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Multi-Objective Electric Vehicle Transshipment Problem with Battery Swapping Technology Under Fuzzy Environment

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Abstract

Objectives: To evaluate the efficiency of the multi-objective battery-swapping electric vehicle transshipment problem by analyzing the total cost and time involved in the entire distribution process. **Methods:** A multi-objective battery-swapping electric vehicle transshipment model is formulated and a case study on a food grain company is considered to demonstrate the pertinent nature of this model. Due to real-life uncertainty, Fermatean fuzzy parameters are considered in this model. Existing neutrosophic fuzzy programming and linear weighted sum method have been used to obtain the solutions for the multi-objective transshipment model. **Findings:** A comparative study has been made for both multi-objective electric vehicle transshipment and multi-objective electric vehicle transportation problems with battery swapping as well as charging technology. Optimum Solutions obtained for the case study by using these two prescribed methods reveal that the multi-objective transshipment problem with battery swapping gives the minimum transportation cost and time than the charging technology. Obtained solutions for multi-objective electric vehicle transshipment problems with battery swapping show a reduction of 7.8% in cost and 11.19% in the charging technology. Meanwhile, obtained solutions for multi-objective electric vehicle transshipment problems show a reduction of 14% in cost and 14.4% in time than the multi-objective transportation problem. **Novelty:** The efficiency of multi-objective electric vehicle transshipment problems with battery swapping technology under the Fermatean fuzzy environment has not yet investigated in the literature.

2020 Mathematics Subject Classification: 90B06.

Keywords: Transshipment problem; Electric vehicle; Battery swapping technology; Fuzzy environment; Multiobjective transshipment problem

1 Introduction

In the recent competitive market of transportation business, the transshipment problem plays a significant role in logistics and supply chain management. A transshipment problem is a special type of linear programming problem that involves moving goods from source to destination through one or more intermediate points. Sometimes source and destination can perform as intermediate points due to circumstantial changes, emergencies, and deficiency of goods. It was first invented by Orden (1956). Recently, researchers have developed a transshipment problem to handle uncertainty arising from several challenges, including limited data, and a lack of information, equipment failures, traffic conditions during the distribution process. To handle the uncertainty, the Fuzzy set was first introduced by Zadeh (1965). Kumar, A., presented an algorithm to solve the transshipment problem with a single objective in an intuitionistic fuzzy environment. [(1)] L. Sujatha discussed the single objective fuzzy transshipment problem by using the fuzzy one-point method. [(2)] The prescribed researchers examined the transshipment problem by converting it into a transportation problem using buffer stock to find the optimum solution for a transshipment problem. Converting the transshipment problem into a transportation problem can lead to more complexity and take much time to solve the problem due to more nodes and arcs being added to serve as source and destination. Raju Prajapati proposed a heuristic algorithm based on a minimum spanning tree approach for solving a single objective transshipment problem directly. [(3)] In the complex world, decision-makers have been focused on two or more objectives simultaneously instead of a single objective to deal with the interconnected obstacles. AI-Sultan, A.T. created a multi-objective model for transshipment problems based on various sizes of vehicles and routes. [(4)] In recent years, few researchers only have discussed the transshipment problem with multiple objectives. Extensive study is needed for multi-objective transshipment problems.

In the contemporary world, Electric mobility has been steadily increasing globally, as an aspect of preventing the greenhouse gas emissions and oil dependency caused by vehicle transport. Electric vehicles (EVs) have substantially less or zero tailpipe emissions and enhanced fuel efficiency when compared to internal combustion engine vehicles. When using the charging technology for electric vehicles, users come across various challenges like energy inefficiency, limited flexibility, lack of compatibility, and long charging times. Among these challenges, longer charging time is one of the most significant problems that affects the usability of electric vehicles, logistics, and customer satisfaction in the entire transshipment system. Fortunately, these issues can be addressed by battery swapping technology in which a drained battery is replaced with full charged one. Gunalay, Yavuz proposed an innovative model and decision support approach for evaluating the urban transshipment problem by using electric vehicles. [(5)] Madhanakkumar, N., et al. discussed an optimal battery-swapping mechanism for electric vehicles to minimize the cost based on energy consumption and time. [(6)] A complete and systematic review of the electric vehicle battery swapping and charging station operation optimization approaches is described by Cui, Dingsong, et al. [(7)]

To the best of our knowledge, there exists no literature taking into consideration to study the efficiency of the Multi-Objective Electric Vehicle Transshipment Problem (MOEVTrP) with battery-swapping technology. In this paper, battery swapping technology has been incorporated into the multi-objective electric vehicle transshipment problem to enhance the efficiency of logistic operations by reducing cost and time based on battery swapping technology. Consequently, the transshipment problem has been examined directly, rather than converting them into a transportation problem. Compared to the transportation problem, this approach enhances the operational efficiency optimizes the total distribution cost, and maintains a strong relationship with customers. The proposed model is formulated in a Fermatean fuzzy environment. Senapati and Yager introduced the Fermatean fuzzy set and it is an extension of the Pythagorean fuzzy set where the sum of the cubes of membership and non-membership degrees is required to be less than or equal to 1. Based on previous discussions on the transshipment problem and recent research articles on the transshipment problem, there are no existing methodologies for addressing the transshipment problem under the Fermatean fuzzy environment. In this paper, transportation cost, time, demand, and supply parameters of a proposed problem have been treated as Fermatean fuzzy numbers as they are the most effective fuzzy set and more capable of handling higher levels of uncertainty. A case study on Food Grain Company has been discussed to demonstrate the nature of this proposed model by using two existing methods named neutrosophic programming and linear weighted sum method. The outline of the rest of the paper is described as follows. Section 2 presented the basic knowledge of Fermatean fuzzy number, assumption, notation, and mathematical formulation of the proposed model, deterministic model, and optimization methods to solve the proposed model. Section 3 presented numerical examples, results, and discussions. Finally, section 4 describes conclusions and future research.

2 Methodology

2.1 Preliminaries

Definition 2.1.1 [8]

Let X be a non-empty set. A Fermatean fuzzy set $\widetilde{E}^F$ of X is defined as $\widetilde{E}^F = \{\langle x,\, \mu_{\widetilde{E}^F}(x),\, v_{\widetilde{E}^F}(x)\rangle : x \in X\}$ where $\mu_{\widetilde{E}^F}(x), \nu_{\widetilde{E}^F}(x) : X \to [0,1]$ are membership and non-membership functions. Additionally, the Fermatean fuzzy number satisfies the condition $0 \le (\mu_{\widetilde{E}^F}(x))^3 + (\nu_{\widetilde{E}^F}(x))^3 \le 1$. Further, for all $x \in X$degree of hesitation is defined by $\pi_{\widetilde{E}^F}(x) = \sqrt{1-(\mu_{\widetilde{E}^F}(x))^3-(\nu_{\widetilde{E}^F}(x))^3}$.

Definition 2.1.2 [8]

A triangular Fermatean fuzzy number (TFFN) is defined by $\widetilde{E}^F = \langle (e^l, e^m, e^n),\, p,\, q\rangle$ whose membership and non-membership functions can be described as

$$\mu_{\widetilde{E}^F}(x) = \begin{cases} \frac{(x-e^l)}{(e^m-e^l)} & if\ e^l \le x \le e^m \\ p & if\ x = e^m \\ \frac{(e^r-x)p}{(e^r-e^m)} & if\ e^m \le x \le e^r \\ 0 & if\ x < e^l\ or\ x > e^r \end{cases} \qquad v_{\widetilde{E}^F}(x) = \begin{cases} \frac{[x-e^m+q(x-e^l)]}{e^m-e^l} & if\ e^l \le x \le e^m \\ q & if\ x = e^m \\ \frac{[x-e^m+q(e^r-x)p]}{e^r-e^m} & if\ e^m \le x \le e^r \\ 1 & if\ x < e^l\ or\ x > e^r \end{cases}$$

Here p and q represents the maximum value of $MF(\mu_{\widetilde{E}^F})$and the minimum value of $MF(\nu_{\widetilde{E}^F})$ respectively, such that $p \in [0,1], q \in [0,1]$ and $0 \le p^3 + q^3 \le 1$. Consider $p = 1$ and $q = 0$. Then TFFN is in the form $\widetilde{E}^F = \left\langle (e^l, e^m, e^n),\, \left(e^{l'}, e^{m'}, e^{n'}\right)\right\rangle$ whose $MF(\mu_{\widetilde{E}^F})$and $MF(\nu_{\widetilde{E}^F})$can be represented by

$$\mu_{\widetilde{E}^F}(x) = \begin{cases} \frac{(x-e^l)}{(e^m-e^l)} & if\ e^l \le x \le e^m \\ 1 & if\ x = e^m \\ \frac{(e^r-x)p}{(e^r-e^m)} & if\ e^m \le x \le e^r \\ 0 & if\ x < e^l\ or\ x > e^r \end{cases} \qquad v_{\widetilde{E}^F}(x) = \begin{cases} \frac{e^m-x}{e^m-e^l} & if\ e^l \le x \le e^m \\ 0 & if\ x = e^m \\ \frac{x-e^m}{e^r-e^m} & if\ e^m \le x \le e^r \\ 1 & if\ x < e^l\ or\ x > e^r \end{cases}$$

Where $e^{l'} \le e^l \le e^m \le e^r \le e^{r'}$.

Definition 2.1. 3 [8]

Consider $\widetilde{E}^F = \left\langle (e^l, e^m, e^n),\, \left(e^{l'}, e^{m'}, e^{n'}\right)\right\rangle$ be a triangular Fermatean fuzzy number. Then $R(\widetilde{E}^F) = \frac{(e^l+4e^m+e^n)(e^{l'}+4e^m+e^{n'})}{12}$ is a ranking function for triangular fermatean fuzzy number$\widetilde{E}^F$.

Definition 2.1.4 [9]

Let X be a universal set. A neutrosophic set $\widetilde{E}$in X is defined by $\widetilde{E} = \left\{\left\langle\ x,\quad T_{\widetilde{E}(x)},\quad I_{\widetilde{E}(x)},\quad F_{\widetilde{E}(x):x\in X}\ \right\rangle\right\}$ where Truth $(T_{\widetilde{E}}(x))$, Indeterminacy $(I_{\widetilde{E}}(x))$, Falsity membership $F_{\widetilde{E}}(x)$ functions such that $T_{\widetilde{E}}(x), I_{\widetilde{E}}(x), F_{\widetilde{E}}(x) : X \to [0,1]$. Also satisfied with the following condition $0 \le T_{\widetilde{E}}(x) + I_{\widetilde{E}}(x) + F_{\widetilde{E}}(x) \le 3$.

Definition 2.1.5 [10]

Energy consumption for vehicles can be examined from various kinds of perspectives, such as well-to-wheel (WTW) and tank-to-wheel (TTW). Most of the transportation fuel consumption uses TTW mode. In this mode, fuel which is loaded by the freight is converted into automobile power. In this paper, we have considered energy consumption based on TWW mode. The energy consumption of electric vehicles in logistics operations is affected by various factors, including road conditions, frontal area, weight, speed, acceleration, and distance. Air resistance and road congestion are two factors that affect the dynamic variation of vehicle speeds, and these factors in turn affect the amount of electricity consumed. The weight of the electric vehicle is considered here as both empty and loaded. The energy consumption of electric vehicles can be defined as follows: $e_{ij} = c_{ij}(w+x_{ij})\tilde{d}^F_{ij} + \gamma v^2 \tilde{d}^F_{ij}$, where $c_{ij} = a + gsin\theta_{ij} + gC_r cos\theta_{ij}$ is a constant related to road sections; and $\gamma = 0.5C_d A\rho$ is coefficient related to Electric vehicles.

2.2 Mathematical Model

In a multi-objective transshipment problem, products are transported from m sources and n destinations through one or more intermediate points. Here m sources and n destinations act as transshipment points. Different parameters and notation are used to formulate a mathematical formulation defined as follows

2.2.1 Notations and Assumptions

The below-mentioned notations are used to construct our model

- m number of sources
- n number of destinations
- $\tilde{a}_i^F$ Fermatean availability of i^{th} source
- $\tilde{b}_j^F$ Fermatean availability of j^{th} destination
- x_{ij} quantity of product to be transported from i^{th}point to j^{th}point
- $\tilde{t}_{ij}^F$ Fermatean transportation time from i^{th}point to j^{th}point
- $\tilde{d}_{ij}^F$ neutrosophic distance from i^{th}point to j^{th}point
- $\widetilde{N}_{ij}^F$ number of battery swapping stations from i^{th}point to j^{th}point
- β power consumption cost per Kilowatt-hour
- α usage cost of electric vehicles per hour
- s_f Battery swapping service time

2.2.2 Fermatean fuzzy multi-objective electric vehicle transshipment problem (MOEVTrP) with battery swapping technology:

The mathematical model for multi-objective electric vehicle transshipment problem (MOEVTrP) is defined as follows

$$\sum_{i=1}^{m+n} \sum_{j=1}^{m+n} \{\alpha(\tilde{t}_{ij}^F) + \beta[c_{ij}(w + x_{ij})\tilde{d}_{ij}^F + \gamma v^2 R(\tilde{d}_{ij}^F)]\} y_{ij} + \sum_{i=1}^{m+n} \sum_{j=1}^{m+n} s_f \widetilde{N}_{ij}^F y_{ij}$$

$$Min \widetilde{Z}_2^F = \sum_{i=1}^{m+n} \sum_{j=1}^{m+n} \left(\tilde{t}_{ij}^F + s_f \widetilde{N}_{ij}^F\right) y_{ij}$$

Subject to the constraints

$$\sum_{j=1}^{m+n} x_{ij} - \sum_{j=1}^{m+n} x_{ji} = \tilde{a}_i^F, i = 1,2,3,4,\ldots,m$$

$$\sum_{i=1}^{m+n} x_{ij} - \sum_{i=1}^{m+n} x_{ji} = \tilde{b}_j^F, j = m+1, m+2, \ldots, m+n$$

$$x_{ij} \geq 0 \, \forall i, \, j = 1,2,3,\ldots.,m+n$$

$$y_{ij} = \begin{cases} 0 \; x_{ij} = 0 \\ 1 \; x_{ij} > 0 \end{cases}$$

The aim of the objective function (1) is to reduce the total costs which include the usage cost of electric vehicles, power consumption cost of electric vehicles, and waiting cost in charging stations. The objective function (2) seeks to reduce total travel time and waiting time at the recharge station. Constraints (3) and (4) states that availability of sources and customers requirement.

2.2.3 Deterministic Model

In this Fermatean multi-objective transshipment model, the parameters such as time, distance, number of swapping stations, supply, and demand are considered triangular Fermatean fuzzy numbers to resolve the prevailing uncertainty in real-life situations. So, this model becomes complex to solve directly. Therefore, this model is transformed into the deterministic model by utilizing the score function as follows:

$$MinR(\widetilde{Z}_1^F) = \sum_{i=1}^{m+n}\sum_{j=1}^{m+n}\{\alpha(\tilde{t}_{ij}^F)+\beta[\alpha(w+x_{ij})R(\tilde{d}_{ij}^F)+\gamma v^2 R(\tilde{d}_{ij}^F)]\}y_{ij}+\sum_{i=1}^{m+n}\sum_{j=1}^{m+n}s_f R(\widetilde{N}_{ij}^F)y_{ij} \quad (2.1)$$

$$MinR(\widetilde{Z}_2^F) = \sum_{i=1}^{m+n}\sum_{j=1}^{m+n}\left(R(\tilde{t}_{ij}^F)+s_f R(\widetilde{N}_{ij}^F)\right)y_{ij} \quad (2.2)$$

Subject to the constraints

$$\sum_{j=1}^{m+n}x_{ij}-\sum_{j=1}^{m+n}x_{ji}=R(\tilde{a}_i^F), i=1,2,3,4,\ldots,m \quad (2.3)$$

$$\sum_{i=1}^{m+n}x_{ij}-\sum_{i=1}^{m+n}x_{ji}=R(\tilde{b}_j^F), j=m+1,m+2,\ldots,m+n \quad (2.4)$$

$$x_{ij}\geq 0\,\forall i,\, j=1,2,3,\ldots.,m+n \quad (2.5)$$

$$y_{ij}=\begin{cases}0 & x_{ij}=0\\ 1 & x_{ij}>0\end{cases} \quad (2.6)$$

2.3 Solution Procedure

To obtain the optimum solution for this above deterministic model, two methods are used in this paper as follows: (i) Neutrosophic Fuzzy Programming and (ii) Linear weighted sum method

2.3.1 Neutrosophic fuzzy programming method

According to the neutrosophic Zimmermann's principles, this modernistic approach has been developed to obtain optimum solutions to multi-objective problems.[11] The neutrosophic compromising programming method is based on a neutrosophic set that consists of three membership functions (maximization of truth and indeterminacy, minimization of falsity membership function) used in certain optimization situations.Bellman and Zadeh have presented three fuzzy set notions: fuzzy decision (D), fuzzy goal (G), and fuzzy constraints (C). These concepts were then applied in numerous instances of decision-making under fuzzy conditions. We know that the fuzzy decision can be defined as $D=G\cap C$. Neutrosophic decisions set D_N together with their corresponding set of objectives and constraints, can be defined in an equivalent manner as follows:

$D_N=\left(\bigcap_{k=1}^{k}k\right)\left(\bigcap_{s=1}^{s}C_s\right)=(x,T_D(x),I_D(x),F_D(x))$where $T_D(x)=min\left\{\begin{array}{c}T_{G1}(x),T_{G2}(x),T_{Gk}(x)\\ T_{C1}(x),T_{C2}(x),T_{Cs}(x)\end{array}\right\}\forall\, x\in\chi,$,
$I_D(x)=min\left\{\begin{array}{c}I_{G1}(x),I_{G2}(x),I_{Gk}(x)\\ I_{C1}(x),I_{C2}(x),I_{Cs}(x)\end{array}\right\}\forall\, x\in\chi,$, $F_D(x)=min\left\{\begin{array}{c}F_{G1}(x),F_{G2}(x),F_{Gk}(x)\\ F_{C1}(x),F_{C2}(x),F_{Cs}(x)\end{array}\right\}\forall\, x\in\chi,$

Where $T_D(x),I_D(x),F_D(x)$ are the truth, indeterminacy, and falsity membership function of neutrosophic decision set D_N. The bounds for each objective function to formulate the various membership functions for multi-objective transshipment problems have been determined. The upper and lower bounds for each objective function are denoted by L_k and U_k which can be calculated as follows: each function is optimized as a single objective function under given constraints. After solving all the objective functions individually, solution sets have been solved. Afterward, these solutions are substituted in each objective function to examine the bounds for each objective as follows $U_k=max\left[Z_k(X^k)\right]$ and $L_k=max\left[Z_k(X^k)\right]\forall k=1,2,3\ldots K$. Then the bounds for the neutrosophic environment are obtained as follows:

$U_k^T=U_k, L_k^T=L_k$for the truth membership
$U_k^F=U_k^T, L_k^F=L_k^T+t_k(U_k^T-L_k^T)$for falsity membership
$U_k^I=L_k^T+s_k(U_k^T-L_k^T), L_k^I=L_k^T$ for indeterminacy membership

Where t_k, s_k are predetermined real numbers in $(0,1)$ utilizing lower and upper bound, the linear membership function under a neutrosophic environment is defined as follows:

$$T_\kappa(Z_\kappa(x)) = \begin{cases} 1 & if\ Z_k(x) < L_k^T \\ \frac{U_k^T - Z_k(x)}{U_k^T - L_k^T} & if\ L_k^T \leq Z_k(x) < U_k^T, \\ 0 & if\ Z_k(x) > U_k^T \end{cases}$$

$$I_\kappa(Z_\kappa(x)) = \begin{cases} 1 & if\ Z_k(x) < L_k^I \\ \frac{U_k^I - Z_k(x)}{U_k^I - L_k^I} & if\ L_k^I \leq Z_k(x) < U_k^I, \\ 0 & if\ Z_k(x) > U_k^I \end{cases}$$

$$F_\kappa(Z_\kappa(x)) = \begin{cases} 1 & if\ Z_k(x) < L_k^F \\ \frac{U_k^F - Z_k(x)}{U_k^F - L_k^F} & if\ L_k^F \leq Z_k(x) < U_k^F, \\ 0 & if\ Z_k(x) > U_k^F \end{cases}$$

Where $L_k^{(.)} \neq U_k^{(.)}$ for all objective functions. If for any objective function, $L_k^{(.)} = U_k^{(.)}$ then the value of membership will be equal to 1. Then the neutrosophic optimization problem can be described below:

$maxmin_{k=1,2,3,...k} I_k(Z_k(x))$

$minmax_{k=1,2,3,...k} F_k(Z_k(x))$

Subject to

Equations Equations (2.3), (2.4), (2.5) and (2.6)

After that, by using auxiliary parameters, the model M_1 can be converted into the following problem under a neutrosophic environment

$M_2 : max\,\lambda$

$max\theta$

$min\eta$

Subject to

$T_k(Z_k(x) \geq \lambda$

$I_k(Z_k(x) \geq \theta$

$F_k(Z_k(x) \geq \eta$

Subject to

Equations Equations (2.3), (2.4), (2.5) and (2.6)

Using the linear membership function, the above model M_2can be expressed as

$$M_3 : Max(\lambda + \theta - \eta)$$

Subject to

$$Z_k(x) + (U_k^T - L_k^T)\lambda \leq U_k^T$$

$$Z_k(x) + (U_k^I - L_k^I)\theta \leq U_k^I$$

$$Z_k(x) - (U_k^F - L_k^F)\eta \leq U_k^F$$

Equations Equations (2.3), (2.4), (2.5) and (2.6)

$$\lambda \geq \theta, \lambda \geq \eta, \lambda + \theta + \eta \leq 3$$

$$\lambda, \theta, \eta \in [0,1], k = 1,2,3, ...K$$

2.3.2 Linear weighted-sum method

In this method, a multi-objective optimization problem is converted into a single objective problem by pre-multiplying each objective function with an assigned weight and then combining its multiple objective functions.[12] Here we have considered W_k as the weight of each objective function. The weight $W_k$is described as the preference over the objective functions. The greatest weight is defined for the more important objective function and the lowest weight is considered for the less important objective function. Then combine them into a single objective function $\sum_{k=1}^{3} W_k Z_k$ with $\sum_{k=1}^{3} W_k = 1$. The following steps are used to obtain the solution for the deterministic multi-objective transshipment problem.

M_4 :Minimize $\sum_{k=1}^{3} W_k R(\widetilde{Z}_k^F(x_{ij}))$

Subject to equations Equations (2.3), (2.4), (2.5) and (2.6)

The two methods prescribed in 2.3.1 & 2.3.2 have been solved with the help of Lingo Global Solver (20.0) to find the optimum solutions for the proposed model.

3 Result and discussion

3.1 Numerical example

The supply data of three food grain warehouses situated in Lucknow, Chandigarh, and Kolkata and demand requirements of Srinagar, Jodhpur, Gangtok, and Siliguri in India are taken from multi-objective fixed charge transportation problem solved by Midya S, Roy SK., for investing the proposed multi-objective transshipment problem.[12] While using the ordinary vehicle for the transportation process, the decision maker faces many challenges. Assume that, the company distributes food grains by using electric vehicles with battery-swapping technology to overcome the disadvantages of using the ordinary vehicle. Due to circumstantial changes, emergency situations, both source and destination act as transshipment points. Some parameters related to electric vehicles are considered here which are taken from[10] as follows: the battery swapping service time $s_f = 0.1h$; gravitational constant $g = 9.81(m/s^2)$; The average speed of the electric vehicle is considered as $60km/h$; rolling friction coefficient $C_r = 0.01$; road angle (rad) $\theta = 0°$; window area of the vehicle $A = 7.15m^2$; Usage cost $\alpha = \$16.1/h$; charging cost $\beta = \$0.11/kwh$. The decision maker wants to minimize the logistic cost associated with energy consumption cost, usage cost, and service time in swapping stations and minimize the duration of transportation through the given route (i=1,2,3,4,5,6, 7; j=1,2,3,4,5,6,7). Supply and demand are measured in tons. Distance in kilometers and travel in hours are considered. Distance, time, number of swapping stations Supply and demand are assumed as triangular Fermatean fuzzy numbers and they are mentioned in Tables 1, 2, 3 and 4. The decision maker wants to find the number of items transported from i^{th} point to j^{th} point to satisfy the total requirement.

Table 1. Distance betweeni^{th}point and j^{th}point

$\tilde{d}_{12}^F$	$\langle(775,781,790);(765,781,799)\rangle$	$R(\tilde{d}_{12}^F) = 781.4$
$\tilde{d}_{13}^F$	$\langle(1000,1010,1020);(990,1010,1030)\rangle$	$R(\tilde{d}_{13}^F) = 1010$
$\tilde{d}_{14}^F$	$\langle(1315,1328,1338);(1305,1328,1347)\rangle$	$R(\tilde{d}_{14}^F) = 1327.4$
$\tilde{d}_{15}^F$	$\langle(914,923,927);(919,923,932)\rangle$	$R(\tilde{d}_{15}^F) = 923$
$\tilde{d}_{16}^F$	$\langle(1060,1065,1070);(1055,1065,1075)\rangle$	$R(\tilde{d}_{16}^F) = 1065$
$\tilde{d}_{17}^F$	$\langle(940,945,950);(930,945,955)\rangle$	$R(\tilde{d}_{17}^F) = 944.6$
$\tilde{d}_{17}^F$	$\langle(940,945,950);(930,945,955)\rangle$	$R(\tilde{d}_{17}^F) = 944.6$
$\tilde{d}_{21}^F$	$\langle(775,781,790);(765,781,790)\rangle$	$R(\tilde{d}_{21}^F) = 781.4$
$\tilde{d}_{23}^F$	$\langle(1785,1789,1795);(1775,1789,1800)\rangle$	$R(\tilde{d}_{23}^F) = 1788.9$
$\tilde{d}_{24}^F$	$\langle(560,569,578);(551,569,587)\rangle$	$R(\tilde{d}_{24}^F) = 569$
$\tilde{d}_{25}^F$	$\langle(720,725,730);(715,725,735)\rangle$	$R(\tilde{d}_{25}^F) = 725$
$\tilde{d}_{26}^F$	$\langle(1840,1845,1850);(1835,1845,1855)\rangle$	$R(\tilde{d}_{26}^F) = 1845$
$\tilde{d}_{27}^F$	$\langle(1718,1724,1730);(1712,1724,1736)\rangle$	$R(\tilde{d}_{27}^F) = 1724$
$\tilde{d}_{31}^F$	$\langle(1000,1010,1020);(990,1010,1030)\rangle$	$R(\tilde{d}_{31}^F) = 1006.6$
$\tilde{d}_{32}^F$	$\langle(1785,1789,1795);(1775,1789,1800)\rangle$	$R(\tilde{d}_{32}^F) = 1788.9$
$\tilde{d}_{34}^F$	$\langle(2330,2338,2346);(2322,2338,2354)\rangle$	$R(\tilde{d}_{34}^F) = 2338$
$\tilde{d}_{35}^F$	$\langle(1930,1934,1938);(1926,1934,1942)\rangle$	$R(\tilde{d}_{35}^F) = 1934$
$\tilde{d}_{36}^F$	$\langle(694,702,710);(686,702,718)\rangle$	$R(\tilde{d}_{36}^F) = 702$
$\tilde{d}_{37}^F$	$\langle(574,582,590);(566,582,598)\rangle$	$R(\tilde{d}_{37}^F) = 582$
$\tilde{d}_{41}^F$	$\langle(1315,1328,1338);(1305,1328,1347)\rangle$	$R(\tilde{d}_{41}^F) = 1327.4$

Continued on next page

Table 1 continued

$\tilde{d}^F_{42}$	$\langle(560,569,578);(551,569,587)\rangle$	$R(\tilde{d}^F_{42})=569$
$\tilde{d}^F_{43}$	$\langle(2330,2338,2346);(2322,2338,2354)\rangle$	$R(\tilde{d}^F_{43})=2338$
$\tilde{d}^F_{45}$	$\langle(1130,1137,1144);(1123,1137,1151)\rangle$	$R(\tilde{d}^F_{45})=1137$
$\tilde{d}^F_{46}$	$\langle(2380,2383,2386);(2377,2383,2389)\rangle$	$R(\tilde{d}^F_{46})=2383$
$\tilde{d}^F_{47}$	$\langle(2270,2272,2274);(2268,2272,2376)\rangle$	$R(\tilde{d}^F_{46})=2272$
$\tilde{d}^F_{51}$	$\langle(914,923,927);(919,923,932)\rangle$	$R(\tilde{d}^F_{51})=923$
$\tilde{d}^F_{52}$	$\langle(720,725,730);(715,725,735)\rangle$	$R(\tilde{d}^F_{52})=725$
$\tilde{d}^F_{53}$	$\langle(1930,1934,1938);(1926,1934,1942)\rangle$	$R(\tilde{d}^F_{53})=1934$
$\tilde{d}^F_{54}$	$\langle(1130,1137,1144);(1123,1137,1151)\rangle$	$R(\tilde{d}^F_{54})=1137$
$\tilde{d}^F_{56}$	$\langle(1980,1985,1990);(1975,1985,1995)\rangle$	$R(\tilde{d}^F_{56})=1985$
$\tilde{d}^F_{57}$	$\langle(940,945,950);(930,945,955)\rangle$	$R(\tilde{d}^F_{57})=944.5$
$\tilde{d}^F_{61}$	$\langle(1060,1065,1070);(1055,1065,1075)\rangle$	$R(\tilde{d}^F_{61})=1065$
$\tilde{d}^F_{62}$	$\langle(1840,1845,1850);(1835,1845,1855)\rangle$	$R(\tilde{d}^F_{62})=1845$
$\tilde{d}^F_{63}$	$\langle(694,702,710);(686,702,718)\rangle$	$R(\tilde{d}^F_{63})=702$
$\tilde{d}^F_{64}$	$\langle(2380,2383,2386);(2377,2383,2389)\rangle$	$R(\tilde{d}^F_{64})=2383$
$\tilde{d}^F_{65}$	$\langle(1980,1985,1990);(1975,1985,1995)\rangle$	$R(\tilde{d}^F_{65})=1985$
$\tilde{d}^F_{67}$	$\langle(110,113,116);(107,113,119)\rangle$	$R(\tilde{d}^F_{67})=113$
$\tilde{d}^F_{71}$	$\langle(110,113,116);(107,113,119)\rangle$	$R(\tilde{d}^F_{71})=944.6$
$\tilde{d}^F_{72}$	$\langle(1718,1724,1730);(1712,1724,1736)\rangle$	$R(\tilde{d}^F_{72})=1724$
$\tilde{d}^F_{73}$	$\langle(574,582,590);(566,582,598)\rangle$	$R(\tilde{d}^F_{73})=582$
$\tilde{d}^F_{74}$	$\langle(2270,2272,2274);(2268,2272,2376)\rangle$	$R(\tilde{d}^F_{74})=2272$
$\tilde{d}^F_{75}$	$\langle(2270,2272,2274);(2268,2272,2376)\rangle$	$R(\tilde{d}^F_{75})=944.5$
$\tilde{d}^F_{76}$	$\langle(110,113,116);(107,113,119)\rangle$	$R(\tilde{d}^F_{76})=113$

Table 2. Transportation time between i^{th} point and j^{th} point

$\tilde{t}^F_{12}$	$\langle(11,13,14);(10,13,16)\rangle$	$R(\tilde{t}^F_{12})=12.9$
$\tilde{t}^F_{13}$	$\langle(15,17,19);(13,17,21)\rangle$	$R(\tilde{t}^F_{13})=17$
$\tilde{t}^F_{14}$	$\langle(15,17,19);(13,17,21)\rangle$	$R(\tilde{t}^F_{14})=22.2$
$\tilde{t}^F_{15}$	$\langle(14,15,16);(13,15,17)\rangle$	$R(\tilde{t}^F_{15})=15$
$\tilde{t}^F_{16}$	$\langle(17,18,19);(16,18,20)\rangle$	$R(\tilde{t}^F_{16})=18$
$\tilde{t}^F_{17}$	$\langle(15,16,18);(14,16,19)\rangle$	$R(\tilde{t}^F_{17})=16.2$
$\tilde{t}^F_{21}$	$\langle(11,13,14);(10,13,16)\rangle$	$R(\tilde{t}^F_{21})=13$
$\tilde{t}^F_{23}$	$\langle(28,30,31);(27,30,31)\rangle$	$R(\tilde{t}^F_{23})=30$
$\tilde{t}^F_{24}$	$\langle(9,10,11);(8,10,13)\rangle$	$R(\tilde{t}^F_{24})=10$
$\tilde{t}^F_{25}$	$\langle(10,12,13);(9,12,14)\rangle$	$R(\tilde{t}^F_{25})=11.8$
$\tilde{t}^F_{26}$	$\langle(30,31,32);(28,31,33)\rangle$	$R(\tilde{t}^F_{26})=30.9$
$\tilde{t}^F_{27}$	$\langle(28,29,30);(26,29,31)\rangle$	$R(\tilde{t}^F_{27})=28.9$
$\tilde{t}^F_{31}$	$\langle(15,17,19);(13,17,21)\rangle$	$R(\tilde{t}^F_{31})=17$
$\tilde{t}^F_{32}$	$\langle(28,30,31);(27,30,33)\rangle$	$R(\tilde{t}^F_{32})=29.9$
$\tilde{t}^F_{34}$	$\langle(37,39,40);(36,39,41)\rangle$	$R(\tilde{t}^F_{34})=38.83$
$\tilde{t}^F_{35}$	$\langle(29,32,33);(28,32,34)\rangle$	$R(\tilde{t}^F_{35})=31.7$
$\tilde{t}^F_{36}$	$\langle(11,12,13);(10,12,14)\rangle$	$R(\tilde{t}^F_{36})=12$
$\tilde{t}^F_{37}$	$\langle(8,10,11);(7,10,13)\rangle$	$R(\tilde{t}^F_{37})=9.9$
$\tilde{t}^F_{41}$	$\langle(21,22,24);(20,22,25)\rangle$	$R(\tilde{t}^F_{41})=22.2$
$\tilde{t}^F_{42}$	$\langle(9,10,11);(8,10,13)\rangle$	$R(\tilde{t}^F_{42})=10.1$
$\tilde{t}^F_{43}$	$\langle(37,39,40);(36,39,41)\rangle$	$R(\tilde{t}^F_{43})=38.8$
$\tilde{t}^F_{45}$	$\langle(18,19,20);(17,19,21)\rangle$	$R(\tilde{t}^F_{45})=19$
$\tilde{t}^F_{46}$	$\langle(39,40,41);(38,40,42)\rangle$	$R(\tilde{t}^F_{46})=40$
$\tilde{t}^F_{47}$	$\langle(37,38,39);(36,38,40)\rangle$	$R(\tilde{t}^F_{47})=38$
$\tilde{t}^F_{51}$	$\langle(14,15,16);(13,15,17)\rangle$	$R(\tilde{t}^F_{51})=15$
$\tilde{t}^F_{52}$	$\langle(10,12,13);(9,12,14)\rangle$	$R(\tilde{t}^F_{52})=12$

Continued on next page

Table 2 continued

$\tilde{t}^F_{53}$	$\langle(29,32,33);(28,32,34)\rangle$	$R(\tilde{t}^F_{53}) = 31.7$
$\tilde{t}^F_{54}$	$\langle(18,19,20);(17,19,21)\rangle$	$R(\tilde{t}^F_{54}) = 19$
$\tilde{t}^F_{56}$	$\langle(32,33,34);(31,33,35)\rangle$	$R(\tilde{t}^F_{56}) = 33$
$\tilde{t}^F_{57}$	$\langle(30,31,33);(29,31,34)\rangle$	$R(\tilde{t}^F_{57}) = 31.2$
$\tilde{t}^F_{61}$	$\langle(17,18,19);(16,18,20)\rangle$	$R(\tilde{t}^F_{61}) = 18$
$\tilde{t}^F_{62}$	$\langle(30,31,32);(28,31,33)\rangle$	$R(\tilde{t}^F_{62}) = 30.9$
$\tilde{t}^F_{63}$	$\langle(11,12,13);(10,12,14)\rangle$	$R(\tilde{t}^F_{63}) = 12$
$\tilde{t}^F_{64}$	$\langle(39,40,41);(38,40,42)\rangle$	$R(\tilde{t}^F_{64}) = 40$
$\tilde{t}^F_{65}$	$\langle(32,33,34);(31,33,35)\rangle$	$R(\tilde{t}^F_{65}) = 33$
$\tilde{t}^F_{67}$	$\langle(1,2,3);(1,2,4)\rangle$	$R(\tilde{t}^F_{67}) = 2.08$
$\tilde{t}^F_{71}$	$\langle(15,16,18);(14,16,19)\rangle$	$R(\tilde{t}^F_{71}) = 16.2$
$\tilde{t}^F_{72}$	$\langle(28,29,30);(26,29,31)\rangle$	$R(\tilde{t}^F_{72}) = 28.9$
$\tilde{t}^F_{73}$	$\langle(8,10,11);(7,10,13)\rangle$	$R(\tilde{t}^F_{73}) = 9.9$
$\tilde{t}^F_{74}$	$\langle(37,38,39);(36,38,40)\rangle$	$R(\tilde{t}^F_{74}) = 38$
$\tilde{t}^F_{75}$	$\langle(30,31,33);(29,31,34)\rangle$	$R(\tilde{t}^F_{75}) = 31.2$
$\tilde{t}^F_{76}$	$\langle(1,2,3);(1,2,4)\rangle$	$R(\tilde{t}^F_{76}) = 2.08$

Table 3. Number of swapping stations between i^{th} point and j^{th} point

$\widetilde{N}^F_{12}$	$\langle(15,16,17);(14,16,18)\rangle$	$R(\widetilde{N}^F_{12}) = 16$
$\widetilde{N}^F_{13}$	$\langle(19,20,21);(18,20,22)\rangle$	$R(\widetilde{N}^F_{13}) = 20$
$\widetilde{N}^F_{14}$	$\langle(26,27,28);(25,27,29)\rangle$	$R(\widetilde{N}^F_{14}) = 27$
$\widetilde{N}^F_{15}$	$\langle(18,19,20);(17,19,21)\rangle$	$R(\widetilde{N}^F_{15}) = 19$
$\widetilde{N}^F_{16}$	$\langle(20,21,22);(19,21,23)\rangle$	$R(\widetilde{N}^F_{16}) = 21$
$\widetilde{N}^F_{17}$	$\langle(18,19,20);(17,19,21)\rangle$	$R(\widetilde{N}^F_{17}) = 19$
$\widetilde{N}^F_{21}$	$\langle(15,16,17);(14,16,18)\rangle$	$R(\widetilde{N}^F_{21}) = 16$
$\widetilde{N}^F_{23}$	$\langle(35,36,37);(34,36,38)\rangle$	$R(\widetilde{N}^F_{23}) = 36$
$\widetilde{N}^F_{24}$	$\langle(11,12,13);(10,12,14)\rangle$	$R(\widetilde{N}^F_{42}) = 12$
$\widetilde{N}^F_{25}$	$\langle(14,15,16);(13,15,17)\rangle$	$R(\widetilde{N}^F_{25}) = 15$
$\widetilde{N}^F_{26}$	$\langle(36,37,38);(35,37,39)\rangle$	$R(\widetilde{N}^F_{26}) = 37$
$\widetilde{N}^F_{27}$	$\langle(34,35,36);(33,35,37)\rangle$	$R(\widetilde{N}^F_{27}) = 35$
$\widetilde{N}^F_{31}$	$\langle(19,20,21);(18,20,22)\rangle$	$R(\widetilde{N}^F_{31}) = 20$
$\widetilde{N}^F_{32}$	$\langle(35,36,37);(34,36,38)\rangle$	$R(\widetilde{N}^F_{32}) = 36$
$\widetilde{N}^F_{34}$	$\langle(46,47,48);(45,47,49)\rangle$	$R(\widetilde{N}^F_{34}) = 47$
$\widetilde{N}^F_{35}$	$\langle(38,39,40);(37,39,41)\rangle$	$R(\widetilde{N}^F_{35}) = 39$
$\widetilde{N}^F_{36}$	$\langle(13,14,15);(12,14,16)\rangle$	$R(\widetilde{N}^F_{36}) = 14$
$\widetilde{N}^F_{37}$	$\langle(11,12,13);(10,12,14)\rangle$	$R(\widetilde{N}^F_{37}) = 12$
$\widetilde{N}^F_{41}$	$\langle(26,27,28);(25,27,29)\rangle$	$R(\widetilde{N}^F_{41}) = 27$
$\widetilde{N}^F_{42}$	$\langle(11,12,13);(10,12,14)\rangle$	$R(\widetilde{N}^F_{42}) = 12$
$\widetilde{N}^F_{43}$	$\langle(46,47,48);(45,47,49)\rangle$	$R(\widetilde{N}^F_{43}) = 47$
$\widetilde{N}^F_{45}$	$\langle(22,23,24);(21,22,24)\rangle$	$R(\widetilde{N}^F_{45}) = 22$
$\widetilde{N}^F_{46}$	$\langle(47,48,49);(46,28,50)\rangle$	$R(\widetilde{N}^F_{46}) = 48$
$\widetilde{N}^F_{47}$	$\langle(45,46,47);(44,46,48)\rangle$	$R(\widetilde{N}^F_{47}) = 46$
$\widetilde{N}^F_{51}$	$\langle(45,46,47);(44,46,48)\rangle$	$R(\widetilde{N}^F_{51}) = 19$
$\widetilde{N}^F_{52}$	$\langle(14,15,16);(13,15,17)\rangle$	$R(\widetilde{N}^F_{52}) = 15$
$\widetilde{N}^F_{53}$	$\langle(38,39,40);(37,39,41)\rangle$	$R(\widetilde{N}^F_{53}) = 39$
$\widetilde{N}^F_{54}$	$\langle(22,23,24);(21,22,24)\rangle$	$R(\widetilde{N}^F_{54}) = 22$
$\widetilde{N}^F_{56}$	$\langle(39,40,41);(38,40,42)\rangle$	$R(\widetilde{N}^F_{56}) = 40$
$\widetilde{N}^F_{57}$	$\langle(37,38,39);(36,38,40)\rangle$	$R(\widetilde{N}^F_{57}) = 38$
$\widetilde{N}^F_{61}$	$\langle(20,21,22);(19,21,23)\rangle$	$R(\widetilde{N}^F_{61}) = 21$
$\widetilde{N}^F_{62}$	$\langle(36,37,38);(35,37,39)\rangle$	$R(\widetilde{N}^F_{62}) = 37$
$\widetilde{N}^F_{63}$	$\langle(13,14,15);(12,14,16)\rangle$	$R(\widetilde{N}^F_{63}) = 14$

Continued on next page

Table 3 continued

$\widetilde{N}_{64}^{F}$	$\langle(47,48,49);(46,28,50)\rangle$	$R(\widetilde{N}_{64}^{F})=48$
$\widetilde{N}_{64}^{F}$	$\langle(47,48,49);(46,28,50)\rangle$	$R(\widetilde{N}_{64}^{F})=48$
$\widetilde{N}_{65}^{F}$	$\langle(39,40,41);(38,40,42)\rangle$	$R(\widetilde{N}_{65}^{F})=40$
$\widetilde{N}_{67}^{F}$	$\langle(2,3,4);(1,3,5)\rangle$	$R(\widetilde{N}_{67}^{F})=3$
$\widetilde{N}_{71}^{F}$	$\langle(18,19,20);(17,19,21)\rangle$	$R(\widetilde{N}_{71}^{F})=19$
$\widetilde{N}_{72}^{F}$	$\langle(34,35,36);(33,35,37)\rangle$	$R(\widetilde{N}_{72}^{F})=35$
$\widetilde{N}_{73}^{F}$	$\langle(11,12,13);(10,12,14)\rangle$	$R(\widetilde{N}_{73}^{F})=12$
$\widetilde{N}_{74}^{F}$	$\langle(45,46,47);(44,46,48)\rangle$	$R(\widetilde{N}_{74}^{F})=46$
$\widetilde{N}_{75}^{F}$	$\langle(37,38,39);(36,38,40)\rangle$	$R(\widetilde{N}_{75}^{F})=38$
$\widetilde{N}_{76}^{F}$	$\langle(2,3,4);(1,3,5)\rangle$	$R(\widetilde{N}_{76}^{F})=3$

Table 4. Supply and Demand

$\tilde{a}_1^F$	$\langle(7,8,9);(6,8,10)\rangle$	$R(\tilde{a}_1^F)=8$
$\tilde{a}_2^F$	$\langle(10,11,12);(9,11,13)\rangle$	$R(\tilde{a}_2^F)=11$
$\tilde{a}_3^F$	$\langle(17,18,19);(16,18,20)\rangle$	$R(\tilde{a}_3^F)=18$
$\tilde{b}_1^F$	$\langle(4,5,6);(3,5,7)\rangle$	$R(\tilde{b}_1^F)=5$
$\tilde{b}_2^F$	$\langle(8,9,10);(7,9,10)\rangle$	$R(\tilde{b}_2^F)=9$
$\tilde{b}_3^F$	$\langle(11,12,13);(10,12,13)\rangle$	$R(\tilde{b}_3^F)=12$
$\tilde{b}_4^F$	$\langle(7,8,9);(6,8,10)\rangle$	$R(\tilde{b}_4^F)=8$

3.2 Optimal solution and comparative study

By using two methods prescribed in 2.3.1 & 2.3.2, the obtained optimum solutions of deterministic multi-objective electric vehicle transshipment problem (MOEVTrP) with battery swapping technology using Lingo Global Solver (20.0) are presented in Table 5. Consequently, the comparison between multi-objective electric vehicle transshipment and transportation problems with battery swapping as well as charging technology is detailed in Table 6.

Table 5. Optimum solutions for multi-objective electric vehicle transshipment problem obtained from two methods

Model	Neutrosophic fuzzy programming	Linear weighted sum method
Multi-objective electric vehicle Transhipment problem with battery swapping technology	$x_{15}=2$,$x_{17}=2$,$x_{24}=4$,$x_{25}=6$,$x_{37}=17$,$x_{76}=12$,$R(\widetilde{Z}_1^F)=\$1683.76$,$R(\widetilde{Z}_2^F)=69.4h$	$x_{15}=2$,$x_{17}=2$,$x_{24}=4$,$x_{25}=6$,$x_{37}=17$,$x_{76}=12$,$R(\widetilde{Z}_1^F)=$ \$1624.4, $R(\widetilde{Z}_2^F)=67.9h$

Table 6. Comparison of multi-objective electric vehicle transshipment and transportation problems with battery swapping as well as charging technology

Model		Neutrosophic fuzzy programming	Linear weighted sum method
Multi-objective electric vehicle transhipment problem	Swapping technology	$x_{15}=2$,$x_{17}=2$,$x_{24}=4$,$x_{25}=6$,$x_{37}=17$,$x_{76}=12$,$R(\widetilde{Z}_1^F)=\$1683.76$,$R(\widetilde{Z}_2^F)=69.4h$	$x_{15}=2$,$x_{17}=2$,$x_{24}=4$,$x_{25}=6$,$x_{37}=17$,$x_{76}=12$,$R(\widetilde{Z}_1^F)=$ \$1624.4, $R(\widetilde{Z}_2^F)=67.9h$
	Charging technology	$x_{15}=2$,$x_{17}=2$,$x_{24}=4$,$x_{25}=6$,$x_{37}=17$,$x_{76}=12$,$R(\widetilde{Z}_1^F)=\$1819.6$,$R(\widetilde{Z}_2^F)=76.8h$	$x_{15}=2$,$x_{17}=2$,$x_{25}=6$,$x_{37}=17$,$x_{76}=12$,$R(\widetilde{Z}_1^F)=$ \$1751.99,$R(\widetilde{Z}_2^F)=75.5h$
Multi objective electric vehicle transportation problem	Swapping technology	$x_{11}=2$,$x_{14}=2$,$x_{21}=4$,$x_{22}=6$,$x_{33}=12$,$x_{34}=1$,$R(\widetilde{Z}_1^F)=$ \$2112.47,$R(\widetilde{Z}_2^F)=81.1h$	$x_{11}=4$,$x_{14}=2$,$x_{21}=8$,$x_{33}=12$,$x_{34}=5$,$R(\widetilde{Z}_1^F)=$ \$1852.9,$R(\widetilde{Z}_2^F)=77.7h$
	Charging technology	$x_{11}=2$,$x_{14}=2$,$x_{21}=4$,$x_{22}=6$,$x_{33}=12$,$x_{34}=1$,$R(\widetilde{Z}_1^F)=$ \$2472,$R(\widetilde{Z}_2^F)=90.1h$	$x_{11}=4$,$x_{14}=2$,$x_{22}=8$,$x_{22}=6$,$x_{33}=12$,$x_{34}=5$, $R(\widetilde{Z}_1^F)=$ \$1997.09,$R(\widetilde{Z}_2^F)=86.4h$

4 Conclusion

Long charging time is one of the significant disadvantages of traditional charging methods in electric vehicles as it affects the total transportation cost and delivery time, during the distribution process. Introducing battery swapping in the electric vehicle transshipment problem will help mitigate these impacts effectively. Due to uncertainty in the real-world scenario, the proposed model has been formulated under a Fermatean fuzzy environment. Pareto optimum solutions have been obtained for neutrosophic programming and the linear weighted sum method using the Lingo Software package. The results conclude that the linear weighted sum method gave a better solution than the neutrosophic programming method. The case study has been discussed for both multi-objective electric vehicle transshipment and transportation problems with both swapping as well as charging technology. From the obtained solutions, there is a significant difference in the value of the objective functions between swapping and charging technology. Obtained solutions for multi multi-objective electric vehicle transshipment problem (MOEVTrP) with battery swapping shows a reduction of 7.8% in cost and 11.19% in the charging technology. Consequently, obtained solutions also show that the multi-objective electric vehicle transshipment problem (MOEVTrP) shows that 14.4% reduction in time and a 14% reduction in cost than the multi-objective transportation problem. The proposed model may be extended by integrating essential environmental factors and social factors to enhance sustainability in the future direction.

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