



## RESEARCH ARTICLE

# Sustainable rough multi-objective two-stage solid transportation problem of third-party e-commerce logistic providers with conditional fixed parameter on safety

L. Brighth Gladys<sup>1</sup>, J. Merline Vinotha<sup>2\*</sup>

## Abstract

Unsafe transportation causes fluctuation in the planned distribution expense, time, and emission factor. It should never be ignored, especially in e-commerce, as it is a significant platform for global marketing. Though there are many e-commerce models available in the literature, not many discussed the transportation model of integrated logistics by third-party logistic providers with safety and its impacts in rough interval scenarios. So, the paper investigates a multi-objective two-stage rough transportation model with a new concept called conditional fixed charge, time, and emission on the overall safety achieved over the target in both forward and reverse logistics to emphasize the importance of safety factors and their effectiveness in the overall transportation system. A case study on the distribution data of smartphones is considered and solved using existing methods like the Fuzzy Programming Approach and the Global Criterion Method in LINGO (19.0). The paper also furnishes a comparative analysis by replacing the solution obtained for the case study with equivalent Compressed Natural Gas vehicles to reflect on its sustainable benefits in transportation.

**Keywords:** Rough transportation problem, Two-stage, Third-party logistic provider, Conditional fixed constraint, Safety factor.

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

## Introduction

### Literature Review

Multi-objective optimization is necessary to manage the conflicting objectives of the transportation problem and

was coined by Lee and Moore. Other than fluctuating objectives, there occur fixed charges that determine the present and futuristic purpose of the business, and this was initially introduced into the transportation problem by Hirsch and Dantzig. To unveil the necessity of multiple conveyances, the Solid Transportation Problem (STP) that contemplates constraints for source, destination, and vehicle capacity was invented by Haley. The transportation problem was subsequently improved by numerous researchers corresponding to real-life necessities. Kacher Y and Singh P. (2021) elaborated on the existing varieties of transportation problems and showcased the scope of futuristic research ideas. Fixed charge multi-objective solid transportation problems with additional constraints, notably product blending and budget, were put forward by Roy SK, Midya S (2019) and Haque S, Bhurjee AK, and Kumar P (2022) in diverse uncertain environments, including fuzzy sets. Rough set theory by Pawlak was found to have a more flexible solution apart from randomness and fuzziness, so rough optimization techniques and transportation models were developed. A profit-maximizing solid transportation model with rough intervals was formed and resolved by Das et al. using rough chance constraint programming and an expected value operator. Midya S and Roy SK (2020) analyzed a rough multi-objective transportation problem with fixed

<sup>1</sup>Research Scholar, PG & Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamil Nadu, India.

<sup>2</sup>Assistant Professor, PG & Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamil Nadu, India.

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

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charge using the fuzzy programming method and linear weighted sum method. Rough sets are also utilized in other areas of uncertainty. To overcome the difficulties in handling and computation, Rebeolledo M (2006) blended the concept of a rough set with intervals, which led to rough intervals. Singh A, Bera UK, and Sarma D (2020) studied a two-stage solid transportation problem with rough interval parameters but without multiple objectives and integrated logistics.

Today's world has encountered a peak phase in internet usage with smartphone penetration, and this has resulted in the mighty growth of the e-commerce industry. The necessity of e-commerce services has become more crucial during the pandemic, and many researchers have started investigating e-commerce and its various activities. Chaudhary. H (2020) has analyzed and concluded that people have started to buy even daily essential goods from online stores after Covid-19. E-commerce businesses overcome numerous challenges every day to make the journey of each person in their supply chain, a fruitful one. An important part of e-commerce is the after-sale service, which includes remanufacturing and refurbishing and is favored by return and exchange policies. Returns management is smoothly practiced as it aids in receiving loyalty from the customer. Das D, Kumar R., and Rajak M (2020) have designed a reverse network design for e-commerce by considering four major participants and minimizing the logistic cost of the whole system.

Transportation is one of the indispensable components of the e-commerce supply chain logistics, and its optimization is very important for industrial growth. Nowadays, outsourcing of e-commerce logistics requirements to Third-Party Logistic Provider (3PLP) has increased as 3PLPs integrate and solve business complexities with high expertise. Fuel prices, government norms, expectations of both the consumer and the client, environmental issues, climate, and road conditions are some of the remarkable obstacles faced by 3PLP in the present e-commerce era. Environmental sustainability is one of the evolving challenges of the transportation problem as they are the major producer of global carbon. A green solid transportation model was formulated and optimized by Yu VF, Bera A, Das SK, Manna S, Jhulki PK, Dey B, and Ali SA (2024) to furnish the effect of cap-and-trade policy on carbon emissions. To spotlight the need for green innovation, Dutta P, Mishra A, Khandelwal S, and Katthawala I (2020) have optimized a multi-objective model with sustainable reverse logistics in the Indian e-commerce market.

Though interesting and simple, E-commerce sellers and distributors often failed to gain trust and reputation due to many dissatisfied customers who demanded on-time delivery of the exactly ordered product without damage. Sinha SN (2020) examined the e-commerce customers'

preferences based on some primary data and concluded delivery services as an integral part of the e-commerce supply chain. Apart from packing, the choice of truck, transportation route, service regulations, vehicle state, driving style, and other uncertainties, especially natural calamities, traffic congestion plays a significant role in the safe delivery of products. Unsafe trucking and the reasons behind it are analyzed keenly by Kumar Gangadhari R. and Kumar Tarei P. (2021) to stress the issues in and around the trucking industry. The concept of safety factor and its significance is already illustrated by Baidya A, Bera UK, and Maiti M (2014) in the transportation problem. Sifaoui T & Aider M (2024) formulated and solved a multi-objective, multi-item fixed charge solid transportation problem with budget and safety constraints. Sharma, M. K. et al. (2024) have developed a multi-objective, multi-item green, 4-dimensional humanitarian aid transportation system with constraints on desired safety measures for tackling disaster operations.

### **Research Gap**

Even though the transportation problem has a magnificent literature review, a multi-objective mathematical model involving integrated logistics for 3PLP has not been examined still in rough transportation problems but is needed for successful accessibility and reliability of the e-commerce platform. Meanwhile, all researchers who considered safety parameters in transportation problems have neglected the scenario of dissatisfaction with safety constraints. The ambiguity in real life creates a sudden rise and decline in the targeted safety, which in turn makes 3PLP responsible for the losses. This lowers the reputation and client/customer satisfaction level and ends up in the ceasing of operations with higher insurance claims. Failure in safety also affects transportation cost, time, and carbon emission in both forward and reverse logistics, and no transportation model has been formulated yet to sort out this issue. 3PLP has started using Compressed Natural Gas (CNG) based conveyances for logistics operations, which is not discussed in previous transportation models.

### **Contributions**

The idea of a rough conditional fixed parameter over the safety target to handle the negative impacts from the failure of targeted safety during transit is introduced in a multi-objective two-stage solid transportation problem with integrated logistics under a rough environment, which is entirely new. As safety is crucial for expensive products like electronics, a case study based on the secondary data for Indian smartphone shipment is taken, and the model is vindicated using Fuzzy Programming Approach (FPA) and Global Criterion Method (GCM). The economical and sustainable difference between the diesel-based and CNG-based conveyances is observed. Sensitivity analysis is done

using LINGO (19.0) to remark on the changes in the objective value with parameter variation. The results emphasize the negligence and significance of sustainability and backup ideas behind the profit of 3PLP in India.

## Methodology

### Preliminaries

#### Rough set

Pawlak's theory on rough sets provides the best and worst approximation of the subsets of the universe  $U$  by defining an equivalence relation called the indiscernibility relation  $R$  on  $U$ . The lower approximation of a set by  $R$  is the smallest that surely belongs to  $X$ , and the upper approximation is the largest that is possibly in the set.

Lower approximation,

$$\underline{R}X = \{x \in U \mid R(x) \in \text{surely in } X\}$$

Upper approximation,

$$\bar{R}X = \{x \in U \mid R(x) \in \text{possibly in } X\}$$

The boundary region  $\bar{R}X - \underline{R}X$  contains a set of elements discriminated not as  $X$  or its complement corresponding to  $R$  in  $U$ . The nullity of the boundary makes the set  $X$  to be crisp. In other words, a set becomes crisp when these two approximations are equal. Else, the set is rough.

#### Rough Intervals

Rough intervals were first developed by Rebolledo, which utilized the concept of lower and upper approximation of rough set theory to intervals. A standard value  $X^R$  is a rough interval when two closed intervals, namely the sure interval  $X^{SI}$  and the possible interval  $X^{PI}$ , are allocated on  $\mathbb{R} \ni X^{SI} \subseteq X^{PI}$ . In general, a rough interval  $X^R = (X^{SI}, X^{PI}) = ([X^{SL}, X^{SU}], [X^{PL}, X^{PU}])$   $\ni X^{PL} \leq X^{SL} \leq X^{SU} \leq X^{PU}$   $X^{SI}$  and  $X^{PI}$  is called the sure and possible approximation interval.

#### Expected value of a rough interval

Let  $C = ([c^{SL}, c^{SU}], [c^{PL}, c^{PU}])$  be a rough interval. Then, the expected value of  $C$  is  $E[C] = \frac{1}{2}[\eta(c^{SL} + c^{SU}) + (1 - \eta)(c^{PL} + c^{PU})]$

where  $\eta \in (0, 1)$  a parameter is fated according to the liking of the decider.

### Mathematical Model

Let the commodity be transported from  $I'$  sending localities to  $K''$  receiving localities in two stages.

#### Assumptions

- 3PLPs are held responsible only for the transportation of products from the seller to sub-hubs and for the reverse logistics.

- Heterogeneous product transportation is not regarded in this model.
- The return and exchange products from sub-hubs are directly transported to the manufacturer by the 3PLP.
- The proposed integrated transportation model does not consider the holding period and its cost, loading and unloading time, and their respective costs.
- Only two of the intermediate stages of the e-commerce supply chain are discussed.

#### Indices, Parameters, and Decision Variables

$I'$ : Set of sources indexed by  $i'$

$J'$ : Set having the stage 1 destination spots indicated by  $j'$

$K''$ : Destination set of stage 2 hinted by  $k''$

$K_1'$ : Set containing conveyances in stage 1 marked by  $k_1'$

$K_2''$ : Set including conveyances in stage 2 indexed by  $k_2''$

$\Re(C_{i\bar{a} \ 1})$ : Rough transportation cost of  $k_1^{\text{th}}$  conveyance from  $i^{\text{th}}$  source to  $j^{\text{th}}$  destination

$\Re(C_{j'k''k_2''})$ : Rough cost for transportation using  $k_2^{\text{th}}$  conveyance from  $j^{\text{th}}$  to  $k''^{\text{th}}$  destination

$\Re(T_{i\bar{a} \ 1})$ : Rough transportation time of  $k_1^{\text{th}}$  conveyance from  $i^{\text{th}}$  source to  $j^{\text{th}}$  destination.

$\Re(T_{j'k''k_2''})$ : Rough transportation time of  $k_2^{\text{th}}$  conveyance from  $j^{\text{th}}$  to  $k''^{\text{th}}$  destination

$\Re(E_{k_1'})$ : Rough  $\text{CO}_2$  emission of transportation via  $k_1^{\text{th}}$  conveyance

$\Re(E_{k_2''})$ : Rough  $\text{CO}_2$  emission of transportation via  $k_2^{\text{th}}$  conveyance

$\Re(CR_{k''})$ : Rough direct reverse logistic transportation cost from  $k''^{\text{th}}$  destination to the manufacturer.

$\Re(TR_{k''})$ : Rough direct reverse logistic transportation time from  $k''^{\text{th}}$  destination to the manufacturer.

$\Re(ER_{k''})$ : Rough  $\text{CO}_2$  emission of reverse logistic transportation from  $k''^{\text{th}}$  destination to the manufacturer.

$\Re(S_1)$ : Overall rough safety target for stage 1

$\Re(S_2)$ : Overall rough safety target for stage 2

$S'$ : Overall safety measure achieved in stage 1

$S''$ : Overall safety measure achieved in stage 2

$\Re\ddot{C}C$ : Rough conditional fixed cost depending on  $S'$

$\Re(CC'')$ : Rough conditional fixed cost depending on  $S'$

$\Re\ddot{C}T$ : Rough conditional fixed time depending on  $S'$

$\Re(CT'')$ : Rough conditional fixed time depending on  $S'$

$\Re\ddot{C}E$ : Rough conditional fixed emission depending on  $S'$

$\Re(CE'')$ : Rough conditional fixed emission depending on  $S'$

$\Re(S_{i\bar{a}_1})$ : Rough safety factor for  $k_1^{\text{th}}$  conveyance from  $i^{\text{th}}$  source to  $j^{\text{th}}$  destination

$\Re(S_{j'k''k_2''})$ : Rough safety factor for  $k_2^{\text{th}}$  conveyance from  $j^{\text{th}}$  to  $k^{\text{th}}$  destination

$\Re(a_{i'})$ : Rough availability at the  $i^{\text{th}}$  source

$\Re(b_{j'})$ : Rough demand at the  $j^{\text{th}}$  destination

$\Re(b_{k''})$ : Rough demand at the  $k^{\text{th}}$  destination

$\Re(e_{k_1'})$ : Rough conveyance capacity of  $k_1^{\text{th}}$  conveyance

$\Re(e_{k_2''})$ : Rough conveyance capacity of  $k_2^{\text{th}}$  conveyance

$\Re(r_{k''})$ : Rough return rate at  $k^{\text{th}}$  destination

$\Re(h_{k''})$ : Rough exchange rate at  $k^{\text{th}}$  destination

$D_{i'j'}$ : Distance between  $i^{\text{th}}$  source and  $j^{\text{th}}$  destination.

$D_{j\bar{u}k}$ : Distance between  $j^{\text{th}}$  destination of stage 1 and  $k^{\text{th}}$  destination of stage 2.

$D_{k''m}$ : Distance between  $k^{\text{th}}$  destination of stage 2 and manufacturer.

$x_{i\bar{a}_1}$ : Quantity of goods transported from  $i^{\text{th}}$  source to  $j^{\text{th}}$  destination via  $k_1^{\text{th}}$  conveyance

$x_{j'k''k_2''}$ : Commodity transported from  $j^{\text{th}}$  to  $k^{\text{th}}$  destination via  $k_2^{\text{th}}$  conveyance

$$y_{i\bar{a}_1} = \begin{cases} 1 & \text{if } \bar{u}_{i\bar{a}_1} > 0 \\ 0 & \text{else} \end{cases}$$

$$y_{j'k''k_2''} = \begin{cases} 1 & \text{if } x_{j'k''k_2''} > 0 \\ 0 & \text{else} \end{cases}$$

$$y_{k''} = \begin{cases} 1 & \text{if } (r_{k''} + h_{k''}) > 0 \\ 0 & \text{else} \end{cases}$$

$$y' = \begin{cases} 1 & \text{if } S' \neq \Re(S_1) \\ 0 & \text{else} \end{cases}$$

$$y'' = \begin{cases} 1 & \text{if } S'' \neq \Re(S_2) \\ 0 & \text{else} \end{cases}$$

*Rough Multi-objective Two-stage Solid Transportation Problem with Conditional Fixed Objective in E-Commerce:*

The objectives to be minimized are formulated as,

$$\begin{aligned} \text{Min}(Z_1^{\Re}) = & \sum_{i'=1}^{I'} \sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} \Re(C_{i'j'k_1'}) x_{i'j'k_1'} + \Re(CC') y' \\ & + \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} \Re(C_{j'k''k_2''}) x_{j'k''k_2''} + \Re(CC'') y'' \end{aligned} \quad (1)$$

$$\begin{aligned} \text{Min}(Z_2^{\Re}) = & \sum_{i \in I} \sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} \Re(T_{i'j'k_1'}) y_{i'j'k_1'} + \Re(CT') y' \\ & + \sum_{j' \in J} \sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} \Re(T_{j'k''k_2''}) y_{j'k''k_2''} + \Re(CT'') y'' \\ & + \sum_{k''=1}^{K''} \Re(TR_{k''}) y_{k''} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{Min}(Z_3^{\Re}) = & \sum_{k_1' \in I} \Re(E_{k_1'}) \left( \sum_{i'=1}^{I'} \sum_{j'=1}^{J'} D_{i'j'k_1'} y_{i'j'k_1'} \right) + \Re(CE') y' \\ & + \sum_{k_2'' \in J} \Re(E_{k_2''}) \left( \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} D_{j'k''k_2''} y_{j'k''k_2''} \right) \\ & + \Re(CE'') y'' + \sum_{k''=1}^{K''} \Re(ER_{k''}) y_{k''} \end{aligned} \quad (3)$$

subject to constraints

$$\sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} x_{i'j'k_1'} \leq \Re(a_{i'}), i = 1, 2, \dots, I' \quad (4)$$

$$\sum_{i'=1}^{I'} \sum_{k_1'=1}^{K_1'} x_{i'j'k_1'} \geq \Re(b_{j'}), j' = 1, 2, \dots, J' \quad (5)$$

$$\sum_{i'=1}^{I'} \sum_{j'=1}^{J'} x_{i'j'k_1'} \leq \Re(e_{k_1'}), k_1' = 1, 2, \dots, K_1' \quad (6)$$

$$\sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} x_{j'k''k_2''} \leq \sum_{i'=1}^I \sum_{k_1'=1}^{K_1'} x_{i'j'k_1'}, j' = 1, 2, \dots, J' \quad (7)$$

$$\sum_{j'=1}^{J'} \sum_{k_2''=1}^{K_2''} x_{j'k''k_2''} \geq \Re(b_{k''}), k''=1, 2, \dots, K'' \quad (8)$$

$$\sum_{j'=1}^{J'} \sum_{k''=1}^{K''} x_{j'k''k_2''} \leq \Re(e_{k_2''}), k_2''=1, 2, \dots, K_2'' \quad (9)$$

$$\Re(CC') = \begin{cases} \Re(CC_1') & \text{if } S' > \Re(S_1) \\ \Re(CC_2') & \text{else} \end{cases} \quad (10)$$

$$\Re(CC'') = \begin{cases} \Re(CC_1'') & \text{if } S'' > \Re(S_2) \\ \Re(CC_2'') & \text{else} \end{cases} \quad (11)$$

$$\Re(CT') = \begin{cases} \Re(CT_1') & \text{if } S' > \Re(S_1) \\ \Re(CT_2') & \text{else} \end{cases} \quad (12)$$

$$\Re(CT'') = \begin{cases} \Re(CT_1'') & \text{if } S'' > \Re(S_2) \\ \Re(CT_2'') & \text{else} \end{cases} \quad (13)$$

$$\Re(CE') = \begin{cases} \Re(CE_1') & \text{if } S' > \Re(S_1) \\ \Re(CE_2') & \text{else} \end{cases} \quad (14)$$

$$\Re(CE'') = \begin{cases} \Re(CE_1'') & \text{if } S'' > \Re(S_2) \\ \Re(CE_2'') & \text{else} \end{cases} \quad (15)$$

$$\text{Where } S' = \sum_{i'=1}^{I'} \sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} \Re(S_{i'j'k_1'}) y_{i'j'k_1'}, S'' = \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} \Re(S_{j'k''k_2''}) y_{j'k''k_2''} \quad (16)$$

$$x_{i'j'k_1'} \geq 0, x_{j'k''k_2''} \geq 0, \forall i', j', k'', k_1', k_2'' \quad (17)$$

Equations (1), (2), and (3) are the objective functions that represent the overall transportation cost, time, and emission of the integrated logistics. (1) contains five parts that comprise the rough transportation cost for stage 1, stage 2, rough conditional fixed cost for safety attained from (16) in stage 1 as well as stage 2, and the rough transportation cost for reverse logistics. Similarly, rough transportation time and emission values for the five parts are given in (2) and (3). (4) is the rough availability constraint for a set of sources in Stage 1. (5) and (8) are the rough demand

constraints for a set of destinations at Stage 1 and Stage 2. (6) and (9) are the rough conveyance capacity constraints for stage-1 and stage 2. Equation (7) states that the quantity of products received in each destination of stage 1 should always be greater than or equal to the quantity distributed from source points of stage 2. Equations (10)-(16) denote the rough conditional fixed value constraint for rough safety achieved from (16) over the target  $\Re(S_1)$   $\Re(S_2)$ , while (17) is the non-negativity constraint.

#### Deterministic Model using Expected Value Operator

The above model cannot be handled first-hand due to the occurrence of rough intervals. With reference to the deterministic model is entrusted as below:

$$\begin{aligned} \text{Min } E(Z_1^{\Re}) = & \sum_{i'=1}^{I'} \sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} E[\Re(C_{i'j'k_1'})] x_{i'j'k_1'} + E[\Re(CC')] y' \\ & + \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} E[\Re(C_{j'k''k_2''})] x_{j'k''k_2''} + E[\Re(CC'')] y'' \end{aligned} \quad (18)$$

$$\begin{aligned} & + \sum_{k''=1}^{K''} E[\Re(CR_{k''})] E[\Re(r_{k''}) + \Re(h_{k''})] \sum_{j'=1}^{J'} \sum_{k_2''=1}^{K_2''} x_{j'k''k_2''} \\ \text{Min } E(Z_2^{\Re}) = & \sum_{i'=1}^{I'} \sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} E[\Re(T_{i'j'k_1'})] y_{i'j'k_1'} + E[\Re(CT')] y' \end{aligned}$$

$$\begin{aligned} & + \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} E[\Re(T_{j'k''k_2''})] y_{j'k''k_2''} + E[\Re(CT'')] y'' \quad (19) \\ & + \sum_{k''=1}^{K''} E[\Re(TR_{k''})] y_{k''} \end{aligned}$$

$$\begin{aligned} \text{Min } E(Z_3^{\Re}) = & \sum_{k_1'=1}^{K_1'} E[\Re(E_{k_1'})] \left( \sum_{i'=1}^{I'} \sum_{j'=1}^{J'} D_{i'j'} y_{i'j'k_1'} \right) + E[\Re(CE')] y' \\ & + \sum_{k_2''=1}^{K_2''} E[\Re(E_{k_2''})] \left( \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} D_{j'k''} y_{j'k''k_2''} \right) \end{aligned} \quad (20)$$

$$+ E[\Re(CE'')] y'' + \sum_{k''=1}^{K''} E[\Re(ER_{k''})] y_{k''}$$

subject to constraints

$$\sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} x_{i'j'k_1'} \leq E[\Re(a_{i'})], i' = 1, 2, \dots, I' \quad (21)$$

$$\sum_{i'=1}^{J'} \sum_{k_1'=1}^{K_1'} x_{i'j'k_1'} \geq E[\mathfrak{R}(b_{j'})], j' = 1, 2, \dots, J' \quad (22)$$

$$\sum_{i'=1}^{J'} \sum_{j'=1}^{J'} x_{i'j'k_1'} \leq E[\mathfrak{R}(e_{k_1'})], k_1' = 1, 2, \dots, K_1' \quad (23)$$

$$\sum_{k''=1}^{K_2''} \sum_{k_2''=1}^{K_2''} x_{j'k''k_2''} \leq \sum_{i'=1}^I \sum_{k_1'=1}^{K_1'} x_{i'j'k_1'k_2''}, j' = 1, 2, \dots, J' \quad (24)$$

$$\sum_{j'=1}^{J'} \sum_{k_2''=1}^{K_2''} x_{j'k''k_2''} \geq E[\mathfrak{R}(b_{k''})], k'' = 1, 2, \dots, K'' \quad (24)$$

$$\sum_{j'=1}^{J'} \sum_{k''=1}^{K''} x_{j'k''k_2''} \leq E[\mathfrak{R}(e_{k_2''})], k_2'' = 1, 2, \dots, K_2'' \quad (25)$$

$$E[\mathfrak{R}(CC')] = \begin{cases} E[\mathfrak{R}(CC_1')] & \text{if } S' > E[\mathfrak{R}(S_1)] \\ E[\mathfrak{R}(CC_2')] & \text{else} \end{cases} \quad (26)$$

$$E[\mathfrak{R}(CC'')] = \begin{cases} E[\mathfrak{R}(CC_1'')] & \text{if } S'' > E[\mathfrak{R}(S_2)] \\ E[\mathfrak{R}(CC_2'')] & \text{else} \end{cases} \quad (27)$$

$$E[\mathfrak{R}(CT')] = \begin{cases} E[\mathfrak{R}(CT_1')] & \text{if } S' > E[\mathfrak{R}(S_1)] \\ E[\mathfrak{R}(CT_2')] & \text{else} \end{cases} \quad (28)$$

$$E[\mathfrak{R}(CT'')] = \begin{cases} E[\mathfrak{R}(CT_1'')] & \text{if } S'' > E[\mathfrak{R}(S_2)] \\ E[\mathfrak{R}(CT_2'')] & \text{else} \end{cases} \quad (29)$$

$$E[\mathfrak{R}(CE')] = \begin{cases} E[\mathfrak{R}(CE_1')] & \text{if } S' > E[\mathfrak{R}(S_1)] \\ E[\mathfrak{R}(CE_2')] & \text{else} \end{cases} \quad (30)$$

$$E[\mathfrak{R}(CE'')] = \begin{cases} E[\mathfrak{R}(CE_1'')] & \text{if } S'' > E[\mathfrak{R}(S_2)] \\ E[\mathfrak{R}(CE_2'')] & \text{else} \end{cases} \quad (31)$$

$$S' = \sum_{i'=1}^{J'} \sum_{j'=1}^{J'} \sum_{k_1'=1}^{K_1'} E[\mathfrak{R}(S_{i'j'k_1'})] y_{i'j'k_1'};$$

where

$$S'' = \sum_{j'=1}^{J'} \sum_{k''=1}^{K''} \sum_{k_2''=1}^{K_2''} E[\mathfrak{R}(S_{j'k''k_2''})] y_{j'k''k_2''}$$

$$x_{i'j'k_1'} \geq 0, x_{j'k''k_2''} \geq 0, \forall i', j', k'', k_1', k_2'' \quad (32)$$

### Optimization Methods

#### Fuzzy Programming Approach (FPA)

This is one of the live optimization approaches developed in 1978 for attaining a compromise solution to multi-objective linear programming problems. Suppose that there are 'z' objectives to be optimized. Then, the linear membership function defined for solving the multi-objective problem is

$$\mu(Z_z(x)) = \begin{cases} 1 & \text{if } Z_z(x) < L_z \\ \frac{U_z - Z_z(x)}{U_z - L_z} & \text{if } L_z \leq Z_z(x) \leq U_z \\ 0 & \text{if } Z_z(x) > U_z \end{cases} \quad (33)$$

where  $U_z$  and  $L_z$  are the worst and best boundary values for  $z^{\text{th}}$  objective function, i.e.,

$U_z = \text{Max}[Z_z(x)]$  &  $L_z = \text{Min}[Z_z(x)] \forall z$ . The mathematical formulation of FPA is

Maximize  $\lambda$

Subject to the constraints  $\mu(Z_z(x)) \geq \lambda, \forall z$  and (21) to (32) and (17), where  $\lambda$  is the aspiration level, which ranges from 0 to 1.

#### Global Criterion Method (GCM)

This is a multi-objective enhancement procedure that reduces the sum of the divergent values from the ideal one by offering a compromise solution. Each objective function subject to the constraints is solved independently of the others, and the deviations are found from all these solution vectors to formulate the following problem with  $z^*$  objectives.

Minimize  $G_{z^*}(x)$

Subject to the constraints (21) to (32) and (17) where

$$G_{z^*}(x) = \text{Min} \left\{ \sum_{z^*=1}^Z \left( \frac{Z_{z^*}(x) - Z_{z^*}'}{Z_{z^*}'' - Z_{z^*}'} \right)^l \right\}^{1/l} \text{ for } l \in [1, \infty] \quad Z_{z^*}''$$

and is the maximum while  $Z_{z^*}'$  is the minimum for objective  $z^*$ .

### Results and Discussion

#### Case Study

Smartphones are distributed from two sources, Bangalore and Thiruvallur, to three districts of Tamil Nadu—Trichy,

Karur, and Salem—with intermediate stages at the districts of Krishnagiri and Dharmapuri. This distribution network uses three different types of conveyances in each of its two stages. It involves the minimization of expense, time, and emission of the 3PLP to satisfy the smartphone demand per day for 2021 via E-commerce at the end destinations. As E-commerce involves return policies, both forward and reverse logistics transportation are included.

The rough transportation cost for the case study is assembled from the 3PLP website, while the rough emission

factor for the forward logistics conveyance is calculated from the fuel type and fuel efficiency of each vehicle available in secondary databases. The stage-1 data are provided in Tables 1-3, whereas stage 2 is provided in Tables 4-7.

The safety target for both stages is furnished based on a questionnaire taken from online customers. For reverse logistics, the rough emission factor of the diesel-based four-wheeler vehicle segment is utilized. Out of the 6 conveyances in forward logistics, one is CNG-based, while others are diesel-based.

**Table 1:** Transportation cost (in Rs.) per tonne, time taken (in hrs.), and safety measures for Stage 1 through conveyance-1

| $i \setminus j$ | <i>KRISHNAGIRI</i>         |                   |                        | <i>DHARMAPURI</i>            |                         |                        |
|-----------------|----------------------------|-------------------|------------------------|------------------------------|-------------------------|------------------------|
| BANGALORE       | [5352,5652]<br>[5280,5724] | [1.6,2] [1.3,2]   | [0.3,0.5]<br>[0.1,0.7] | [6725,7184]<br>[6409,7497]   | [1.8,2] [1.52,5.6]      | [0.4,0.7] [0.3,1]      |
| THIRUVALLUR     | [8324,8996]<br>[8044,9276] | [3.5,4] [3.2,5.7] | [0.8,0.8]<br>[0.7,0.9] | [9754,10591]<br>[9318,11027] | [4.3,5.8]<br>[3.08,6.3] | [0.6,0.8]<br>[0.5,0.9] |

**Table 2:** Transportation cost (in Rs.) per tonne, time taken (in hrs.) & safety measures for Stage 1 through conveyance-2

| $i \setminus j$ | <i>KRISHNAGIRI</i>           |                       |                        | <i>DHARMAPURI</i>              |                        |                        |
|-----------------|------------------------------|-----------------------|------------------------|--------------------------------|------------------------|------------------------|
| BANGALORE       | [6446,6850]<br>[6204,7092]   | [1.7,2]<br>[0.78,2.2] | [0.2,0.2]<br>[0.1,0.3] | [8030,8646]<br>[7914,8762]     | [2.1,2.9]<br>[1.1,3.5] | [0.2,0.6]<br>[0.2,0.6] |
| THIRUVALLUR     | [9820,10716]<br>[9423,11113] | [3,6]<br>[1,7]        | [0.6,0.8]<br>[0.5,0.9] | [11170,12246]<br>[10874,12542] | [2,6]<br>[2,8]         | [0.8,0.9]<br>[0.5,1]   |

**Table 3:** Transportation cost (in Rs.) per tonne, time taken (in hrs.), and safety measures for Stage 1 through conveyance-3

| $i \setminus j$ | <i>KRISHNAGIRI</i>             |                    |                        | <i>DHARMAPURI</i>              |                       |                     |
|-----------------|--------------------------------|--------------------|------------------------|--------------------------------|-----------------------|---------------------|
| BANGALORE       | [4401,4799]<br>[3940,5260]     | [2.1,2.6] [1.2,82] | [0.4,0.6]<br>[0.3,0.7] | [6850,7150]<br>[6480,7520]     | [3,3.4]<br>[1.1,4.22] | [0.5,0.5] [0.4,0.6] |
| THIRUVALLUR     | [10650,11750]<br>[10170,12230] | [2,4] [2,9]        | [0.9,0.9]<br>[0.8,1]   | [12990,13910]<br>[12764,14136] | [5,5] [4,6]           | [0.9,1] [0.7,1]     |

**Table 4:** Transportation cost (in Rs.) per tonne, time taken (in hrs.) for Stage 2 through conveyance-1

| $j \setminus k$ | <i>TRICHY</i>                                   | <i>KARUR</i>                                     | <i>SALEM</i>                                     |
|-----------------|-------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| KRISHNAGIRI     | [8004,8564] [7800,8768]<br>[3.6,5] [3,8]        | [6120,7272] [5891,7501]<br>[2.1,5.4] [1.4,5.38]  | [3402,4046] [3004,4444]<br>[2,2] [2,2]           |
| DHARMAPURI      | [6317,7187] [6120,7384]<br>[3.9,4.4] [2.3,6.08] | [4725,5651] [4633,5743]<br>[1.9,2.9] [1.75,4.73] | [1976,2440] [1940,2476]<br>[0.9,1.3] [0.89,1.99] |

**Table 5:** Transportation cost (in Rs.) per tonne, time taken (in hrs.) for Stage 2 through conveyance-2

| $j \setminus k$ | <i>TRICHY</i>                                       | <i>KARUR</i>                                       | <i>SALEM</i>                                    |
|-----------------|-----------------------------------------------------|----------------------------------------------------|-------------------------------------------------|
| KRISHNAGIRI     | [10750,11770] [10010,12510]<br>[4.1,5.28] [3.8,5.5] | [9370,10206] [9107,10469]<br>[2.95,3.4] [2.4,4.65] | [6580,7044] [6270,7354]<br>[1.3,1.9] [1.2,2.92] |
| DHARMAPURI      | [9310,10138] [8988,10460]<br>[3.5,4.7] [2.1,5.22]   | [7930,8574] [7745,8759]<br>[2.3,3] [1.7,3.4]       | [5140,5412] [4814,5738]<br>[0.6,1.2] [0.5,1.82] |

**Table 6:** Transportation cost (in Rs.) per tonne, time taken (in hrs.) for Stage 2 through conveyance-3

| $j \backslash k$ | TRICHY                                           | KARUR                                  | SALEM                                              |
|------------------|--------------------------------------------------|----------------------------------------|----------------------------------------------------|
| KRISHNAGIRI      | [9130,9895] [8864,10161]<br>[5,6.8] [1.52,7]     | [7934,8561] [7454,9041]<br>[2,5] [2,6] | [5516,5864] [5331,6049]<br>[2,2.25] [1.95,2.8]     |
| DHARMAPURI       | [7856,8474] [7618,8712]<br>[3.97,4.5] [3.7,5.15] | [6686,7169] [6341,7514]<br>[3,3] [2,4] | [4268,4472] [4173,4567]<br>[1.09,1.87] [0.56,2.16] |

**Table 7:** Safety measures for Stage 2 through conveyance-1,2 &3

| $j \backslash k$ | TRICHY                                                            | KARUR                                                             | SALEM                                                             |
|------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|
| KRISHNAGIRI      | [0.2,0.3] [0.2,0.5]<br>[0.4,0.7] [0.1,0.8]<br>[0.8,0.8] [0.3,0.9] | [0.3,0.5] [0.3,0.5]<br>[0.1,0.2] [0.2,0.3]<br>[0.1,0.1] [0.1,0.1] | [0.7,0.8] [0.8,0.9]<br>[0.2,0.4] [0.1,0.5]<br>[0.9,0.9] [0.8,0.1] |
| DHARMAPURI       | [0.9,0.9] [0.9] [0.9]<br>[0.7,0.8] [0.7,1]<br>[0.4,0.7] [0.5,0.8] | [0.1,0.2] [0.2,0.3]<br>[0.4,0.7] [0.3,1]<br>[0.9,0.9] [0.8,1]     | [0.2,0.2] [0.2,0.6]<br>[0.5,0.5] [0.2,0.8]<br>[0.6,0.8] [0.5,0.9] |

Availability (in tonne):  $\Re(a_{1\cdot}) = [1.537, 2.496][1, 3.703]$ ,

$$\Re(a_{2\cdot}) = [1.8, 2.5][1.4, 3.5]$$

Demand (in tonne):  $\Re(b_{1\cdot}) = [1.9, 2.7][1.34, 3.596]$ ,

$$\Re(b_{2\cdot}) = [2.05, 2.21][1.14, 3.5]$$

Conveyance capacity (in tonne):

$$\Re(e_{1\cdot}) = [0.5, 1.5][0.25, 1.75], \Re(e_{2\cdot}) = [2.25, 2.75][2, 3],$$

$$\Re(e_{3\cdot}) = [0.6, 1.8][0.4, 2]$$

Conditional fixed charge (in Rs.):

$$\Re(CC') = \begin{cases} [5000, 5000][4000, 6000] & \text{if } S' > [2, 2][1, 3] \\ [8000, 12000][7000, 14000] & \text{else} \end{cases}$$

Conditional fixed time (in hrs.):

$$\Re(CT') = \begin{cases} [4, 6][3, 7] & \text{if } S' > [2, 2][1, 3] \\ [5, 7][5, 9] & \text{else} \end{cases}$$

Conditional fixed emission (in tonne):

$$\Re(CE') = \begin{cases} [0.04, 0.06][0, 0.1] & \text{if } S' > [2, 2][1, 3] \\ [0.05, 0.15][0.03, 0.17] & \text{else} \end{cases}$$

Demand (in tonne):

$$\Re(b_{1\cdot}) = [1.1, 1.77][0.504, 2.9],$$

$$\Re(b_{2\cdot}) = [0.54, 0.6145][0.4, 0.9035]$$

$$\Re(b_{3\cdot}) = [2.004, 3][1.10, 2.08]$$

Conveyance capacity (in tonne):

$$\Re(e_{1\cdot}) = [0.6, 1.4][0.3, 1.7], \Re(e_{2\cdot}) = [2.5, 2.5][2.25, 2.75],$$

$$\Re(e_{3\cdot}) = [1, 2][0.8, 2.2]$$

Conditional fixed charge (in Rs.):

$$\Re(CC'') = \begin{cases} [9000, 11000][8000, 12000] & \text{if } S'' > [4, 6][2, 8] \\ [18000, 22000][17000, 23000] & \text{else} \end{cases}$$

Conditional fixed time (in hrs.):

$$\Re(CT'') = \begin{cases} [7, 10][5, 18] & \text{if } S'' > [4, 6][2, 8] \\ [6, 8][5, 12] & \text{else} \end{cases}$$

Conditional fixed emission (in tonne):

$$\Re(CE'') = \begin{cases} [0.3, 0.3][0.2, 0.4] & \text{if } S'' > [4, 6][2, 8] \\ [0.4, 0.6][0, 1] & \text{else} \end{cases}$$

CO<sub>2</sub> Emission factor:

Diesel-based vehicle= [2.62, 2.71] [2.13, 3.1] kg CO<sub>2</sub>/ litre

CNG based vehicle= [2.63, 2.69] [2.21, 3.23] kg CO<sub>2</sub>/ kg

Fuel efficiency:

CNG based vehicle = [16.1,17.9] [14.7,20.1] km/kg

For other diesel-based vehicles, fuel efficiencies are [19.3,19.9] [18.1,21.1], [9,11] [7,13], [13.4,14.9] [12.1,16.8], [19,20.2] [18.8,20.4], [7,13] [6,14] km/liter.

$$\Re(r_{1''}) = [0.05, 0.05][0.03, 0.07],$$

$$\Re(r_{2''}) = [0.05, 0.07][0.04, 0.08],$$

$$\Re(r_{3''}) = [0.05, 0.1][0.03, 0.1],$$

$$\Re(h_{1''}) = [0.03, 0.03][0.03, 0.03],$$

$$\Re(h_{2''}) = [0.03, 0.05][0.02, 0.06], \Re(h_{3''}) = [0.04, 0.06][0.01, 0.09]$$

$$\Re(CR_{\bar{u}}) = [8270, 9437][6053, 10390],$$

$$\Re(CR_{\bar{u}}) = [6999, 7927][6129, 8645],$$

$$\Re(CR_{\bar{u}}) = [4742, 6000][3347, 6041]$$

$$\Re(TR_{1''}) = [6.5, 7.4][5.1, 8.2], \Re(TR_{2''}) = [5, 5.3][4.9, 7.2],$$

$$\Re(TR_{\bar{u}}) = [3.4, 4.2][2.9, 4.58]$$

CO<sub>2</sub> Emission factor of diesel-based four-wheeler vehicle segment = [170.1,175.3] [168.5,180.42] g/Km

$$\Re(E_{k''}) = CO_2 \text{ Emission factor} \times D_{k''m}$$

### Solution

The above problem is formulated into a mathematical model, and its deterministic equivalent is obtained. The minimum value of the objective functions favoring both forward and reverse logistics is found using the LINGO (19.0) solver for the above-mentioned two multi-objective optimization methods, and it is bestowed in Table 8.

### Sensitivity Analysis and Inference

Sensitivity analysis is carried out to reveal how changes in the coefficients of the optimization problem affect the solution. The reduced cost for each variable using LINGO (19.0) solver with GCM is,

**Table 8:** Compromise value of the objective function in FPA and GCM.

| OBJECTIVES | FPA            | GCM            |
|------------|----------------|----------------|
| $Z_1$      | Rs. 93592.01   | Rs. 93591.03   |
| $Z_2$      | 63.17 hrs      | 63.17 hrs      |
| $Z_3$      | 1.044490 tonne | 1.044356 tonne |

**Table 9:** Comparative analysis on same capacity vehicles with different fuels.

| VEHICLE TYPE | DIESEL BASED   |                | CNG BASED      |                |
|--------------|----------------|----------------|----------------|----------------|
| METHODS      | FPA            | GCM            | FPA            | GCM            |
| $Z_1$        | Rs. 94696.01   | Rs. 94695.03   | Rs. 80978.59   | Rs. 80977.61   |
| $Z_2$        | 63.17 hrs      | 63.17 hrs      | 63.17 hrs      | 63.17 hrs      |
| $Z_3$        | 1.045084 tonne | 1.044950 tonne | 0.987274 tonne | 0.987140 tonne |

$$x_{1'1'1'} = 389.4999, x_{1'2'1'} = 328.7499, x_{2'1'1'} = 0, x_{2'2'1'} = 0, x_{1'1'2'} = 0,$$

$$x_{1'2'2'} = 177.5, x_{2'1'2'} = 72.49998, x_{2'2'2'} = 0, x_{1'1'3'} = 0, x_{1'2'3'} = 887.4998,$$

$$x_{2'1'3'} = 3052.499, x_{2'2'3'} = 3789.999, x_{1'1'1''} = 112,$$

$$x_{1'2'1''} = 0, x_{1'3'1''} = 0, x_{2'1'1''} = 95.99998, x_{2'2'1''} = 7.999998,$$

$$x_{2'3'1''} = 0, x_{1'1'2''} = 20, x_{1'2'2''} = 23.99999, x_{1'3'2''} = 20, x_{2'1'2''} = 0,$$

$$x_{2'2'2''} = 3.99999, x_{2'3'2''} = 0, x_{1'1'3''} = 0, x_{1'2'3''} = 211, x_{1'3'3''} = 625.4999,$$

$$x_{2'1'3''} = 168.5, x_{2'2'3''} = 406.9999, x_{2'3'3''} = 821.4998$$

Here,  $x_{1'1'1'}$ , the reduced cost of 389.4999 means that the objective coefficient of that variable should decrease by 389.4999 for  $x_{1'1'1'}$  it to become an alternative solution for the problem.

The corresponding dual price of the constraints is,

$$a_{1'} = 3547.499, a_{2'} = 0, b_{1'} = -10195.5, b_{2'} = -10192, e_{1'} = 1535.5,$$

$$e_{2'} = 2048, e_{3'} = 2048, b_{1''} = -11923, b_{2''} = -10506.5, b_{3''} = -7395,$$

$$e_{1''} = 3067.999, e_{2''} = 0, e_{3''} = 1727.5$$

Here, dual price  $a_{1'} = 3547.499$  is positive and means that adding one unit of supply minimizes the objective value by 3547.499, whereas negative dual prices increase the objective function with every additional unit in the respective constraint. Similar interpretations can be made for the remaining constraints.

### Conclusion

The practical meaning of the safety factor is magnificent, as it affects cost, time, and emission factors with uncertain fluctuations. The real-life absurdities are always waiting at the door to collapse the plans of mankind. Introducing conditional fixed parameters on the safety achieved at each stage of transportation will enable the 3PLP to overcome the financial crisis effectively. As only a few of the researchers investigated e-commerce models in a rough environment, the model is studied under a rough interval scenario. The results conclude that GCM, rather than FPA, offers a much better solution. The case study discussed in this paper has employed both CNG and diesel-based vehicles for forward

logistics. The improving technology has found many suitable replacements for diesel-based trucks. There is a notable difference in the value of the objective functions when the 3PLP uses CNG-based vehicles completely rather than diesel ones, as they vary in their efficiency, emission, and rarely speed. A comparative result tabulated in Table 9 furnishes the importance of the usage of diesel alternatives by 3PLP in the Indian transportation network. It is obtained by substituting equivalent CNG vehicle's costs, time & emission on the solution obtained for the case study.

Regardless of the result, there may be changes in the corresponding safety factor of the conveyance while switching to other fuels, which is neglected and left for future research. Furthermore, the assumptions of the proposed model can be modified, and the investigation of multi-item, multi-stage e-commerce logistics in two-fold uncertain environments can be thought of as an extension. Also, the paper can be modeled as a profit maximization problem from the view of e-commerce sellers by adding other costs related to 3PLP, noise constraints, traffic constraints, and so on to enhance sustainability.

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