainability criteria in its mode selection process along with the costs. The management realized that strategically selecting best combination of modes not only decreases logistics costs but also promote greener transportation as well as increase social viability. Therefore, management invited three experts from three departments, i.e. Vendor

Managed Inventory (VMI), Green Logistics (GL), Operations and Direct Shipment (ODS) with the aim to select best combination of modes to deliver shipment from origin to destination. A brainstorming session was conducted to identify sustainability criteria of mode selection problem. Experts widely discussed and gave their preferences to criteria that are practically critical and extensively used in the literature where exact information about those criteria are readily available. The next step was to identify weights of criteria for prioritizing the identified criteria. Each expert provided their opinions on the relative importance of each criterion over other criteria for selecting transportation modes using the linguistic variable. The final opinion obtained of each expert in the form of linguistic scale is then converted into the corresponding IFNs as provided in Table II. The intuitionistic fuzzy decision matrices of expert 1 (E1), expert 2 (E2) and expert 3 (E3) are shown in Tables IV–VI.

The aggregated intuitionistic fuzzy decision matrix for the three experts obtained using IFWA operator is shown in Table VII. Next, the degree of importance of each expert is calculated using the IFN scale provided in the Table III. The opinion of the

Criteria	Costs	Damage during transportation	Shipping delays	GHG emissions	Traffic congestion	Speed of delivery	Distance
Costs	(0.5, 0.4, 0.1)	(0.85, 0.1, 0.05)	(0.95, 0.05, 0.0)	(0.95, 0.05, 0.0)	(0.95, 0.05, 0.0)	(0.75. 0.15, 0.1)	(0.95, 0.05, 0.0)
Damage during transportation	(0.15, 0.8, 0.005)	(0.5, 0.4, 0.1)	(0.65, 0.25, 0.1)	(0.75. 0.15, 0.1)	(0.75. 0.15, 0.1)	(0.35, 0.55, 0.1)	(0.85, 0.1, 0.05)
Shipping delays	0.05, 0.95, 0.0)	(0.25, 0.65, 0.1)	(0.5, 0.4, 0.1)	(0.75. 0.15, 0.1)	(0.85, 0.1, 0.05)	(0.25, 0.65, 0.1)	(0.75. 0.15, 0.1)
GHG emissions	(0.15 0.8, 0.05)	(0.25, 0.65, 0.1)	(0.35, 0.55, 0.1)	(0.5, 0.4, 0.1)	(0.65, 0.25, 0.1)	(0.25, 0.65, 0.1)	(0.75. 0.15, 0.1)
Traffic congestion	(0.05, 0.95, 0.0)	(0.15, 0.8, 0.05)	(0.15, 0.8, 0.05)	(0.25, 0.65, 0.1)	(0.5, 0.4, 0.1)	(0.15, 0.8, 0.05)	(0.65, 0.25, 0.1)
Speed of Delivery	0.25, 0.65, 0.1)	(0.65, 0.25, 0.1)	(0.65, 0.25, 0.1)	(0.75. 0.15, 0.1)	(0.85, 0.1, 0.05)	(0.5, 0.4, 0.1)	(0.95, 0.05, 0.0)
Distance	(0.05, 0.95, 0)	(0.15, 0.8, 0.05)	(0.25, 0.65, 0.1)	(0.25, 0.65, 0.1)	(0.35, 0.55, 0.1)	(0.05, 0.95, 0.0)	(0.5, 0.4, 0.1)

Table IV. Intuitionistic fuzzy decision matrix of Expert 1 (E1)

Criteria	Costs	Damage during transportation	Shipping delays	GHG emissions	Traffic congestion	Speed of delivery	Distance
Costs	(0.5, 0.4, 0.1)	(0.95, 0.05, 0.0)	(0.95, 0.05, 0.0)	(0.75. 0.15, 0.1)	(0.85, 0.1, 0.05)	(0.5, 0.4, 0.1)	(0.95, 0.05, 0.0)
Damage during transportation	0.25, 0.65, 0.1)	(0.5, 0.4, 0.1)	(0.65, 0.25, 0.1)	(0.65, 0.25, 0.1)	(0.85, 0.1, 0.05)	(0.5, 0.4, 0.1)	(0.85, 0.1, 0.05)
Shipping delays	0.25, 0.65, 0.1)	(0.65, 0.25, 0.1)	(0.5, 0.4, 0.1)	(0.75. 0.15, 0.1)	(0.95, 0.05, 0.0)	(0.35, 0.55, 0.1)	(0.65, 0.25, 0.1)
GHG emissions	(0.35, 0.55, 0.1)	(0.35, 0.55, 0.1)	(0.35, 0.55, 0.1)	(0.5, 0.4, 0.1)	(0.75. 0.15, 0.1)	(0.35, 0.55, 0.1)	(0.75. 0.15, 0.1)
Traffic congestion	0.05, 0.95, 0.0)	(0.15, 0.8, 0.05)	(0.15, 0.8, 0.05)	(0.5, 0.4, 0.1)	(0.5, 0.4, 0.1)	(0.05, 0.95, 0.0)	(0.75. 0.15, 0.1)
Speed of delivery	(0.35, 0.55, 0.1)	(0.75. 0.15, 0.1)	(0.65, 0.25, 0.1)	(0.65, 0.25, 0.1)	(0.75. 0.15, 0.1)	(0.5, 0.4, 0.1)	(0.85, 0.1, 0.05)
Distance	0.05, 0.95, 0.0)	(0.15, 0.8, 0.05)	(0.35, 0.55, 0.1)	(0.15, 0.8, 0.05)	(0.25, 0.65, 0.1)	(0.15, 0.8, 0.05)	(0.5, 0.4, 0.1)

Table V. Intuitionistic fuzzy decision matrix of Expert 2 (E2)

Criteria	Costs	Damage during transportation	Shipping Delays	GHG emissions	Traffic congestion	Speed of delivery	Distance
Costs	(0.5, 0.4, 0.1)	(0.75. 0.15, 0.1)	(0.95, 0.05, 0.0)	(0.65, 0.25, 0.1)	(0.85, 0.1, 0.05)	(0.65, 0.25, 0.1)	(0.85, 0.1, 0.05)
Damage during transportation	(0.15, 0.8, 0.05)	(0.5, 0.4, 0.1)	(0.65, 0.25, 0.1)	(0.75. 0.15, 0.1)	(0.95, 0.05, 0.0)	(0.25, 0.65, 0.1)	(0.85, 0.1, 0.05)
Shipping delays	(0.15, 0.8, 0.05)	(0.65, 0.25, 0.1)	(0.5, 0.4, 0.1)	(0.65, 0.25, 0.1)	(0.35, 0.55, 0.1)	(0.35, 0.55, 0.1)	(0.75. 0.15, 0.1)
GHG emissions	(0.35, 0.55, 0.1)	(0.35, 0.55, 0.1)	(0.35, 0.55, 0.1)	(0.5, 0.4, 0.1)	(0.75. 0.15, 0.1)	(0.35, 0.55, 0.1)	(0.85, 0.1, 0.05)
Traffic congestion	(0.05, 0.95, 0.0)	(0.15, 0.8, 0.05)	(0.15, 0.8, 0.05)	(0.35, 0.55, 0.1)	(0.5, 0.4, 0.1)	(0.25, 0.65, 0.1)	(0.65, 0.25, 0.1)
Speed of delivery	(0.5, 0.4, 0.1)	(0.65, 0.25, 0.1)	(0.75. 0.15, 0.1)	(0.65, 0.25, 0.1)	(0.65, 0.25, 0.1)	(0.5, 0.4, 0.1)	(0.95, 0.05, 0.0)
Distance	(0.05, 0.95, 0.0)	(0.05, 0.95, 0.0)	(0.15, 0.8, 0.05)	(0.35, 0.55, 0.1)	(0.25, 0.65, 0.1)	(0.25, 0.65, 0.1)	(0.5, 0.4, 0.1)

Table VI. Intuitionistic fuzzy decision matrix of expert 3 (E3)

Criteria	Costs	Damage during transportation	Shipping delays	GHG emissions	Traffic congestion	Speed of delivery	Distance
Costs	(0.504, 0.395, 0.100)	(0.895, 0.080, 0.025)	(0.952, 0.048, 0.0)	(0.848, 0.113, 0.039)	(0.900, 0.076, 0.024)	(0.643, 0.250, 0.106)	(0.937, 0.057, 0.006)
Damage during transportation	(0.195, 0.731, 0.074)	(0.504, 0.395, 0.100)	(0.655, 0.246, 0.100)	(0.717. 0.181, 0.101)	(0.866, 0.094, 0.039)	(0.400, 0.498, 0.102)	(0.854, 0.097, 0.049)
Shipping Delays	0.163, 0.776, 0.060)	(0.550, 0.343, 0.108)	(0.504, 0.395, 0.100)	(0.733. 0.166, 0.101)	(0.868, 0.110, 0.022)	(0.320, 0.579, 0.101)	(0.717, 0.181, 0.101)
GHG emissions	(0.290, 0.622, 0.088)	(0.320, 0.579, 0.101)	(0.354, 0.546, 0.101)	(0.504, 0.395, 0.100)	(0.724, 0.175, 0.101)	(0.320, 0.579, 0.101)	(0.783, 0.133, 0.084)
Traffic Congestion	(0.051, 0.949, 0.000)	(0.152, 0.798, 0.051)	(0.152, 0.798, 0.051)	(0.391, 0.506, 0.102)	(0.504, 0.395, 0.100)	(0.138, 0.815, 0.047)	(0.700, 0.198, 0.102)
Speed of delivery	0.363, 0.535, 0.102)	(0.700, 0.198, 0.102)	(0.682, 0.217, 0.101)	(0.693, 0.206, 0.102)	(0.777, 0.144, 0.079)	(0.504, 0.395, 0.100)	(0.924, 0.064, 0.012)
Distance	(0.051, 0.949, 0)	(0.128, 0.832, 0.040)	(0.274, 0.634, 0.091)	(0.240, 0.677, 0.083)	(0.289, 0.610, 0.101)	(0.145, 0.805, 0.050)	(0.504, 0.395, 0.100)

Table VII. Aggregated intuitionistic fuzzy decision matrix (B)

expert (E2) working in the ODS department was considered to be very important for this study based on his experience and knowledge level. The opinion of expert (E1) working in GL department was considered important whereas the expert (E3) working in the VMI department was reflected as medium important for determining weights of criteria.

The linguistic variable is then converted into corresponding IFNs and the weight vector for experts' importance was calculated as $\delta = (0.349, 0.419, 0.245)$ using Equation (2). Then, the column elements of matrix B are aggregated and entropy weights of criteria are calculated using Equation (6) and their values are obtained as $\varpi_1 = 0.700$, $\varpi_2 = 0.760$, $\varpi_3 = 0.781$, $\varpi_4 = 0.805$, $\varpi_5 = 0.674$, $\varpi_6 = 0.857$ and $\varpi_7 = 0.620$. In the next step, the distance

(β_ij) between the aggregated intuitionistic fuzzy decision matrix and ideal reference sequence was to calculated using Equation (8). Then, β_max and β_min from the distance matrix (β) are calculated as shown in Table VIII. The grey relational coefficient matrix is then determined using Equation (9) and is provided in Table IX.

The weight vector obtained by solving the above model is calculated as $W_{\text{Criteria}} = (0.199, 0.152, 0.144, 0.130, 0.111, 0.161, 0.103)^T$.

4. Multi-mode selection model

Following sets of assumptions are made while formulating multi-objective multi-mode selection model:

(1) the shipment to be transported is considered under standard delivery;

(2) product considered is non-perishable in nature;

(3) while calculating costs only weight and distance factors have been taken into consideration and volume is not considered;

(4) diesel ship and electric train is considered for calculating speed and GHG emissions for sea and rail modes;

(5) Boeing aircraft with capacity of 40,000 pounds has been considered; and

(6) damage to the shipments includes damages during freight movement, loading-unloading process and interruptions/disruptions due to disaster.

The index set, decision variable and parameters used in the formulation of the model are defined as follows:

(1) Index

- i = number of modes, for $i = 1,2, \ldots, N$.
- j = number of objectives, for $j = 1,2, \ldots, J$.
- k = number of constraints, for $i = 1,2, \ldots, K$.

(2) Decision variable

- x_i = distance covered by each mode.

(3) Parameters of the model

- D = total distance to be covered from origin to destination.
- N = number of competing modes for selection.
- C_i = cost of transportation per kg per km by each mode i.
- Q_i = percentage of units damage per km by each mode i.
- S_i = percentage of shipping delays per km by each mode i.
- G_i = GHG emission kg per km per container by each mode i.
- H_i = average speed of delivery per km by each mode i.
- v_i = number of vehicles required to transport shipment to destination by each mode i.
- C_{cap} = total carbon emission cap for FT.
- B_i = budget allocated to each mode i.
- I_i = infrastructure availability for each mode i.

Distance matrix	Criteria	Costs	Damage during transportation	Shipping delays	GHG emissions	Traffic congestion	Speed of delivery	Distance	Min. β_{ij}	Max. β_{ij}
β_{11}	Costs	0.496	0.105	0.048	0.152	0.100	0.357	0.063	0.048	0.496
β_{21}	Damage during transportation	0.805	0.496	0.345	0.283	0.134	0.600	0.146	0.134	0.805
β_{31}	Shipping delays	0.837	0.450	0.496	0.267	0.132	0.680	0.283	0.132	0.837
β_{41}	GHG emissions	0.710	0.680	0.646	0.496	0.276	0.680	0.217	0.217	0.710
β_{51}	Traffic congestion	0.949	0.848	0.848	0.609	0.496	0.862	0.300	0.300	0.949
β_{61}	Speed of delivery	0.637	0.300	0.318	0.307	0.223	0.496	0.076	0.076	0.637
β_{71}	Distance	0.949	0.872	0.726	0.760	0.711	0.855	0.496	0.496	0.949
β_max										0.949
β_min									0.048	

Table VIII.
Distance matrix (β)

The following equation shows a typical MMSP for sustainable FT developed using linear programming as follows:

$$\left.\begin{array}{l}\text{Minimize } Z_1 = \sum_{i=1}^{n} C_i\, x_i \\ \text{Minimize } Z_2 = \sum_{i=1}^{n} Q_i\, x_i \\ \text{Minimize } Z_3 = \sum_{i=1}^{n} S_i\, x_i \\ \text{Minimize } Z_4 = \sum_{i=1}^{n} G_i\, x_i \\ \text{Minimize } Z_5 = \sum_{i=1}^{n} H_i\, x_i \\ \text{Minimize } Z_6 = \sum_{i=1}^{n} v_i\, x_i \\ \text{Subject to,} \\ \sum_{i=1}^{n} x_i = D \\ x_i \leqslant I_i \\ \sum_{i=1}^{n} G_i x_i \leqslant C_{cap} \\ C_i\, x_i \leqslant B_i \\ x_i \end{array}\right\}. \quad (13)$$

There are total six objectives undertaken in this study. Each objective function (Z_1, Z_2, Z_3, Z_4, Z_5 and Z_6) has been explained in Table X. This study considers different weights for objectives and constraints to deal with real-life situation.

Criteria	Costs	Damage during transportation	Shipping delays	GHG emissions	Traffic congestion	Speed of delivery	Distance
Costs	0.539	0.902	1.000	0.834	0.910	0.629	0.972
Damage during transportation	0.409	0.539	0.638	0.690	0.859	0.487	0.842
Shipping delays	0.399	0.565	0.539	0.705	0.861	0.453	0.690
GHG emissions	0.441	0.453	0.466	0.539	0.696	0.453	0.756
Traffic congestion	0.367	0.395	0.395	0.483	0.539	0.391	0.675
Speed of delivery	0.470	0.675	0.660	0.669	0.749	0.539	0.949
Distance	0.367	0.388	0.436	0.423	0.441	0.393	0.539

Table IX.
Grey relational coefficient matrix (γ_{ij})

	Definition
Objective function	
Objective function (Z_1)	minimizes costs of transportation (per kg per km) by each mode *i*
Objective function (Z_2)	minimizes percentage of units damage per km by each mode *i*
Objective function (Z_3)	minimizes percentage of shipping delays per km by each mode *i*
Objective function (Z_4)	minimizes GHG emissions (kg per km per container) by each mode *i*
Objective function (Z_5)	maximizes average speed of delivery by minimizing hours per km traveled by each mode *i*
Objective function (Z_6)	minimizes traffic congestion (vehicles per km) by each mode *i*
Constraints	
Constraint (22)	puts restriction on total distance to be traveled by each mode *i*
Constraint (23)	puts restriction on availability of infrastructure for each mode *i*
Constraint (24)	puts restriction on the overall budget allocated to each mode *i*
Constraint (25)	puts restriction on carbon footprint to each mode *i*
Constraint (26)	ensures all variables greater than zero

Table X.
Summary of objective functions used in this study

4.1 Fuzzy multi-objective linear programming

In the MMSP, we have considered four key modes of transportation, namely, road, railway, air and sea. To solve the multi-modal selection model, a small case of shipment handled by the case company has been considered. The company has received an order wherein it is supposed to deliver total 7,425 metric tons of consignment from Delhi NCR to Chennai within the country. In this model, distance has been considered as a fuzzy variable. This is because distance varies as the modes of transportation are being used. Distance may also vary due to traffic congestion, driver behavior, etc. The distance between Delhi and Chennai is predicted to be 2,767 km and it is assumed that it can vary from 2,717 km to 2,867 km. The carbon emission cap (C^{cap}) is taken as 30,000 kg in this model. The quantitative information on each variable used in the model was provided by the expert of the case company is presented in Table XI.

The numerical illustration of multi-objective linear programming has been provided in Table XII.

According to computational procedure, the objective function Z_1 is first minimized using the set of constraints to get lower-bound of objective function. Again, the same objective function is maximized using the same set of constraints to get upper-bound of objective function. This procedure is repeated for the rest of five objective functions ($Z2$, $Z3$, $Z4$, $Z5$ and $Z6$). The upper and lower bound for each objective function has been summarized in Table XIII.

Modes	Cost per kg per km	Number of units damaged per km (%)	Shipping delays (per km)	GHG emission kg per km per container	Speed of delivery (hour/km)	Traffic congestion (vehicle-km)	Total budget for each mode (INR million)
Road	16	1.2	0.05	0.507	0.017	297	7,250,000
Rail	9	1.98	0.157	0.311	0.02	12	228,000
Sea	8.4	2.4	0.36	0.274	0.022	1	25,000
Air	35	8.4	0.01	2.535	0.0011	71	7,000

Table XI. Quantitative information on each criterion to select transportation mode

$Z_1 = 16\,x_1 + 9\,x_2 + 8.4\,x_3 + 35\,x_4$

$Z_2 = 0.012\,x_1 + 0.0198\,x_2 + 0.024x_3 + 0.084\,x_4$

$Z_3 = 0.05\,x_1 + 0.157\,x_2 + 0.36\,x_3 + 0.01\,x_4$

$Z_4 = 0.507\,x_1 + 0.311\,x_2 + 0.274\,x_3 + 2.535\,x_4$

$Z_5 = 0.017\,x_1 + 0.02\,x_2 + 0.022\,x_3 + 0.0011\,x_4$

$Z_6 = 297\,x_1 + 12\,x_2 + 1\,x_3 + 71\,x_4$

Subject to

$$\sum_{i=1}^{4} x_i = 2{,}767$$
$$x_1 = 2{,}766.5$$
$$x_2 = 2{,}175$$
$$x_3 = 2{,}234$$
$$x_4 = 1{,}760$$
$$0.507x_1 + 0.311x_2 + 0.274x_3 + 2.5x_1 \leqslant 30{,}000$$
$$16\,x_1 \leqslant 72{,}50{,}000$$
$$9\,x_2 \leqslant 2{,}28{,}000$$
$$8.4\,x_3 \leqslant 25{,}000$$
$$35\,x_4 \leqslant 7{,}000$$

x_1, x_2, x_3, x_4 are integers

Table XII. Numerical example of multi-objective linear programming

Further, two approaches are used to formulate the FMOLP. The first approach is an asymmetric approach that allocates weights according to the degree of importance of variables in MMSP. The second approach is symmetric approach that allocates same weight to the variables. These two approaches are used to compare the results. In case of asymmetric approach, weighted additive method is used. The weights obtained using GRA–IFP are used to formulate crisp MMSP. While formulating crisp linear programming, the additive value of membership functions of objectives and constraints are maximized. The crisp multi-objective linear programming model for multi-mode selection using weighted additive method is provided in Table XIV.

Here, the first six terms represented by λ_1, λ_2, λ_3, λ_4, λ_5 and λ_6 are membership functions of objective functions and γ_1 represents membership function of distance constraint. Linear programming-based software LINGO (version 16) has been used to solve the above model. The optimal solution obtained using this software for the above formulated model is as follows:

- Objective function value is $\lambda = 0.734$ and values of $\lambda_1 = 0.8656$, $\lambda_2 = 0.8122$, $\lambda_3 = 0.6562$, $\lambda_4 = 0.9213$, $\lambda_5 = 0.2237$ and $\lambda_6 = 0.7623$ and the value of $x_1 = 592$, $x_2 = 2{,}175.00$, $x_3 = 0$ and $x_4 = 0.00$.

Table XIII. The data set for calculation of membership function

S. No.	Objective function	$\mu = 1$	$\mu = 0$
1	Z_1	23,562.60	62,367.06
2	Z_2	33.20790	123.5503
3	Z_3	100.255	887.921
4	Z_4	777.879	3,300.95
5	Z_5	31.89629	59.808
6	Z_6	8,630	821,686

Table XIV. Formulation of multi-mode selection problem using asymmetrical approach

Maximize $= 0.199\ \lambda_1 + 0.152\ \lambda_2 + 0.144\ \lambda_3 + 0.13\ \lambda_4 + 0.161\ \lambda_5 + 0.111\ \lambda_6 + 0.103\ \gamma_1$

subject to

$\lambda_1 \leqslant (62{,}637.06 - (16\ x_1 + 9\ x_2 + 8.4\ x_3 + 35\ x_4))/38{,}804.46$

$\lambda_2 \leqslant (123.5503 - (0.012\ x_1 + 0.0198\ x_2 + 0.024\ x_3 + 0.084\ x_4))/90.3424$

$\lambda_3 \leqslant (887.921 - (0.05\ x_1 + 0.157\ x_2 + 0.36\ x_3 + 0.01\ x_4))/787.666$

$\lambda_4 \leqslant (3{,}300.95 - (0.507\ x_1 + 0.311\ x_2 + 0.274\ x_3 + 2.535\ x_4))/2{,}523.071$

$\lambda_5 \leqslant (59.808 - (0.017\ x_1 + 0.02\ x_2 + 0.022\ x_3 + 0.0011\ x_4))/27.91171$

$\lambda_6 \leqslant (821{,}686 - (297\ \mathrm{x1} + 12\ x_2 + 1\ x_3 + 71\ x_4))/813{,}056$

$\gamma_1 \leqslant (2{,}867 - (x_1 + x_2 + x3 + x4))/100$

$\gamma_1 \leqslant ((x_1 + x_2 + x_3 + x_4) - 2{,}717)/50$

$x_1 \leqslant 2{,}766.5$

$x_2 \leqslant 2{,}175$

$x_3 \leqslant 2{,}234$

$x_4 \leqslant 1{,}760$

$0.507\ x_1 + 0.311\ x_2 + 0.274\ x_3 + 2.5\ x_4 \leqslant 30{,}000$

$16\ x_1 \leqslant 62{,}500$

$9\ x_2 \leqslant 54{,}167$

$8.4\ x_3 \leqslant 29{,}177$

$35\ x4 \leqslant 33{,}333$

$x_1, x_2, x_3, x_4 \geqslant 0$

$$Z_1 = 29,047, \ Z_2 = 50.169, \ Z_3 = 371.075, \ Z_4 = 976.569, \ Z_5 = 53.564 \text{ and } Z_6 = 201,924.$$

The MMSP is again solved using Zimmermann approach. In the case of symmetrical approach, all membership functions are assigned same weight. λ is considered as the overall membership function for all objective functions ($Z1$, $Z2$, $Z3$, $Z4$, $Z5$ and $Z6$) and the constraints. The overall membership function is to be maximized in this problem. The optimal solution obtained using LINGO (version 16) software for the model formulated in Table XV is as follows:

- Objective function value is $\lambda = 0.546$ and the value of $x_1 = 902.1217$, $x_2 = 1{,}440.103$, $x_3 = 0.00$ and $x_4 = 402.0538$.

$$Z_1 = 41,466.7572, \ Z_2 = 71.96, \ Z_3 = 275.22, \ Z_4 = 1,924.454, \ Z_5 = 44.58 \text{ and}$$

$$Z_6 = 313,755.2.$$

5. Results and discussions

A sustainable FTS involves freight processes that are economically efficient, socially inclusive and environment friendly. Such system offers a profitable, affordable, reliable, low-carbon and safer FT ecosystem. From the weight vector obtained using GRA–IFP it can be observed that among the three dimensions of sustainability, economic criteria have been given higher importance by experts. Among economic criteria, costs of FT emerged out to be the most critical criteria for the firm while selecting mode followed by other economic criteria such as damage during transportation, shipping delays, speed of delivery. Environmental and social dimensions of sustainability measured by GHG emission and traffic congestion are least preferred criteria for the case firm.

Maximize $=\lambda$
subject to
$\lambda \leqslant (62{,}637.06-(16\ x_1+9\ x_2+8.4\ x_3+35\ x_4))/38{,}804.4$
$\lambda \leqslant (123.5503-(0.012\ x_1+0.0198\ x_2+0.024\ x_3+0.084\ x_4))/90.3424$
$\lambda \leqslant (887.921-(0.05\ x_1+0.157\ x_2+0.36\ x_3+0.01\ x_4))/787.666$
$\lambda \leqslant (3{,}300.95-(0.507\ x_1+0.311\ x_2+0.274\ x_3+2.535\ x_4))/2{,}523.071$
$\lambda \leqslant (59.808-(0.017\ x_1+0.02\ x_2+0.022\ x_3+0.0011\ x_4))/27.91171$
$\lambda \leqslant (821{,}686-(297\ x_1+12\ x_2+1\ x_3+71\ x_4))/813{,}056$
$\lambda \leqslant (2{,}867-(x_1+x_2+x_3+x_4))/100$
$\lambda \leqslant ((x_1+x_2+x_3+x_4)-2{,}717)/50$
$x_1 \leqslant 2{,}766.5$
$x_2 \leqslant 2{,}175$
$x_3 \leqslant 2{,}234$
$x_4 \leqslant 1{,}760$
$0.507\ x_1+0.311\ x_2+0.274\ x_3+2.5\ x_4 \leqslant 30{,}000$
$16\ x_1 \leqslant 62{,}500$
$9\ x_2 \leqslant 54{,}167$
$8.4\ x_3 \leqslant 29{,}177$
$35\ x_4 \leqslant 33{,}333$
$x_1, x_2, x_3, x_4 \geqslant 0$

Table XV. Formulation of multi-mode selection problem using symmetrical approach

When the MMSP is solved by symmetrical approach, it was observed that the cost of transportation has been increased by 42.76 percent, if the relative importance of the criteria is not taken into consideration. Percentage of units damaged per km has been increased by 43.43 percent in case of symmetrical approach, which further increases the transportation costs. It was further observed that not considering relative weights of sustainable criteria while making decisions on transportation modes drastically increases GHG emissions by 97 percent. This could be due to the fact that in the case of symmetrical approach, air as the mode of transportation has been selected with the share of 14.6 percent. On social dimension front, traffic congestion increases by 55.38 percent in case of symmetric approach of selecting modes of transportation. This is because the share of road increases in case of symmetrical approach that has comparatively lesser capacity to transport the shipment. On service level front, speed of delivery increases by 16.67 percent, if we consider relative weights of criteria. It can be clearly observed that the profitability decreases if weights of criteria are not considered. In the proposed approach, the modes selected for the chosen route are road and rail with distance allocation of 592 and 2,175 km, respectively. However, in case of symmetrical approach, three modes are selected wherein maximum share of freight movement (52.5 percent) will be carried out by rail, followed by road (32.9 percent) and air (14.6 percent).

Table XVI shows the modes selected along with their respective distance allocation. In the proposed model, costs and damages have been given more weightages. However, 14.6 percent of the distance has been allocated to air in the case of symmetrical approach. This is because air is the fastest mode of transportation with highest average speed as compared to the other three transportation modes. It can be further analyzed that rail is considered to be the best mode of transportation among other modes. This is because the cost of transportation by the rail as the mode of transportation is lowest. Also, this mode incurs lower percentage of damages to freight, emits lower GHG, has higher transferability rate, higher average speed and lower possibilities of delays (SteadieSeifi *et al.*, 2014). Thus, rail has been allocated 2,175 km of distance as a complete share of infrastructural availability. Further, road is emerged out to be the second best mode of transportation with 21.4 and 32.8 percent of distance allocated to it in case of asymmetrical and symmetrical approach, respectively. This is due to its higher average speed, lower shipping delays and lower damages during freight movement.

6. Scenario building and sensitivity analysis

In this section, we have carried out a set of sensitivity analysis to generate insights from the changing behavior of the asymmetrical model considering weights of economic, environmental and social criteria that influence the decision of selecting sustainable modes of transportation. This section of the study clearly depicts that modes are either complementing or competing each other under various set-ups. In this study, the performance of model is tested under three distinct scenarios. These scenarios are generated by focusing on three dimensions of TBL, i.e. economic, environmental and social perspectives.

In the first scenario, the operations of logistics service provider are assumed to be economic and other dimensions of sustainability, i.e. environment and social criteria are kept

Table XVI. Summary of mode selection and total distance allocation

Transportation mode	D_i	Solution using asymmetrical approach	Distance allocation percentage for asymmetrical	Solution using symmetrical approach	Distance allocation percentage for symmetrical
Road	2,766.5	592	21.4	902.1217	32.9
Rail	2,175	2,175.00	78.6	1,440.103	52.5
Sea	2,234	0.00	0	0.00	0
Air	1,760	0.00	0	402.0538	14.6

as having same importance. The economic dimension generally involves indicators related to service level, operational performance and costs. Therefore, the effect of economic-driven perspective on transportation mode selection has been investigated by varying weights of cost and service goals (percentage of units damaged, shipping delays and speed of transportation) in the model from 0 to 1, while keeping weights of other criteria as equal. Figure 5 presents the model performance tested at ten levels of experimentation.

It can be observed that as the weight of economic criteria approaches toward 1, road seizes the complete share of rail. This is because the negative impact of road on environment and society has been neglected. Also, throughout the experiment, air is the most unfavorable mode of transportation as it has not been allocated any load due to its high transportation costs, higher GHG emissions and higher percentage of damages during freight movement. In short, road is emerged out to be the most economical mode for logistics service providers.

Similarly, environmental scenario that considers the impact of GHG emissions on the model performance has been presented in Figure 6. As we keep on increasing the weights of cost and environmental criteria, road loses its share to sea as it is environmentally and economically viable to ship the freight via sea, whereas other service level and social dimensions are kept constant. As the environmental dimension attains highest weight, sea captures the share with 80 percent of the distance is traveled by sea. Therefore, sea and rail emerged out to be the greenest modes that can assist logistics service providers in improving their environmental performance.

The sensitivity analysis on social dimension was done by varying the weights of cost and social criteria of the model. Figure 7 depicts the sensitivity analysis of social dimension

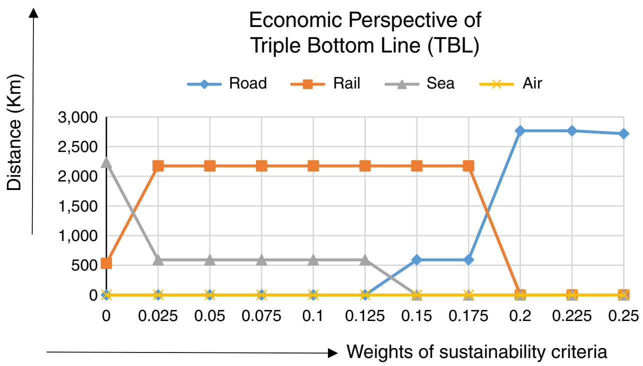


Figure 5.
Sensitivity analysis by changing weights of economic criteria

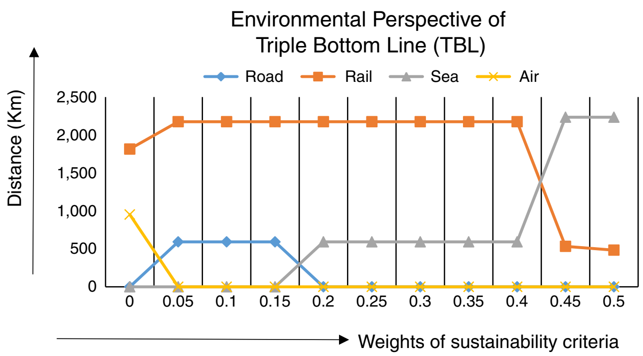


Figure 6.
Sensitivity analysis by changing weights of environmental criteria

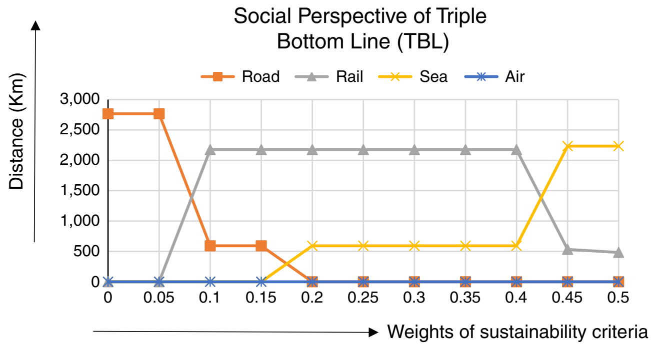


Figure 7.
Sensitivity analysis by changing weights of social criteria

of sustainability. It can be observed that from the figure that as the weight of social criteria approaches to 1, rail mode has lost its share to sea mode. The reason of such allocation can be attributed to the fact that sea is most cost effective and socially efficient than rail. Thus, it can be summarized that sea and rail are the best modes to improve the social responsibility of the freight transporters.

The key purpose of the sensitivity analysis was to check the robustness of the model. However, it was found out that the modes of transportation changes according to the preference given to either economic, environmental or social criteria MMSP. Therefore, it was concluded from sensitivity analysis that road is the best mode for economically driven companies, whereas sea and rail together can be considered to be the greenest as well as socially responsible modes of transportation. Freight transporters can broadly use these modes of transportation for delivering their shipments as per their preference toward the three dimensions of sustainability.

7. Conclusion

Mode selection is a crucial strategic decision for enhancing sustainability in the freight operations. In the present study, GRA–IFP and FMOLP methods are used to formulate a mathematical model for selecting best modes of transportation. This study has integrated GHG emissions as one of the goals in the objective function and carbon emission cap (C^{cap}) as one of the constraints to assess the environmental performance of each mode. Further, traffic congestion has been considered to simultaneously assess social performance of any logistics service providers. The proposed model is very useful as it brings out insights to improve the overall sustainable performance of freight transporters. A case study has been used to demonstrate the efficacy and implications of GRA–IFP and FMOLP for MMSP. The sensitivity analysis carried out in the study has shown that among all the four modes, road fits better on economic criteria. FT is considered to be the most environmentally damaging activity. Thus, to improve the environmental performance of freight operations, sea and rail are found to be the greenest modes of transportation. The social performance of freight transporters can also be improved by using sea and rail as the modes of transportation. To summarize, road and rail are the most sustainable modes of transportation to carry shipments from shippers to receivers.

References

Atanassov, K.T. (1986), "Intuitionistic fuzzy sets", *Fuzzy Sets and Systems*, Vol. 20 No. 1, pp. 87-96.

Baumol, W.J. and Vinod, H.D. (1970), "An inventory theoretic model of freight transport demand", *Management Science*, Vol. 16 No. 7, pp. 413-421.

Björklund, M. and Gustafsson, S. (2015), "Toward sustainability with the coordinated freight distribution of municipal goods", *Journal of Cleaner Production*, Vol. 98, pp. 194-204.

Cullinane, K. and Toy, N. (2000), “Identifying influential attributes in freight route/mode choice decisions: a content analysis”, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 36 No. 1, pp. 41-53.

De-Jong, G. and Ben-Akiva, M. (2007), “A micro-simulation model of shipment size and transport chain choice”, *Transportation Research Part B: Methodological*, Vol. 41 No. 9, pp. 950-965.

Foster, J.R. and Strasser, S. (1990), “Carrier/modal selection factors: the shipper/carrier paradox”, *Journal of the Transportation Research Forum*, Vol. 31 No. 1, pp. 206-212.

Hoen, K.M.R., Tan, T., Fransoo, J.C. and van Houtum, G.J. (2014), “Effect of carbon emission regulations on transport mode selection under stochastic demand”, *Flexible Services and Manufacturing Journal*, Vol. 26 Nos 1-2, pp. 170-195.

Jeffs, V.P. and Hills, P.J. (1990), “Determinants of modal choice in freight transport”, *Transportation*, Vol. 17 No. 1, pp. 29-47.

Kahi, S.V., Yousefi, S., Shabanpour, H. and Farzipoor Saen, R. (2017), “How to evaluate sustainability of supply chains? A dynamic network DEA approach”, *Industrial Management & Data Systems*, Vol. 117 No. 9, pp. 1866-1889.

Kengpol, A., Tuammee, S. and Tuominen, M. (2014), “The development of a framework for route selection in multimodal transportation”, *The International Journal of Logistics Management*, Vol. 25 No. 3, pp. 581-610.

Kent, J.L. and Stephen Parker, R. (1999), “International containership carrier selection criteria: shippers/carriers differences”, *International Journal of Physical Distribution & Logistics Management*, Vol. 29 No. 6, pp. 398-408.

Li, D.F. (2010), “A ratio ranking method of triangular intuitionistic fuzzy numbers and its application to MADM problems”, *Computers & Mathematics with Applications*, Vol. 60 No. 6, pp. 1557-1570.

McGinnis, M.A. (1979), “Shipper attitudes toward freight transportation choice: a factor analytic study”, *International Journal of Physical Distribution & Materials Management*, Vol. 10 No. 1, pp. 25-34.

McKinnon, A.C. (1989), “Choice of transport mode”, *Physical Distribution Systems*, Routledge, London.

Meixell, M.J. and Norbis, M. (2008), “A review of the transportation mode choice and carrier selection literature”, *The International Journal of Logistics Management*, Vol. 19 No. 2, pp. 183-211.

Muerza, V., Larrodé, E. and Moreno-Jiménez, J.M. (2017), “Identification and selection of ICTs for freight transport in product service supply chain diversification”, *Industrial Management & Data Systems*, Vol. 117 No. 7, pp. 1469-1484.

Murphy, D.J. and Farris, M.T. (1993), “Time-based strategy and carrier selection”, *Journal of Business Logistics*, Vol. 14 No. 2, pp. 25-40.

Nijkamp, P., Reggiani, A. and Tsang, W.F. (2004), “Comparative modelling of interregional transport flows: applications to multimodal European freight transport”, *European Journal of Operational Research*, Vol. 155 No. 3, pp. 584-602.

Ozceylan, E. (2010), “A decision support system to compare the transportation modes in logistic”, *International Journal of Lean Thinking*, Vol. 1 No. 1, pp. 58-83.

Punakivi, M. and Hinkka, V. (2006), “Selection criteria of transportation mode: a case study in four Finnish industry sectors”, *Transport Reviews*, Vol. 26 No. 2, pp. 207-219.

Qaiser, F.H., Ahmed, K., Sykora, M., Choudhary, A. and Simpson, M. (2017), “Decision support systems for sustainable logistics: a review and bibliometric analysis”, *Industrial Management & Data Systems*, Vol. 117 No. 7, pp. 1376-1388.

Roberts, K. (2012), “Key factors and trends in transportation mode and carrier selection”, *The Journal of Undergraduate Research at the University of Tennessee*, Vol. 4 No. 1, pp. 41-52.

Shaw, K., Shankar, R., Yadav, S.S. and Thakur, L.S. (2012), “Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain”, *Expert Systems with Applications*, Vol. 39 No. 9, pp. 8182-8192.

SteadieSeifi, M., Dellaert, N.P., Nuijten, W., Van Woensel, T. and Raoufi, R. (2014), "Multimodal freight transportation planning: a literature review", *European Journal of Operational Research*, Vol. 233 No. 1, pp. 1-15.

Tiwari, R.N., Dharmar, S. and Rao, J.R. (1987), "Fuzzy goal programming – an additive model", *Fuzzy Sets and Systems*, Vol. 24 No. 1, pp. 27-34.

Tuzkaya, U.R. and Önüt, S. (2008), "A fuzzy analytic network process based approach to transportation-mode selection between Turkey and Germany: a case study", *Information Sciences*, Vol. 178 No. 15, pp. 3133-3146.

Vannieuwenhuyse, B., Gelders, L. and Pintelon, L. (2003), "An online decision support system for transportation mode choice", *Logistics Information Management*, Vol. 16 No. 2, pp. 125-133.

Zeimpekis, V., Aktas, E., Bourlakis, M. and Minis, I. (2018), *Sustainable Freight Transport: Theory, Models, and Case Studies*, Springer, Switzerland.

Zhang, S.F. and Liu, S.Y. (2011), "A GRA-based intuitionistic fuzzy multi-criteria group decision making method for personnel selection", *Expert Systems with Applications*, Vol. 38 No. 9, pp. 11401-11405.

Zimmermann, H.J. (1978), "Fuzzy programming and linear programming with several objective functions", *Fuzzy Sets and Systems*, Vol. 1 No. 1, pp. 45-55.

Corresponding author
Vijayta Fulzele can be contacted at: vijayta.fulzele22@gmail.com