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A 4-dimensional multi goal transportation framework in the decomposed fuzzy configuration

M. K. Sharma*, Kailash Dhanuk and Sadhna Chaudhary

ABSTRACT: Decomposed Fuzzy Sets (DFS), a recent advancement of Intuitionistic Fuzzy Sets, extend the traditional framework by integrating functional and dysfunctional viewpoints into the formulation of membership and non-membership functions. To rank and defuzzify DFS, this article first presents a score index. A four-dimensional, multi-goal transportation framework with DFS configuration is then developed to handle uncertainty embedded in real world transportation systems. The proposed framework seeks to minimize travel time and total transportation costs. In order to deal with the proposed 4-dimensional transportation network, fuzzy programming and devised score index is employed. A numerical computation accomplished to elaborate the efficiency of devised model in the real-world transportation systems.

Key Words: Decomposed fuzzy set, score index, 4-dimensional transportation system, multi-objective transportation problem.

Contents

1. Introduction

There is uncertainty and ambiguity associated with imprecise human judgments and information in real life. Zadeh (1965) put forth the theory of fuzzy sets, as a solution to the ambiguity and uncertainty in information. In realm decision-making issues, fuzzy set, that only represent membership degrees, is not able to completely portray uncertainty; as a result, scholars have put forth a number of expansions to fuzzy set theory. Atanassov (1986) delved intuitionistic fuzzy sets an extended version of fuzzy set, which are represented through varying levels of associative and non-associative. and are capable of handling uncertain information more flexibly.

Thereafter, researchers have Expanded to encompass a range of uncertainty theories, including Neutrosophic sets (Samarandache, 2006), complex fuzzy sets (Ramot et al., 2002), fuzzy multi sets (Miyamoto, 2005), fuzzy soft sets (Maji et al. 2001), Hesitant fuzzy set (Tora, 2010) and Pythagorean fuzzy sets (Yager, 2013), Fermatean fuzzy set (Senapati and Yager, 2020), Dual hesitant fermatean fuzzy set (Zhou et al., 2023), time sequential complex fermatean hesitant fuzzy set (Sharma et al. 2024), time-sequential

* Corresponding author.
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probabilistic fermatean hesitant fuzzy set (Chaudhary et al. 2024) for managing complex scenarios characterized by uncertainty. The decomposed fuzzy set (DFS) is recently developed by Cebi et al. (2022) that explores associative and non-associative degree from a functional and dysfunctional standpoint.

Derived from classical and solid transport problems a 4-D transportation problem (4-DTP) is a commercial framework for logistics. It offers a realistic picture of modern transport networks as it includes known available sources, goals, modes of transit, and routes.

Research has utilized a 4-D transportation framework, incorporating novel concepts, to study real-world transportation systems, with pioneering work in this area. A 4-D TP for the supply of breakable goods was modelled by Bera et al. (2020) by utilizing hybrid random type-2 parameters. For the ingratiating management of the supply chain, Samantha et al. (2020) proposed a 4-DTP that aspires to optimize multiple goals in a single framework. In a neutrophilic scenario, Giri et al. (2022) presented two approaches to address an environmentally conscious 4-D, fixed-charge TP with several desired results.

Akhtar et al. (2023) devised a 4-DTP to offer breakable items with fixed expenses in a type-2 imprecise scenario. Under intuitionistic fuzzy settings, Bind et al. (2023) delved a sustainable 4-DTP that aims to optimize goals. The goal of their research is to reduce product breakage, shipping time, and carbon footprints in order to maximize profits. Devnath et al. (2023) proposed a two- stage 4D-TP for the shipment of various goods along with integration of fuzzy risk. To distribute humanitarian assistance aftermath the Biparjoy cyclone, Sharma et al. (2023) formulated a green transportation framework under complex fermatean hesitant fuzzy settings. The framework aims to optimize the transportation time and costs, as well as job creation and pollution reduction. Here is an overview of the research carried out in this article:

- A score index for the defuzzification and ranking of DFS is proposed.
- A 4-dimensional multi-objective transportation problem with DFS settings is developed to formulate
- The proposed 4-dimensional transportation system aims to optimize total transportation cost (TC) and total travel time (TT).
- A methodology encompassing of score index and fuzzy programming to address the suggested transportation network is also devised.
- Numerical computation is also carried out in order to illustrate the applicability of proposed score function and formulated transportation network.

This manuscript is organized as follows: In Section 1, fundamentals and literature reviews of 4-D transportation framework and DFS are presented. In Section 2, fundamental properties of DFS are presented. The proposed score index for the DFS is discussed in section 3. A 4-D transportation system with multiple goal under DFS settings is developed in section 4. Section 5 is all about the proposed methodology to get the optimality of devised capacitated transportation network. On the basis of the detailed methodology recommended, Section 6 provides a numerical example. A discussion of the research article's main findings and future prospects is presented in Section 7.

2. Prerequisite

In this section, we provide fundamental details regarding DFS for the acquittance of proposed work.

2.1. Decomposed fuzzy set

A DFS is stated as follows:

$$\wp = \left\{ z, \mathfrak{F}\left(\alpha^{\mathfrak{F}}(z), \beta^{\mathfrak{F}}(z)\right), \mathfrak{D}\left(\alpha^{\mathfrak{D}}(z), \beta^{\mathfrak{D}}(z)\right) : z \in Z \right\}$$

Where $\mathfrak{F}$ and $\mathfrak{D}$ are functioning and dysfunctional perspectives respectively. Also, $\alpha^{\mathfrak{F}}(z)$ and $\beta^{\mathfrak{F}}(z)$ are membership and non-membership degrees of z in the context of functioning perspective $\mathfrak{F}$. Moreover,

$\alpha^{\mathfrak{D}}(z)$, $\beta^{\mathfrak{D}}(z)$ are membership and non-membership degrees of z in the context of dysfunctional perspective $\mathfrak{D}$. Subject to:

$$0 \leq \alpha^{\mathfrak{F}}(z) + \beta^{\mathfrak{F}}(z) \leq 1,$$

$$0 \leq \alpha^{\mathfrak{D}}(z) + \beta^{\mathfrak{D}}(z) \leq 1,$$

$$0 \leq \alpha^{\mathfrak{F}}(z) + \beta^{\mathfrak{F}}(z) + \alpha^{\mathfrak{D}}(z) + \beta^{\mathfrak{D}}(z) \leq 2.$$

For convenience,

$$\wp = \left\{ \mathfrak{F}\left(\alpha^{\mathfrak{F}}, \beta^{\mathfrak{F}}\right), \mathfrak{D}\left(\alpha^{\mathfrak{D}}, \beta^{\mathfrak{D}}\right) \right\}$$

is known as decomposed fuzzy element (DFE).

2.2. Fundamental Operations

A DFS is stated as follows: Let $\wp_1 = \left\{ \mathfrak{F}\left(\alpha_1^{\mathfrak{F}}, \beta_1^{\mathfrak{F}}\right), \mathfrak{D}\left(\alpha_1^{\mathfrak{D}}, \beta_1^{\mathfrak{D}}\right) \right\}$ and $\wp_2 = \left\{ \mathfrak{F}\left(\alpha_2^{\mathfrak{F}}, \beta_2^{\mathfrak{F}}\right), \mathfrak{D}\left(\alpha_2^{\mathfrak{D}}, \beta_2^{\mathfrak{D}}\right) \right\}$ be two DFEs, the basic operations are stated as follows:

i) Addition

$$\wp_1 \oplus \wp_2 = \left\{ \mathfrak{F}\left(\frac{\alpha_1^{\mathfrak{F}} + \alpha_2^{\mathfrak{F}} - 2\alpha_1^{\mathfrak{F}}\alpha_2^{\mathfrak{F}}}{1 - \alpha_1^{\mathfrak{F}}\alpha_2^{\mathfrak{F}}}, \frac{\beta_1^{\mathfrak{F}}\beta_2^{\mathfrak{F}}}{\beta_1^{\mathfrak{F}} + \beta_2^{\mathfrak{F}} - \beta_1^{\mathfrak{F}}\beta_2^{\mathfrak{F}}} \right), \mathfrak{D}\left(\alpha_1^{\mathfrak{D}} + \alpha_2^{\mathfrak{D}} - \alpha_1^{\mathfrak{D}}\alpha_2^{\mathfrak{D}}, \beta_1^{\mathfrak{D}}\beta_2^{\mathfrak{D}} \right) \right\}$$

ii) Multiplication

$$\wp_1 \otimes \wp_2 = \left\{ \mathfrak{F}\left(\alpha_1^{\mathfrak{F}}\alpha_2^{\mathfrak{F}}, \beta_1^{\mathfrak{F}} + \beta_2^{\mathfrak{F}} - \beta_1^{\mathfrak{F}}\beta_2^{\mathfrak{F}} \right), \mathfrak{D}\left(\frac{\alpha_1^{\mathfrak{D}}\alpha_2^{\mathfrak{D}}}{\alpha_1^{\mathfrak{D}} + \alpha_2^{\mathfrak{D}} - \alpha_1^{\mathfrak{D}}\alpha_2^{\mathfrak{D}}}, \frac{\beta_1^{\mathfrak{D}} + \beta_2^{\mathfrak{D}} - 2\beta_1^{\mathfrak{D}}\beta_2^{\mathfrak{D}}}{1 - \beta_1^{\mathfrak{D}}\beta_2^{\mathfrak{D}}} \right) \right\}$$

iii) Scalar Multiplication

$$\lambda\wp_1 = \left\{ \mathfrak{F}\left(\frac{\lambda\alpha_1^{\mathfrak{F}}}{(\lambda - 1)\alpha_1^{\mathfrak{F}} + 1}, \frac{\lambda\beta_1^{\mathfrak{F}}}{(\lambda - 1)\beta_1^{\mathfrak{F}} + 1} \right), \mathfrak{D}\left(1 - (1 - \alpha_1^{\mathfrak{D}})^{\lambda}, (\beta_1^{\mathfrak{D}})^{\lambda} \right) \right\}$$

iv) Exponent

$$\wp_1^{\lambda} = \left\{ \mathfrak{F}\left(1 - (1 - \alpha_1^{\mathfrak{F}})^{\lambda}, (\beta_1^{\mathfrak{F}})^{\lambda} \right), \mathfrak{D}\left(\frac{\lambda\alpha_1^{\mathfrak{D}}}{(\lambda - 1)\alpha_1^{\mathfrak{D}} + 1}, \frac{\lambda\beta_1^{\mathfrak{D}}}{(\lambda - 1)\beta_1^{\mathfrak{D}} + 1} \right) \right\}$$

3. Novel Score Index

In this section, we propose a score index for the DFE. The propose score index allows to rank various DFEs and also enhance the applicability of the DFS in the field of optimization. For a DFE $\wp = \left\{ \mathfrak{F}(\alpha^{\mathfrak{F}}, \beta^{\mathfrak{F}}), \mathfrak{D}(\alpha^{\mathfrak{D}}, \beta^{\mathfrak{D}}) \right\}$, the score index is mathematically stated as follows:

$$s_{\wp} = \begin{cases} x + \dfrac{\alpha^{\mathfrak{F}} + \beta^{\mathfrak{F}} - \alpha^{\mathfrak{D}} + \beta^{\mathfrak{D}}}{2}, & s_{\wp} > 0 \\ 0, & s_{\wp} \leq 0 \end{cases}$$

Example: Let $\wp = \{100, \mathfrak{F}(0.85, 0.15), \mathfrak{D}(0.15, 0.85)\}$ be a DFE, then by utilizing the above proposed score index we have:

$$s_{\wp} = 100 + \frac{0.85 + 0.15 - 0.15 + 0.85}{2} = 100.85$$

Table 1: Symbols and Descriptions

Symbol	Description	Type
o	Origins	Integer
d	Destinations	Integer
t	Mode of transportation	Integer
$\tilde{A}_o^{\wp}$	Availability of oth source	DFE
$\tilde{B}_d^{\wp}$	Demand of dth destination	DFE
$\tilde{E}_t^{\wp}$	Capacity of tth conveyance	DFE
L_{odt}	Distance of oth origin to dth destination via tth mode of transportation	Real
x_{odt}	Amount carried by tth transport from oth origin to dth destination	Real
c_{odt}	Total transportation cost per unit in the transportation of goods from oth origin to dth destination via tth mode of transportation	Integer
f_{odt}	Total transportation cost per unit in the transportation of goods from oth origin to dth destination via tth mode of transportation	Integer
n	Number of goals	Integer
Z_n	Objective function $(n = 1, 2)$	Real

4. Proposed 4-Dimensional Transportation System

This section aims to formulate a 4-dimensional transportation system with two objectives under the DFE parameters. Here, our aim is to optimize total transportation cost along with the travel time. Supply, need, and efficiency of the transport method. are taken in the form of DFE.

Model 1

Minimization of TC

$$\min \quad Z_1 = \sum_{o=1}^{O}\sum_{d=1}^{D}\sum_{t=1}^{T}(c_{odt}x_{odt})$$

Minimization of TT

$$\min \quad Z_2 = \sum_{o=1}^{O}\sum_{d=1}^{D}\sum_{t=1}^{T}(f_{odt}x_{odt})$$

subject to

$$\sum_{d=1}^{D}\sum_{t=1}^{T} x_{odt} \leq \tilde{A}_o^{\wp}, \qquad o = 1, \ldots, O$$

$$\sum_{o=1}^{O}\sum_{t=1}^{T} x_{odt} \geq \tilde{B}_d^{\wp}, \qquad d = 1, \ldots, D$$

$$\sum_{o=1}^{O}\sum_{d=1}^{D} x_{odt} \leq \tilde{E}_t^{\wp}, \qquad t = 1, \ldots, T$$

$$x_{odt} \geq 0, \qquad \forall o, d, t$$

The feasible condition for proposed capacitated transportation system in model 1 are as follows:

$$\sum_{o=1}^{O}\tilde{A}_o^{\wp} \geq \sum_{d=1}^{D}\tilde{B}_d^{\wp}; \quad \sum_{t=1}^{T}\tilde{E}_t^{\wp} \geq \sum_{d=1}^{D}\tilde{B}_d^{\wp};$$

The proposed 4-dimensional transportation system in model 1 is formulated under DFE configuration. It is a laborious task to handle model 1 in its current form. Thus, we have to utilize the proposed score index to obtain the Pareto-efficient solution of the devised capacitated transportation network.

Model 2

Minimization of TC

$$\min \quad Z_1 = \sum_{o=1}^{O}\sum_{d=1}^{D}\sum_{t=1}^{T}(c_{odt}x_{odt})$$

Minimization of TT

$$\min \quad Z_2 = \sum_{o=1}^{O}\sum_{d=1}^{D}\sum_{t=1}^{T}(f_{odt}x_{odt})$$

subject to

$$\begin{aligned} &\sum_{d=1}^{D}\sum_{t=1}^{T}x_{odt} \leq s_{\wp}(\tilde{A}_o^{\wp}), && o = 1,\ldots,O \\ &\sum_{o=1}^{O}\sum_{t=1}^{T}x_{odt} \geq s_{\wp}(\tilde{B}_d^{\wp}), && d = 1,\ldots,D \\ &\sum_{o=1}^{O}\sum_{d=1}^{D}x_{odt} \leq s_{\wp}(\tilde{E}_t^{\wp}), && t = 1,\ldots,T \\ &x_{odt} \geq 0, && \forall o,d,t \end{aligned}$$

The feasible conditions for model 2 are:

$$\sum_{o=1}^{O}s_{\wp}(\tilde{A}_o^{\wp}) \geq \sum_{d=1}^{D}s_{\wp}(\tilde{B}_d^{\wp}); \quad \sum_{t=1}^{T}s_{\wp}(\tilde{E}_t^{\wp}) \geq \sum_{d=1}^{D}s_{\wp}(\tilde{B}_d^{\wp});$$

5. Solution Procedure

In this section, using fuzzy programming (Zimmerman, 1978) and our proposed score index, we established a methodology for dealing proposed transportation system with DFE parameters. Following is a systematic listing of the steps of proposed approach and Figure 1 portrays them.

Step 1: Analyze each objective separately, considering all the constraints of the deterministic version of the proposed model.

Step 2: Find the l_n lower bounds and upper bounds u_n for every goal. Build the membership function $\chi_n(Z_n(X))$ corresponding to every $Z_n(X)$.

$$\chi_n(Z_n(X)) = \begin{cases} 1 & Z_n \leq L_n \\ \dfrac{U_n - Z_n(X)}{U_n - L_n} & L_n \leq Z_n \leq U_n \\ 0 & Z_n \geq U_n \end{cases}$$

$l_n = \min\{Z_n(X)\}$ and $u_n = \max\{Z_n(X)\}$ for $n = 1, 2$.

Step 3: Develop Model 3

$$\begin{aligned} &\text{Max} && \alpha \\ &\text{s.t} && \chi_n(Z_n(X)) \geq \alpha \quad (n = 1, 2) \\ & && \alpha \in [0, 1], \\ &\text{s.t.} && \text{the constraints of model 2} \end{aligned}$$

Step 4: Integrate the Lingo 20.0 software to get the solution.

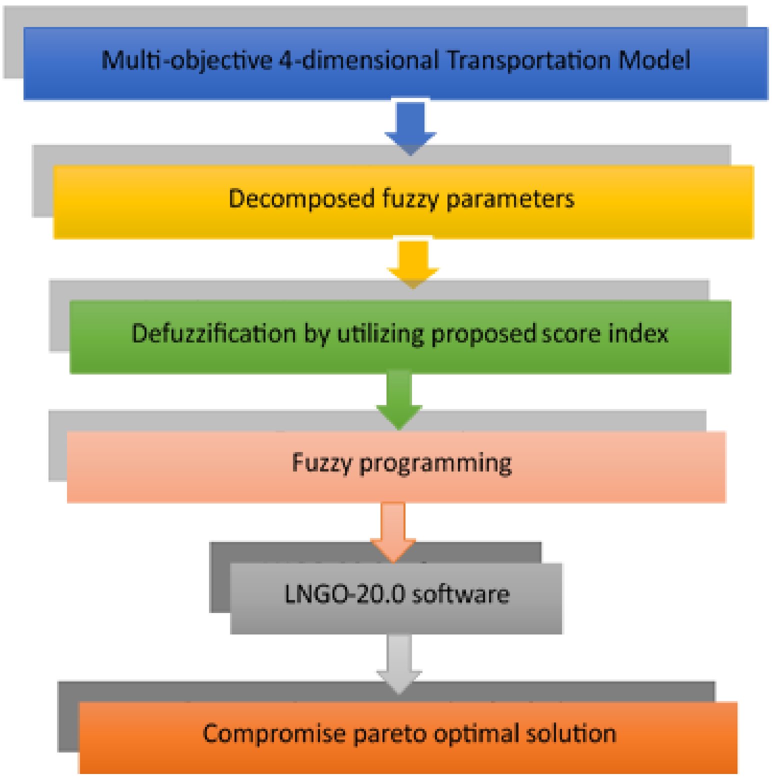

Figure 1: Pictorial depiction of proposed approach to tackle 4-D multi objective transportation problem under DFS settings

6. Numerical Computation

The motive of this section is to illustrate the importance of the devised transportation system with multiple objectives. Let O_1 and O_2 be two sources of the goods that are to be transported to targets D_1 and D_2 via mode of transport T_1 and T_2. The supply, requirements, and capability of the vehicles, for the numerical example are depicted in Table 2. Moreover, total TC, TT, and distance between origin and destinations are presented in Table 3.

Table 2: DFE availability, demand, and capacity of conveyances

Parameters	**DFE**	**Score Index**
$\tilde{A}_1^{\wp}$	$\{400, \mathfrak{F}(0.85, 0.15), \mathfrak{D}(0.15, 0.85)\}$	400.85
$\tilde{A}_2^{\wp}$	$\{300, \mathfrak{F}(0.75, 0.25), \mathfrak{D}(0.25, 0.75)\}$	300.85
$\tilde{B}_1^{\wp}$	$\{200, \mathfrak{F}(0.65, 0.35), \mathfrak{D}(0.35, 0.65)\}$	200.85
$\tilde{B}_2^{\wp}$	$\{200, \mathfrak{F}(0.75, 0.25), \mathfrak{D}(0.25, 0.75)\}$	200.85
$\tilde{E}_1^{\wp}$	$\{300, \mathfrak{F}(0.85, 0.15), \mathfrak{D}(0.15, 0.85)\}$	300.85
$\tilde{E}_2^{\wp}$	$\{300, \mathfrak{F}(0.60, 0.40), \mathfrak{D}(0.40, 0.60)\}$	300.85

Table 3: Crisp inputs for proposed transportation framework

Parameter	Value
c_{111}	2
c_{112}	5
c_{121}	3
c_{122}	4
c_{211}	6
c_{212}	8
c_{221}	2
c_{222}	6
f_{111}	2
f_{112}	1
f_{121}	1
f_{122}	2
f_{211}	2
f_{212}	2
f_{221}	3
f_{222}	1
L_{111}	10
L_{112}	10
L_{121}	10
L_{122}	10
L_{211}	10
L_{212}	10
L_{221}	10
L_{222}	10

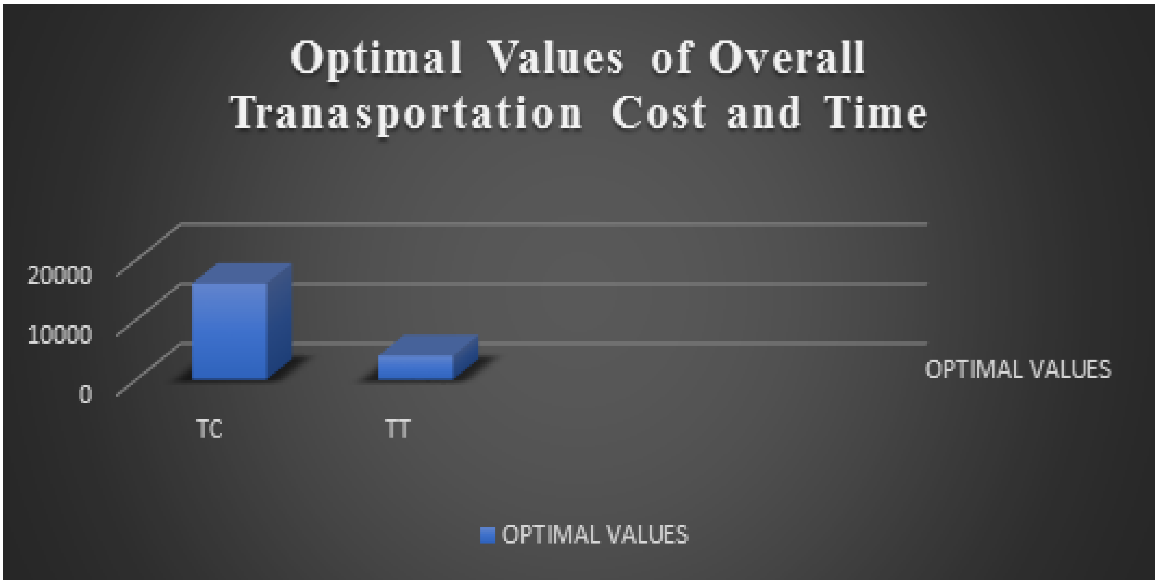

Figure 2: Optimal values of transportation cost and transportation time

$$
\begin{aligned}
\min Z_1 = {} & 20x_{111} + 50x_{112} + 30x_{121} + 40x_{122} + 60x_{211} + 80x_{212} + 20x_{221} + 60x_{222} \\
\min Z_2 = {} & 20x_{111} + 10x_{112} + 10x_{121} + 20x_{122} + 20x_{211} + 20x_{212} + 30x_{221} + 10x_{222} \\
& x_{111} + x_{112} + x_{121} + x_{122} \leq 400.85 \\
& x_{211} + x_{212} + x_{221} + x_{222} \leq 300.85 \\
& x_{111} + x_{112} + x_{211} + x_{212} \geq 200.85 \\
& x_{121} + x_{122} + x_{221} + x_{222} \geq 200.85 \\
& x_{111} + x_{121} + x_{211} + x_{221} \leq 300.85 \\
& x_{112} + x_{122} + x_{212} + x_{222} \leq 300.85
\end{aligned}
$$

Table 4: Optimal solution of proposed 4-dimensional transportation problem

Objective	**Solution**
Overall TC	$Z_1 = 16093.5$, $x_{112} = 200.85$, $x_{121} = 200$, $x_{221} = 0.85$
Overall TT	$Z_2 = 4017$, $x_{112} = 200.85$, $x_{121} = 200$, $x_{222} = 0.85$

7. Conclusion

Newly delved in the area of fuzzy sets, DFSs consider the membership and non-membership degree of the elements in a set from a functional perspective as well as from a dysfunctional one. We have introduced a score index for the ranking and defuzzification of DFS. The proposed score index will enhance the applicability of DFS in real world optimization problems. The DFS configuration is then used to formulate a multi-objective 4-dimensional transportation system. The transport network seeks to maximize both TC and TT during the transit of goods. We have applied fuzzy programming and devised score index to solve the proposed 4-dimensional transportation problem. Furthermore, an analysis of the model's efficacy in a real-world transportation system is carried out numerically. The proposed score function can be utilized in several decision-making issues such as multi criteria decision making problem and multi attribute decision making issues.

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M. K. Sharma,

Department of Mathematics,

Chaudhary Charan Singh University, Meerut-250004,

India.

E-mail address: `drmukeshsharma@gmail.com` *and*

Kailash Dhanuk,
Department of Mathematics,
Chaudhary Charan Singh University, Meerut-250004,
India.
E-mail address: kailash.dhanuk@dsc.du.ac.in

and

Sadhana Chaudhary,
Department of Mathematics,
Chaudhary Charan Singh University, Meerut-250004,
India.
E-mail address: sadhnachaudhary2109@gmail.com