



RESEARCH ARTICLE

Sustainable fuzzy rough multi-objective multi-route cold transportation model with traffic flow and route constraints

L. Brighth Gladys, J. Merline Vinotha*

Abstract

Refrigerated transportation is a reputed worldwide preservation technique for perishables but not always a pollution free mean of transport. Most of the countries, including India, employ environmentally unsustainable diesel-based cooling systems throughout the entire distribution time. So, this paper proposes two sustainable multi-objective binary linear programming transportation models for fully diesel-based refrigerated trucks and for diesel refrigerated trucks with electric plug-in. Other than the vehicles' running time, the models consider additional time components notably precooling time, traffic idling time, resting time that are unavoidable during cold transit. Route constraint is also added in the models to choose the optimum route from the multiple transport routes. Traffic flow between each route is considered as one of the objectives along with the operating expenses and distribution time and they are taken to be triangular fuzzy rough numbers to handle real-life uncertainty. The data of sea fish is taken for case study and the put forward models are solved using existing methods of multi-objective optimization like Fuzzy Goal Programming and Weighted Fuzzy Goal Programming in LINGO (19.0). The results are compared to highlight the conveyance that offers better operational efficiency and favours environmental sustainability.

Keywords: cold transportation, multi-objective, multi-route, sustainability, route constraint, traffic flow

Mathematics Subject Classification (2020): 90B06, 90C08

Introduction

The transportation problem is a distinct linear programming problem that minimizes or maximizes transportation metrics related to the distribution of products from sources to destinations. Amidst the diverse products, perishables such as fruits, vegetables, flowers, meat, poultry, etc., always demand exceptional transportation due to their quick reactivity to temperature changes. Kumar A & Agarwal S (2023) performed a literature review on Indian agri-fresh

foods and remarked that the challenges while incorporating perishability received a comparatively higher attention in the supply chain. Scherhauser S, Moates G, Hartikainen H, Waldron K & Obersteiner G (2018) appraised the environmental effect of food waste in Europe and emphasized the importance of food waste prevention. Temperature sensitive items are lost numerously in the post-production stages and so demand for special preservation and solid waste management technologies are increasing each day.

Cold supply chain is one among the flourishing preservation technologies that helps in refrigerated storage and distribution of perishables. Gupta P, Kumar P, Elarga HHHH & Hafner A (2023) thrashed out the statistics on Indian refrigerated transport market and elaborated certain strategies to vanquish the difficulties in them. Arora M, Kumar R & Raju TB (2023) identified the issues in the Indian cold supply chain for frozen food products in which sustainability, cold chain awareness and infrastructure, safety, quality were found profound. The ecological consequences of various traditional cold chain methods are analysed by Ferretti I, Mazzoldi L & Zaroni S (2018) and portable refrigerated units are suggested as an effective replacement to enhance sustainability. Though fossil fuels are the most available and reliable energy sources, environmentalists disapprove them due to their polluting nature. An explicit comparison

PG & Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamil Nadu, India.

***Corresponding Author:** J. Merline Vinotha, PG & Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamil Nadu, India, E-Mail: merlinevinotha@gmail.com

How to cite this article: Gladys, L.B., Vinotha, J.M. (2025). Sustainable fuzzy rough multi-objective multi-route cold transportation model with traffic flow and route constraints. *The Scientific Temper*, 16(1):3656-3663.

Doi: 10.58414/SCIENTIFICTEMPER.2025.16.1.11

Source of support: Nil

Conflict of interest: None.

between the fuel types and a SWOT analysis is performed by Yaqoob H, Teoh YH, Goraya T. S, Sher F, Jamil MA, Rashid T & Yar K.A (2021) to discover the optimum sustainable fuel and to adopt electric vehicles. Xu F, Crawford C, Feng Y, Lin Z & Li S (2023) examined the environment-economic power of diesel, hybrid electric and plug-in hybrid electric trucks to stress on the importance of switching conventional non-renewable fuel-based vehicles to electric vehicles. This kind of environmental awareness has aroused the thirst for lowering unsustainability which includes emission from refrigerated transport and so Neittaanmäki P, Akimov K, Akimova V & Tuovinen R (2024), Yakavenka V, Mallidis I, Vlachos D, Iakovou E & Eleni Z (2020) analysed sustainable objectives to favor green transportation.

Apart from fuel types, supply chain managers are frequently analysing other additional constraints needed for effective movement of goods as traditional transportation models contain only the supply and demand constraints which is inadequate for the present era. Constraints for product capacity by Gupta S, Ali I & Ahmed A (2020), conveyance capacity by Haley KB (1962), budget restriction by Giri PK, Maiti, MK & Maiti M (2015), Kundu P, Kar S & Maiti M (2013), Majumder S, Kundu P, Kar S, & Pal T (2019), safety factor by Baidya A, Bera UK & Maiti M (2013) etc. are already initiated for enhancing transportation. There always exists multiple routes between a source and destination and they vary in distance, travel time, road condition and so on. So, route optimization is one of the significant measures handled by the logistics industry to meet customer's demand while repressing additional expense and distribution time. Shivani and Rani. D (2024) proposed a multi-objective 4D green solid transportation problem with multiple routes under two different driving styles. Erkut E and Ingolfsson A (2000) proposed models for avoiding a catastrophe while transporting hazardous materials by accessing and finding the best route among the available paths. Multi-route scenarios are already discussed in transportation problem, but route constraints are not frequently debated though they have a greater impact on efficiency, productivity, safety, customer experience etc. Xie L and Cao C (2021) discussed a multi-modal and multi-route 0-1 integer programming transportation model for hazardous materials with several route constraints.

Various types of time namely travel time, loading and unloading time, idling time, fueling time, transfer time, resting time etc. incur during freight transportation and their ignorance have a significant impact on operational cost, inventory management, delivery deadline, customer service, environment, safety etc. Sambracos E & Ramfou I (2013) estimated the effects of change in Freight Transport Time (FTT) on the economic performance of manufacturing companies. The impact of diesel vehicles idling on fuel consumption and exhaust emission are discussed by Rahman SA, Masjuki HH, Kalam MA, Abedin MJ, Sanjid A &

Sajjad HJEC (2013). The effect of congestion on fuel cost and travel time cost was discussed by Errampalli M, Senathipathi V and Thamban D (2015) with development of fuel and time related congestion equations. Truck Stop Electrification (TSE) or shore power for truck is already introduced in some countries to cutdown unsustainability during transit. TSE sites are much useful for perishables as they are more prone to temperature changes when the truck engine is shutdown. Numerous other solutions are suggested and practiced by Baghestani A, Tayarani M, Allahviranloo M & Gao HO (2020) to reduce the impact of these kind of uncertain time in literature yet they remain unadopted in many countries.

Though there exist enough awareness on the importance of route optimization on the multi-route transport network with varying distribution time, no mathematical model is still investigated in literature on this subject. Also, the efficiency of various transit conveyances is not analysed in models as they differ by cost, performance, environmental impact, energy source and availability, maintenance. Traffic flow is one among the striking factors of transport emission but is neglected in general though its minimization enhances environmental sustainability. Thus, this paper proposes models for traffic flow optimization through optimal route selection and resolves fuzzy rough cold transportation problem to negotiate the ignorance of various time components and the advantage of conventional vehicles with electric plug-in option which is not yet adopted in many countries including India but could be a remarkable choice for sustainability.

Preliminaries

Fuzzy Rough Set

A set $\tilde{H}^{\mathfrak{R}} = [(\tilde{H}^{\mathfrak{RL}}, \mu_{\tilde{H}^{\mathfrak{R}}}^L) : (\tilde{H}^{\mathfrak{RU}}, \mu_{\tilde{H}^{\mathfrak{R}}}^U)]$ is called a fuzzy rough set of the real line where $\mu_{\tilde{H}^{\mathfrak{R}}}^L$ and $\mu_{\tilde{H}^{\mathfrak{R}}}^U$ are membership functions defined from $\mathbb{R}$ to $[0,1]$ such that $\tilde{H}^{\mathfrak{RL}} \subseteq \tilde{H}^{\mathfrak{RU}}$.

Triangular Fuzzy Rough Set

A triangular fuzzy rough set $\tilde{H}^{\mathfrak{R}}$ is interpreted as $\tilde{H}^{\mathfrak{RL}} \tilde{H}^{\mathfrak{RU}}$ where $\tilde{H}^{\mathfrak{RL}} = (h_1^L, h_2, h_3^L)$ & $\tilde{H}^{\mathfrak{RU}} = (h_1^U, h_2, h_3^U)$ such that $h_1^U \leq h_1^L \leq h_2 \leq h_3^L \leq h_3^U$ and its membership functions are defined by

$$\mu_{\tilde{H}^{\mathfrak{R}}}^L(x) = \begin{cases} \frac{x - h_1^L}{h_2 - h_1^L} & h_1^L \leq x \leq h_2 \\ \frac{x - h_3^L}{h_2 - h_3^L} & h_2 \leq x \leq h_3^L \\ 0 & \text{otherwise} \end{cases}$$

$$\mu_{\tilde{H}^{\mathfrak{R}}}^U(x) = \begin{cases} \frac{x-h_1^U}{h_2^U-h_1^U} & h_1^U \leq x \leq h_2^U \\ \frac{x-h_3^U}{h_2^U-h_3^U} & h_2^U \leq x \leq h_3^U \\ 0 & \text{otherwise} \end{cases}$$

Confidence interval at the α -level

The rough interval obtained by defining α - $\tilde{u}$ for the fuzzy rough number

$$\tilde{H}^{\mathfrak{R}} = \left[\left(h_1^L, h_2, h_3^L \right) : \left(h_1^U, h_2, h_3^U \right) \right] \text{ where } \alpha \in [0,1] \text{ is}$$

$$\left(\tilde{H}^{\mathfrak{RL}} \right)_{\alpha} = \left[h_1^L(\alpha), h_3^L(\alpha) \right] = \left[h_1^L + (h_2 - h_1^L)\alpha, h_3^L + (h_2 - h_3^L)\alpha \right]$$

$$\left(\tilde{H}^{\mathfrak{RU}} \right)_{\alpha} = \left[h_1^U(\alpha), h_3^U(\alpha) \right] = \left[h_1^U + (h_2 - h_1^U)\alpha, h_3^U + (h_2 - h_3^U)\alpha \right]$$

Ranking function for Triangular Fuzzy Rough Interval

For $\tilde{H}^{\mathfrak{R}} = \left[\left(h_1^L, h_2, h_3^L \right) : \left(h_1^U, h_2, h_3^U \right) \right]$, the ranking function is

$$r(\tilde{H}^{\mathfrak{R}}) = \frac{1}{4} \left[\int_0^1 \left(h_1^L(\alpha) + h_3^L(\alpha) + h_1^U(\alpha) + h_3^U(\alpha) \right) d\alpha \right]$$

Arithmetic Operations on Triangular Fuzzy Rough Interval

Let $\tilde{G}^{\mathfrak{R}} = \left[\left(g_1^L, g_2, g_3^L \right) : \left(g_1^U, g_2, g_3^U \right) \right]$ and

$\tilde{H}^{\mathfrak{R}} = \left[\left(h_1^L, h_2, h_3^L \right) : \left(h_1^U, h_2, h_3^U \right) \right]$ be two triangular

fuzzy rough numbers.

• Addition

$$\tilde{G}^{\mathfrak{R}} + \tilde{H}^{\mathfrak{R}} = \left[\left(\tilde{G}^{\mathfrak{RL}} + \tilde{H}^{\mathfrak{RL}} \right) : \left(\tilde{G}^{\mathfrak{RU}} + \tilde{H}^{\mathfrak{RU}} \right) \right]$$

$$\tilde{G}^{\mathfrak{RL}} + \tilde{H}^{\mathfrak{RL}} = (g_1^L + h_1^L, g_2 + h_2, g_3^L + h_3^L)$$

$$\tilde{G}^{\mathfrak{RU}} + \tilde{H}^{\mathfrak{RU}} = (g_1^U + h_1^U, g_2 + h_2, g_3^U + h_3^U)$$

• Subtraction

$$\tilde{G}^{\mathfrak{R}} - \tilde{H}^{\mathfrak{R}} = \left[\left(\tilde{G}^{\mathfrak{RL}} - \tilde{H}^{\mathfrak{RL}} \right) : \left(\tilde{G}^{\mathfrak{RU}} - \tilde{H}^{\mathfrak{RU}} \right) \right]$$

$$\tilde{G}^{\mathfrak{RL}} - \tilde{H}^{\mathfrak{RL}} = (g_1^L - h_1^L, g_2 - h_2, g_3^L - h_3^L)$$

$$\tilde{G}^{\mathfrak{RU}} - \tilde{H}^{\mathfrak{RU}} = (g_1^U - h_1^U, g_2 - h_2, g_3^U - h_3^U)$$

• Multiplication

$$\tilde{G}^{\mathfrak{R}} \times \tilde{H}^{\mathfrak{R}} = \left[\left(\tilde{G}^{\mathfrak{RL}} \times \tilde{H}^{\mathfrak{RL}} \right) : \left(\tilde{G}^{\mathfrak{RU}} \times \tilde{H}^{\mathfrak{RU}} \right) \right]$$

$$\tilde{G}^{\mathfrak{RL}} \times \tilde{H}^{\mathfrak{RL}} = (g_1^L \times h_1^L, g_2 \times h_2, g_3^L \times h_3^L)$$

$$\tilde{G}^{\mathfrak{RU}} \times \tilde{H}^{\mathfrak{RU}} = (g_1^U \times h_1^U, g_2 \times h_2, g_3^U \times h_3^U)$$

• Division

$$\text{If } 0 \notin \tilde{H}^{\mathfrak{R}}, \tilde{G}^{\mathfrak{R}} \div \tilde{H}^{\mathfrak{R}} = \left[\left(\tilde{G}^{\mathfrak{RL}} \div \tilde{H}^{\mathfrak{RL}} \right) : \left(\tilde{G}^{\mathfrak{RU}} \div \tilde{H}^{\mathfrak{RU}} \right) \right]$$

$$\tilde{G}^{\mathfrak{RL}} \div \tilde{H}^{\mathfrak{RL}} = (g_1^L \div h_1^L, g_2 \div h_2, g_3^L \div h_3^L)$$

$$\tilde{G}^{\mathfrak{RU}} \div \tilde{H}^{\mathfrak{RU}} = (g_1^U \div h_1^U, g_2 \div h_2, g_3^U \div h_3^U)$$

Sustainable Multi-Objective Multi-Route Fuzzy Rough Cold Transportation Models

Assumptions

- Precooling is performed only at the sources of the distribution network in both the models and its duration varies with conveyance type.
- Traveling time, idling time due to traffic flow and resting time are route dependent and so equal in both the models.
- Idling time due to traffic flow on each route affects the idling time of all the other vehicles moving on that route in both the models.
- In Model-A, fully diesel refrigerated truck rest only at lay-bys while in Model-B, diesel vehicle with plug-in rest only at TSE sites and they do not impact traffic flow.

Limitation

- Fueling time and off-route times for resting places like truck stop electrification site and fuel station is not considered in both the models.

Notations & Decision Variables

$\tilde{C}_1^{\mathfrak{R}}$ - fuzzy rough diesel cost per liter

$\tilde{C}_p^{\mathfrak{R}}$ - fuzzy rough diesel cost for electric power per kilowatt

$\tilde{P}^{\mathfrak{R}}$ - fuzzy rough power needed for electric refrigeration

$\tilde{t}_{p_i}^{d \mathfrak{R}}$ - fuzzy rough precooling time with diesel at the i^{th} source

$\tilde{t}_{p_i}^{e \mathfrak{R}}$ - fuzzy rough precooling time with electricity at the i^{th} source

$\tilde{t}_{ri}^{\mathfrak{R}}$ - fuzzy rough resting time during transport from i^{th} source to j^{th} destination via r^{th} route

$\tilde{t}_{li}^{\mathfrak{R}}$ - fuzzy rough idling time incurred by traffic flow in r^{th} route between i^{th} source and j^{th} destination

$\tilde{t}_{ii}^{\mathfrak{R}}$ - fuzzy rough traveling time from i^{th} source to j^{th} destination via r^{th} route

$\tilde{e}_f^{\mathfrak{R}}$ - fuzzy rough emission factor for diesel

$\tilde{f}_t^{\mathfrak{R}}$ - fuzzy rough diesel consumption per hour of travel time

$\tilde{f}_l^{\mathfrak{R}}$ - fuzzy rough diesel consumption per hour of idling time due to traffic flow

$\tilde{f}_r^{\mathfrak{R}}$ - fuzzy rough diesel consumption of auxiliary unit per hour of resting time

$\tilde{e}_c^{\mathfrak{R}}$ - fuzzy rough emission cost

$\tilde{k}_{ii}^{\mathfrak{R}}$ - fuzzy rough traffic flow of the r^{th} route from i^{th} source to j^{th} destination.

$\tilde{a}_i^{\mathfrak{R}}$ - fuzzy rough supply at the i^{th} source

$\tilde{b}_j^{\mathfrak{R}}$ - fuzzy rough demand at the j^{th} destination

x_{ii} - quantity of items transported from i^{th} source and j^{th} destination via r^{th} route

y_{ii} - binary variable denoting the usage of r^{th} route between i and j

Description & Mathematical Formulation

Transportation Model for Fully Diesel-Based Refrigerated Truck (Model-A)

Diesel Refrigerated trucks are the commonly preferred transportation mode used for cold transportation as they are more durable and have sufficient fuel station infrastructure. The following is the mathematical formulation of a fully diesel-based reefer, which utilises an auxiliary diesel unit when the engine is off.

$$\begin{aligned} \text{Min } Z_1 = & \tilde{C}_1 \left[\sum_{i=\bar{u}}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{f}_t^{\mathfrak{R}} \tilde{t}_{ijr}^{\mathfrak{R}} + \tilde{f}_l^{\mathfrak{R}} \tilde{t}_{lijr}^{\mathfrak{R}} \tilde{k}_{ijr}^{\mathfrak{R}} + \tilde{f}_r^{\mathfrak{R}} (\tilde{t}_{pi}^{\mathfrak{R}} + \tilde{t}_{rjr}^{\mathfrak{R}})) y_{ijr} \right] \\ & + \tilde{e}_f^{\mathfrak{R}} \left[\tilde{e}_c^{\mathfrak{R}} \sum_{i=\bar{u}}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{f}_t^{\mathfrak{R}} \tilde{t}_{ijr}^{\mathfrak{R}} + \tilde{f}_l^{\mathfrak{R}} \tilde{t}_{lijr}^{\mathfrak{R}} \tilde{k}_{ijr}^{\mathfrak{R}} + \tilde{f}_r^{\mathfrak{R}} (\tilde{t}_{pi}^{\mathfrak{R}} + \tilde{t}_{rjr}^{\mathfrak{R}})) y_{ijr} \right] \end{aligned} \quad (1a)$$

$$\text{Min } Z_2 = \sum_{i=\bar{u}}^I \sum_{j=1}^J \sum_{r=1}^R \tilde{k}_{ijr}^{\mathfrak{R}} y_{ijr} \quad (2a)$$

$$\text{Min } Z_3 = \sum_{i=\bar{u}}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{t}_{ijr}^{\mathfrak{R}} + \tilde{t}_{pi}^{\mathfrak{R}} + \tilde{t}_{rjr}^{\mathfrak{R}} + \tilde{t}_{lijr}^{\mathfrak{R}} \tilde{k}_{ijr}^{\mathfrak{R}}) y_{ijr} \quad (3a)$$

Subject to

$$\sum_{j=1}^J \sum_{r=1}^R x_{ijr} \leq \tilde{a}_i^{\mathfrak{R}}, i = 1, 2, \dots, I \quad (4a)$$

$$\sum_{i=1}^I \sum_{r=1}^R x_{ijr} \geq \tilde{b}_j^{\mathfrak{R}}, j = 1, 2, \dots, J \quad (5a)$$

$$\sum_{r=1}^R y_{ijr} \leq 1, i = 1, 2, \dots, I \text{ \& } j = 1, 2, \dots, J \quad (6a)$$

$$x_{ijr} \geq 0, \forall i, j, r \text{ \& } x_{ijr} \in \mathbb{Z}^+ \quad (7a)$$

$$y_{ii} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{else} \end{cases} \quad (8a)$$

Transportation Model for Diesel Refrigerated Truck with Electric Plug-In (Model-B)

Innovative refrigerated transportation has a huge global impact on distribution and supply chain, and so many logistic providers have started to focus on cold transport means. Though fully diesel operated trucks have many advantages, it is clearly harmful to the environment. This model is specially designed for refrigerated trucks with plug-ins that perform electric refrigeration whenever needed with the aid of plug-ins.

$$\begin{aligned} \text{Min } Z_1 = & \tilde{C}_1 \left[\sum_{i=1}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{f}_t^{\mathfrak{R}} \tilde{t}_{ijr}^{\mathfrak{R}} + \tilde{f}_l^{\mathfrak{R}} \tilde{t}_{lijr}^{\mathfrak{R}} \tilde{k}_{ijr}^{\mathfrak{R}}) y_{ijr} \right] \\ & + \tilde{C}_p^{\mathfrak{R}} \left[\tilde{P} \sum_{i=1}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{t}_{pi}^{\mathfrak{R}} + \tilde{t}_{rjr}^{\mathfrak{R}}) y_{ijr} \right] \end{aligned} \quad (1b)$$

$$\begin{aligned} & + \tilde{e}_f^{\mathfrak{R}} \left[\tilde{e}_c^{\mathfrak{R}} \sum_{i=1}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{f}_t^{\mathfrak{R}} \tilde{t}_{ijr}^{\mathfrak{R}} + \tilde{f}_l^{\mathfrak{R}} \tilde{t}_{lijr}^{\mathfrak{R}} \tilde{k}_{ijr}^{\mathfrak{R}}) y_{ijr} \right] \\ \text{Min } Z_2 = & \sum_{i=\bar{u}}^I \sum_{j=1}^J \sum_{r=1}^R \tilde{k}_{ijr}^{\mathfrak{R}} y_{ijr} \end{aligned} \quad (2b)$$

$$\text{Min } Z_3 = \sum_{i=\bar{u}}^I \sum_{j=1}^J \sum_{r=1}^R (\tilde{t}_{ijr}^{\mathfrak{R}} + \tilde{t}_{pi}^{\mathfrak{R}} + \tilde{t}_{rjr}^{\mathfrak{R}} + \tilde{t}_{lijr}^{\mathfrak{R}} \tilde{k}_{ijr}^{\mathfrak{R}}) y_{ijr} \quad (3b)$$

Subject to (4a) - (8a).

(1a) and (1b) are the objective corresponding to operating expense. First part of (1a) is the diesel consumption cost for precooling, traveling, idling and resting time of refrigerated truck, the second part is the emission cost for the same. The first part and third part of (1b) is the diesel consumption cost for traveling and idling time and its respective emission cost while second part of (1b) is the electrification cost during precooling and resting time. (2a) and (2b) is the overall traffic flow measured in Passenger Car Units (PCU) along the multi-route network which is same for both the models. (3a) and

(3b) is the total distribution time of a completely diesel-based refrigerated truck and diesel reefer truck with electric plug-in. (4a) and (5a) are the supply and demand constraints while (6a) denote the route optimization constraint.

Solution Methodology

All the fuzzy rough coefficients are made deterministic using the ranking function and the models are solved using the following two methods.

Fuzzy Goal Programming Approach (FGPA)

It is one of the multi-objective optimization methods which focuses on reducing the distance between the optimum value and the aspiration level of each of the objectives. The mathematical formulation of the fuzzy goal programming approach, as stated by Zangiabadi M & Maleki H (2007), is

$$\text{Min } \tau$$

$$s.t. \mu_k(x) + d_k^- + d_k^+ = 1, \text{ where } \mu_k(x) = \begin{cases} 1 & \text{if } Z_k(x) < L_k \\ 1 - \frac{Z_k(x) - L_k}{U_k - L_k} & \text{if } L_k \leq Z_k(x) \leq U_k \\ 0 & \text{if } Z_k(x) > U_k \end{cases}$$

$$\tau \geq d_k^-, k = 1, 2, \dots, K$$

$$d_k^- d_k^+ = 0 \text{ \& } \tau \in [0, 1]$$

and (4a) – (8a)

Weighted Fuzzy Goal Programming Approach (WFGPA)

This method was introduced by Hannan EL (1981) to overcome the disadvantages of traditional goal programming by assigning weights to each goal with respect to its significance or decision maker's priority. The following is the mathematical formulation of WFGPA.

$$\text{Min } \sum_{k=1}^K w_k (d_k^- + d_k^+), \sum_{k=1}^K w_k = 1$$

$$s.t. \mu_k(x) \leq d_k^- + d_k^+ \leq 1, \text{ where } \mu_k(x)$$

$$= \begin{cases} 1 & \text{if } Z_k(x) < L_k \\ 1 - \frac{Z_k(x) - L_k}{U_k - L_k} & \text{if } L_k \leq Z_k(x) \leq U_k \\ 0 & \text{if } Z_k(x) > U_k \end{cases}$$

$$d_k^- d_k^+ = 0 \text{ \& } \tau \in [0, 1]$$

and (4a) – (8a)

Results and Discussion

Case Study

Sea fishes are available in almost all districts of Tamil Nadu due to its enhanced transportation facilities. The sea fish demand of district of Ariyalur, Tanjore and Trichy are moreover satisfied by nearby districts like Nagapattinam and Ramanathapuram. Average daily demand of seafish in each district is found from questionnaire. Multiple routes between the sources and destination, their distance and time are furnished from Maps (Tables 1-4). Average Traffic flow is found from the National Highways Authority of India (NHAI) website by analyzing the tolls on specific routes (Table 5). The cost for the model is taken from various secondary databases.

$$\tilde{C}_1^{\text{gr}} = \text{Rs. } [92, 93.6, 94.5] [91, 93.6, 95], \tilde{C}_p^{\text{gr}} = \text{Rs. } [13.5, 15, 18.3] [12, 15, 20] \text{ per kWh,}$$

$$\tilde{t}_{p_1}^{d^{\text{gr}}} = [1.8, 2, 3] [1.6, 2, 4] \text{ hr, } \tilde{t}_{p_2}^{d^{\text{gr}}} = [1.8, 2, 4, 3] [2, 2, 4, 3, 4] \text{ hr,}$$

$$\tilde{t}_{p_1}^{e^{\text{gr}}} = [0.9, 0.1, 1.5] [0.8, 1, 2] \text{ hr, } \tilde{t}_{p_2}^{e^{\text{gr}}} = [1, 1.2, 1.5] [0.9, 1.2, 1.7] \text{ hr,}$$

$$\tilde{a}_1^{\text{gr}} = [159.5, 160, 161.5] [157, 160, 162] \text{ tonne,}$$

$$\tilde{a}_2^{\text{gr}} = [102.75, 104, 105.5] [100.5, 104, 107.25] \text{ tonne, } \tilde{b}_1^{\text{gr}} =$$

$$[47.5, 52, 52.5] [47, 52, 53] \text{ tonne,}$$

Table 1: Distance (in km)

DESTINATION				
SOURCE	ROUTE	1	2	3
1	1	131	88	151
	2	119	95	180
	3	160	101	183
2	1	253	196	177
	2	243	213	196
	3	236	185	215

Table 2: Fuzzy Rough traveling time (in hrs)

$\frac{j}{i \quad r}$		1	2	3
1	1	[3.25, 3.5, 3.75] [3, 3.5, 4]	[2.4, 2.5, 2.75] [2.3, 2.5, 2.8]	[3.3, 3.39, 3.43] [3.2, 3.39, 3.5]
	2	[3.4, 3.6, 3.7] [3.2, 3.6, 3.8]	[2.22, 2.4, 2.5] [2.1, 2.4, 2.6]	[3.74, 4.15, 4.8] [3.5, 4.15, 5]
3	1	[4.1, 4.3, 4.7] [4, 4.3, 5]	[2.79, 2.85, 2.9] [2.7, 2.85, 2.92]	[4.58, 4.6, 4.62] [4.5, 4.6, 4.7]
	2	[3.8, 4.47, 5.12] [3.5, 4.47, 5.3]	[2.3, 3, 3.62] [2.3, 3, 7]	[2.9, 3.1, 3.75] [2.7, 3.1, 4]
2	2	[4.33, 4.5, 4.8] [4.2, 4.5, 4.9]	[2.6, 3.5, 4.5] [2.1, 3.5, 4.7]	[3.62, 3.7, 3.8] [3.5, 3.7, 3.9]
	3	[4.5, 5, 5.7] [4.5, 6]	[3.2, 4, 4.75] [3, 4, 4.8]	[3.1, 3.7, 4.2] [3, 3.7, 4.6]

Table 3: Fuzzy Rough resting time (in hrs)

$\frac{j}{i}$		1	2	3
r				
1	1	[0.3608,0.3885,0.41625] [0.333,0.3885,0.444]	[0.2664,0.2775,0.30525] [0.2553,0.2775,0.3108]	[0.3663,0.3763,0.3807] [0.3552,0.3763,0.3885]
	2	[0.3774,0.3996,0.4107] [0.3552,0.3996,0.4218]	[0.2464,0.2664,0.2775] [0.2331,0.2664,0.2886]	[0.4151,0.4607,0.5328] [0.3885,0.4607,0.555]
	3	[0.4551,0.4773,0.5217] [0.444,0.4773,0.555]	[0.3097,0.3164,0.3219] [0.2997,0.3164,0.3241]	[0.5084,0.5106,0.5128] [0.4995,0.5106,0.5217]
2	1	[0.4218,0.4962,0.5683] [0.3885,0.4962,0.5883]	[0.2553,0.333,0.4018] [0.222,0.333,0.4107]	[0.3219,0.3441,0.4163] [0.2997,0.3441,0.444]
	2	[0.4806,0.4995,0.5328] [0.4662,0.4995,0.5439]	[0.2886,0.3885,0.4995] [0.2331,0.3885,0.5217]	[0.4018,0.4107,0.4218] [0.3885,0.4107,0.4329]
	3	[0.4995,0.555,0.6327] [0.444,0.555,0.666]	[0.3552,0.444,0.5273] [0.333,0.444,0.5328]	[0.3441,0.4107,0.4662] [0.333,0.4107,0.5106]

Table 4: Fuzzy Rough idling time (in hrs)

$\frac{j}{i}$		1	2	3
r				
1	1	[0.0228,0.0245,0.0263] [0.021,0.0245,0.028]	[0.0192,0.02,0.022] [0.0184,0.02,0.0224]	[0.0165,0.017,0.0172] [0.016,0.017,0.0175]
	2	[0.0204,0.0216,0.0222] [0.0192,0.0216,0.0228]	[0.0111,0.012,0.0125] [0.0105,0.012,0.013]	[0.0187,0.0208,0.024] [0.0175,0.0208,0.025]
	3	[0.0205,0.0215,0.0235] [0.02,0.0215,0.025]	[0.01674,0.0171,0.0174] [0.0162,0.0171,0.0175]	[0.0229,0.023,0.0231] [0.0225,0.023,0.0235]
2	1	[0.0152,0.0179,0.02048] [0.014,0.0179, 0.0212]	[0.0115,0.015,0.0181] [0.01,0.015,0.0185]	[0.0174,0.0186,0.0225] [0.0162,0.0186,0.024]
	2	[0.013,0.0135,0.0144] [0.0126,0.0135,0.0147]	[0.0104,0.014,0.018] [0.0084,0.014,0.0188]	[0.0145,0.0148,0.0152] [0.014,0.0148,0.0156]
	3	[0.0225,0.025,0.0285] [0.02,0.025,0.03]	[0.016,0.02,0.0238] [0.015,0.02,0.024]	[0.0124,0.0148,0.0168] [0.012,0.0148,0.0184]

$\tilde{b}_2^{\text{rt}} = [137,139,145] [136,139,146]$ tonne, $\tilde{b}_3^{\text{rt}} = [71.4,73,74.6]$
[71,73,75] tonne,

$\tilde{P}^{\text{rt}} = [34.6,36,37.7] [34,36,38.5]$ kWh, $\tilde{e}_f^{\text{rt}} = [2.6,2.64,2.68]$
[2.53,2.64,2.7] Kg CO₂/litre,

$\tilde{e}_c^{\text{rt}} = \text{Rs. } [97.4,100,103.2] [97,100,105]$ per Kg CO₂, $\tilde{f}_l^{\text{rt}} =$

[2.6,3,4.3] [2,3,5] litres/hr,

$\tilde{f}_t^{\text{rt}} = [3.7,4.2,4.65] [3.3,4.2,4.8]$ litres/hr, $\tilde{f}_r^{\text{rt}} = [0.3,1,1.2]$

[0.25,1,1.5] litres/hr.

Table 5: Fuzzy Rough Traffic flow (in pcu)

$\frac{j}{i}$		1	2	3
r				
1	1	[91,93,95] [90,93,97]	[64,65,67] [63,65,68]	[52,53,55] [51,53,57]
	2	[85,87,88] [84,87,90]	[62,63,65] [61,63,66]	[90,93,97] [91,93,98]
	3	[63,64,68] [62,64,69]	[61,64,66] [60,64,69]	[93,94,97] [91,94,98]
2	1	[55,57,58] [54,57,59]	[51,52,54] [49,52,56]	[48,50,53] [45,50,54]
	2	[49,51,52] [48,51,55]	[46,47,49] [44,47,50]	[46,47,49] [45,47,50]
	3	[85,87,88] [83,87,90]	[91,93,94] [89,93,96]	[46,49,52] [45,49,53]

Solutions

Fuzzy Goal Programming Approach (FGPA)

In the following Tables 6, 7 & 8, C1=Diesel cost incurred from travel, C2=Diesel cost incurred from traffic idling, C3= Diesel cost incurred from precooling and resting, CE=Electrification cost incurred from precooling and resting at TSE sites, E1= Emission cost incurred from travel, E2= Emission cost incurred from traffic idling, E3= Emission cost for precooling and resting, P= Precooling time, R= Resting time, I=Idling time, T= Travel time.

Table 6: Comparison of solutions from FGPA for model-A and model-B

MODEL A			MODEL B		
Z ₁	C1	5127.960	Z ₁	C1	5127.960
	C2	971.6287		C2	971.6287
	C3	932.1353		CE	3528.907
	E1	14678.54		E1	14678.54
	E2	2739.873		E2	2739.873
	E3	2686.005		TOTAL	27046.91
Z ₂	TOTAL	27136.14	Z ₂	TOTAL	218
	T	13.2151		T	13.2151
	L	3.1656		L	3.1656
Z ₃	P	9.55	Z ₃	P	4.85
	R	1.4669		R	1.4669
	TOTAL	27.3976		TOTAL	22.6976

Table 7: Results from WFGPA for Model A for the above-mentioned weights

Weights		i	ii	iii
Z ₁	C1	5335.560	5127.96	4699.643
	C2	7837.937	971.6287	1328.103
	C3	937.1599	932.1353	921.7688
	E1	15272.78	14678.54	13452.5
	E2	2655.714	2739.873	3745.086
	E3	2700.483	2686.005	2656.133
Z ₂	TOTAL	27843.49	27136.14	26803.24
	T	214	218	251
	L	13.75	13.2151	12.1113
Z ₃	L	3.0684	3.1656	4.3271
	P	9.55	9.55	9.55
	R	1.5263	1.4669	1.3444
TOTAL		27.8948	27.2976	23.3327

Table 8: Results from WFGPA for Model B for the above-mentioned weights

Weights		i	ii	iii
Z ₁	C1	5335.560	5127.96	4699.643
	C2	941.7837	971.6287	1328.103
	CE	3562.082	3528.907	3460.461
	E1	15277.78	14678.54	13452.5
	E2	2655.714	2739.873	3745.086
	TOTAL	27767.92	27046.91	26685.8
Z ₂	T	214	218	251
	L	13.7501	13.2151	12.1113
	L	3.0684	3.1656	4.3271
Z ₃	P	4.85	4.89	4.85
	R	1.5263	1.4669	1.3444
	TOTAL	23.19477	22.6976	22.6327

Weighted Fuzzy Goal Programming Approach (WFGPA)

Varying weights for which the solution is found are **(0.05,0.9,0.05), (0.3,0.4,0.3), (0.8,0.1,0.1)**. Here, the traffic flow's weightage is varied to favor sustainability.

Conclusion

The transportation sector procures and puts numerous items from the industrial and manufacturing sectors for sale. As route optimization is a crucial segment of perishable item transportation, the above models are proposed. From the two models, it is easy to note that the operating expenses and distribution time for a refrigerated trailer with the plug-in (Model B) is comparatively lower than the fully diesel-based refrigerated truck (Model A). Also, it is observed

that the time taken for precooling using electric plug-ins is lower than diesel-based precooling, which greatly impacts the operational cost, including emission cost in model A. The emission cost is higher for Model A than for Model B. The result also pinpoints the effect of traffic flow on idling time and carbon emission cost during transportation. In both models, the overall operating expense and overall time do not decline linearly with the traffic flow as routes are of different distances. An increase in idling time and emission cost is observed with an increase in traffic flow in both models. But undoubtedly, the plug-in model (model B) is more environmentally efficient than the conventional diesel one (model A), which clearly intensifies the need for shore powers and electrification. From the solutions, WFGPA renders the best solution than FGPA. Alternative

conveyance options and technology can be studied in the proposed multi-route traffic flow optimization model to add more sustainability. Anti-idling charges and traffic congestion costs can be included as future extensions. Other time parameters, including fueling time, off-route time, loading and unloading time, station dwell time, etc., can also be included in the model and resolved using advanced innovation or additional constraints.

Acknowledgment

"The authors are grateful to the reviewers and the editors for improving the quality of the paper."

Funding

"This research received no external funding."

Conflicts of Interest

"The authors declare no conflicts of interest."

References

- Arora, M., Kumar, R., & Raju, T. B. (2023). Identification of issues in the cold chain of Indian frozen food. *International Journal of Logistics Economics and Globalisation*, 10(1), 1-22.
- Baghestani, A., Tayarani, M., Allahviranloo, M., & Gao, H. O. (2020). Evaluating the traffic and emissions impacts of congestion pricing in New York City. *Sustainability*, 12(9), 3655.
- Baidya, A., Bera, U. K., & Maiti, M. (2013). A solid transportation problem with safety factor under different uncertainty environments. *Journal of Uncertainty Analysis and Applications*, 1, 1-22.
- Erkut, E., & Ingolfsson, A. (2000). Catastrophe avoidance models for hazardous materials route planning. *Transportation Science*, 34(2), 165-179.
- Errampalli, M., Senathipathi, V., & Thamban, D. (2015). Effect of congestion on fuel cost and travel time cost on multi-lane highways in India. *Int. J. Traffic Transp. Eng*, 5(4), 458-472.
- Ferretti, I., Mazzoldi, L., & Zanoni, S. (2018). Environmental impacts of cold chain distribution operations: a novel portable refrigerated unit. *International Journal of Logistics Systems and Management*, 31(2), 267-297.
- Giri, P. K., Maiti, M. K., & Maiti, M. (2015). Fully fuzzy fixed charge multi-item solid transportation problem. *Applied Soft Computing*, 27, 77-91.
- Gupta, P., Kumar, P., Elarga, H. H. H. H., & Hafner, A. (2023). Refrigerated Transportation and Cold-chain Logistics in India—Current Status and Future Prospects. In *Proceedings of the 26th IIR International Congress of Refrigeration: Paris, France, August 21-25, 2023-volume 3*. International Institute of Refrigeration.
- Gupta, S., Ali, I., & Ahmed, A. (2020). An extended multi-objective capacitated transportation problem with mixed constraints in fuzzy environment. *International Journal of Operational Research*, 37(3), 345-376.
- Haley, K. B. (1962). New methods in mathematical programming—the solid transportation problem. *Operations research*, 10(4), 448-463.
- Hannan, E. L. (1981). On fuzzy goal programming. *Decision sciences*, 12(3), 522-531.
- <https://afdc.energy.gov/conserve/idle-reduction-equipment>
- Kumar, A., & Agrawal, S. (2023). Challenges and opportunities for agri-fresh food supply chain management in India. *Computers and Electronics in Agriculture*, 212, 108161.
- Kundu, P., Kar, S., & Maiti, M. (2013). Multi-objective multi-item solid transportation problem in fuzzy environment. *Applied mathematical modelling*, 37(4), 2028-2038.
- Majumder, S., Kundu, P., Kar, S., & Pal, T. (2019). Uncertain multi-objective multi-item fixed charge solid transportation problem with budget constraint. *Soft Computing*, 23, 3279-3301.
- Neittaanmäki, P., Akimov, K., Akimova, V., & Tuovinen, R. (2024). Challenges and Current Solutions of Refrigerated Transportation. In *Advanced Computational Methods and Design for Greener Aviation* (pp. 241-256). Cham: Springer International Publishing.
- Rahman, S. A., Masjuki, H. H., Kalam, M. A., Abedin, M. J., Sanjid, A., & Sajjad, H. J. E. C. (2013). Impact of idling on fuel consumption and exhaust emissions and available idle-reduction technologies for diesel vehicles—A review. *Energy Conversion and Management*, 74, 171-182.
- Sambracos, E., & Ramfou, I. (2013). The effect of freight transport time changes on the performance of manufacturing companies. *Available at SSRN 2337931*.
- Scherhauser, S., Moates, G., Hartikainen, H., Waldron, K., & Obersteiner, G. (2018). Environmental impacts of food waste in Europe. *Waste management*, 77, 98-113.
- Shivani, & Rani, D. (2024). Multi-objective multi-item four dimensional green transportation problem in interval-valued intuitionistic fuzzy environment. *International Journal of System Assurance Engineering and Management*, 15(2), 727-744.
- Xie, L., & Cao, C. (2021). Multi-modal and multi-route transportation problem for hazardous materials under uncertainty. *Engineering Optimization*, 53(12), 2180-2200.
- Xu, F., Crawford, C., Feng, Y., Lin, Z., & Li, S. (2023). Environment-economic analysis of diesel, hybrid electric, plug-in hybrid electric trucks in China. *Transportation Research Part D: Transport and Environment*, 117, 103661.
- Yakavenka, V., Mallidis, I., Vlachos, D., Iakovou, E., & Eleni, Z. (2020). Development of a multi-objective model for the design of sustainable supply chains: The case of perishable food products. *Annals of Operations Research*, 294, 593-621.
- Yaqoob, H., Teoh, Y. H., Goraya, T. S., Sher, F., Jamil, M. A., Rashid, T., & Yar, K. A. (2021). Energy evaluation and environmental impact assessment of transportation fuels in Pakistan. *Case Studies in Chemical and Environmental Engineering*, 3, 100081.
- Zangiabadi, M., & Maleki, H. (2007). Fuzzy goal programming for multiobjective transportation problems. *Journal of applied mathematics and Computing*, 24, 449-460.