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Fixed Charge Solid Transportation Problem Based on Carbon Emission with Budget Constraints in Uncertain Environment (UFSTPCEBC)

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ABSTRACT

The major factor affecting the limits of air pollution and climate change is the release of CO_2 gas and other greenhouse gases as a result of several transportation systems. Moving forward, reducing carbon emissions should be our fundamental mission for a pollution-free environment. Once more, a single objective transportation system is rarely appropriate in cases that include multiple criteria. Therefore, for developing real-world transportation problems, multiple objectives are considered. There are some reservations or suspicions due to time constraints, data limitations, lack of information, or measurement flaws in real-world issues. Based on this fact, the decision-maker takes into account the designed problems' indeterminacy. Uncertainty theory has become a crucial tool for simulating real-world decision-making issues to handle this uncertainty. By creating an uncertain multi objective fixed charge solid transportation problem with carbon emission and budget constraints at each destination, this paper proposes a profit maximization, deterioration and time minimization technique that takes the possibility of indeterminacy into account. Here, goods are acquired at various source locations for varying rates, and they are subsequently carried to various destinations utilizing a variety of vehicles. The items are sold to the customers at different selling prices. The suggested model assumes that the following variables are uncertain: unit transportation costs, fixed charges, transportation times, supply at origins, demands at destinations, conveyance capacities, rate of carbon emission, rate of deterioration, and budget at destinations. We created an expect-chance constraint model utilizing uncertain programming approaches to simulate the suggested model. The uncertainty theory framework is used to develop this model. Goal programming is used to formulate and solve the equivalent deterministic transformations of these models. Finally, a numerical example that demonstrates the model is provided.

1. INTRODUCTION

The goal of the classical transportation problem (TP) is to identify the best solution (transportation plan) that will result in the lowest possible transportation expense. Hitchcock's [1] seminal article originated the term "transportation problem" by modeling it as a typical optimization problem with supply and demand dimensions. However, in real-world circumstances, we frequently need to take into account the type of transportation (for example, goods trains, cargo aircraft, and trucks), in addition to supply and demand limitations. In such cases, a TP is converted into a solid transportation problem (STP), in which in addition to availability and demand constraints, another constraint relating to the conveyance is taken into account. The classic TP was initially applied to the solid transportation problem (STP) by Schell [2]. Later, Bhatia et al. [3] minimized the shipping time of an STP. After that, Jiménez and Verdegay [4] dealt with an STP in their study and found a solution by considering the quantities of supply & demand, and conveyance capacity as interval values rather than point values.

Hirsch and Dantzig [5] developed the fixed charge transportation problem, a different variation of the TP (FTP). Finding the best transportation strategy to reduce overall costs between sources and destinations is the goal of FTP. The variable cost of shipping and a separate set fee makes up the total cost. While the set fee, which frequently arises as a result of the expenditure connected to permit fees, property tax or toll costs, etc., is associated with every practical transportation plan, the shipping cost is directly based on the quantity of the transported item(s) from sources to destinations. Different solution approaches for FTP have been put out by various scholars [6-8].

The majority of real-world decision-making issues are typically phrased as multi-objective optimization issues because they may be effectively described with numerous competing criteria. Furthermore, due to incompleteness, a lack of data, statistical analysis, or other factors, the corresponding parameters for such situations may be imprecise. Therefore, many researchers have presented a variety of theories to process and represent ill-defined or imprecise data for decision-making problems, such as the fuzzy set [9], type-2 fuzzy set [10, 11], and rough set [12]. The uncertainty theory (UT) put forward by Liu [13] deals with human belief levels and may effectively assess individual expert belief levels in terms of uncertain measures. Numerous publications on the topic have been published in the literature.

Numerous TP-related experiments with uncertain input parameters may be found in the literature. Considering the transportation expenses as a new solution method for TP, Kaur and Kumar [14] solved using the Trapezoidal-shaped fuzzy numbers in general. By utilizing Zimmermann's [15] fuzzy programming technique, Bit et al. [16] addressed the multi-objective STP in the multi-objective domain. Later, a bi-objective STP with fuzzy parameters was proposed by Gen et al. [17]. A transportation mode selection problem was recently solved by Kundu et al. [18] using an interval type-2 fuzzy multi criteria group decision-making (MCGDM) technique. Kundu et al. [19] discussed a multi-objective STP by applying budget limits at destinations using fuzzy random hybrid parameters while taking into account the budget restriction of a TP. Later, by representing transportation cost, availability and demand, and conveyance capacity as interval numbers, Baidya and Bera [20] presented a budget constraint STP. A fuzzy multi-criteria decision-making (MCDM) strategy was also examined by Kundu et al. [21] in order to identify the most desired mode of transportation and resolve a STP.

The green STP was recently resolved by Das et al. [22] in a type 2 fuzzy environment. Liu et al. [23] posed an FTP in a fuzzy environment and solved it using a genetic algorithm while taking fixed charge in an ambiguous area into consideration. The FTP was then explored by Pramanik et al. [24] who took into account the shipping cost, fixed fee, availability, and demand in a two-stage supply chain under type-2 Gaussian fuzzy transportation network.

Most of the time, the transportation industry moves goods and people via bus, rail, truck, vehicle, ship, airplane, etc. The transportation system is primarily responsible for the release of CO_2 gas and other greenhouse gases since internal combustion engines emit these gases. Light-duty vehicles like passenger cars, mini-busses, and other vehicles emit around half of the greenhouse gases and the remainder is released by heavy-duty vehicles like trucks, ships, and freight transporters, among others.

There is a substantial risk of environmental and air pollution from greenhouse gas emissions. The amount of carbon dioxide released varies on the fuel used, the engine type, the road's condition, the driving guidelines, etc. Numerous scientists investigated carbon emissions in diverse situations. Here, we present various research papers on the issue of carbon emissions in transportation. The possibility of reducing carbon emissions in China's transportation sector was examined by Ding et al. [25]. Sengupta et al. [26] used a Gamma type-2 defuzzification strategy to solve an STP with carbon emission. For a single-period problem, Song and Leng [27] evaluated carbon emission policies. Smart transportation CO_2 emission reduction solutions were the focus of Tarulescu et al.'s [28] investigation. A multi-stage, multi-objective FSTP in a green supply chain was presented by Midya et al. [29] in 2021.

Various TP variations have been researched in the literature within the context of UT [13, 30-37]. We have provided some recent reviews of several TP variations operating in various uncertain situations in Table 1. Despite all the advancements in TP, the following gaps in the literature should be noted.

The mechanism for reducing carbon emissions is more crucial to the transportation system. Minimizing the cost of carbon emissions directly increases the system's profit because it lowers the cost of all transportation and, indirectly, the rate of air pollution. A transportation system's carbon emission system is more crucial. A reduction in carbon emission fees directly increases the system's profit since it lowers indirect air pollution rates and contributes to a reduction in overall transportation expenses.

To the best of our knowledge, no one has taken into account the carbon system while simultaneously maximizing profit, limiting time, minimizing breakability, and using a fixed charge STP model with a budget constraint. The mechanism for reducing carbon emissions is more crucial to the transportation system. A reduction in carbon emission fees directly increases the system's profit since it lowers indirect air pollution rates and contributes to a reduction in overall transportation expenses. Budgetary restrictions and carbon capacity are used to optimize profit and reduce degradation. The application of Liu's UT to the multi objective solid transportation problem formulation utilizing dependent chance-constrained programming is unstudied. CCM for any fixed charge STP with a budget constraint and a carbon emission target utilizing typical uncertain variables within the context of UT [13] has not been implemented yet.

Table 1. Existing models with proposed model

Author(s)	Environment	objectives	Various types of TP					
			TP	**STP**	**FTP**	**Items**	**Budget constraint**	**Carbon emission**
Sheng and Yao [30]	UT	s	✓	×	✓	s	×	×
Sheng and Yao [31]	UT	s	✓	×	×	s	×	×
Mou et al. [33]	UT	m	✓	×	×	s	×	×
Kundu et al. [19]	RAN, F, RAN F	m	✓	✓	×	s	✓	×
Kundu et al. [38]	F	m	✓	✓	×	m	×	×
Kundu et al. [21]	T2F	s	✓	×	✓	s	×	×
Giri et al. [39]	F	s	✓	✓	✓	m	×	×
Sinha et al. [40]	IT2F	m	✓	✓	×	s	×	×
Das et al. [22]	RI	s	✓	✓	×	s	×	×
Dalman [41]	UT	m	✓	✓	×	m	×	×
Gao and Kar [42]	UT	s	✓	✓	×	s	×	×
Kundu et al. [18]	UT	s	✓	✓	×	s	×	×
Liu et al. [43]	R	s	✓	✓	✓	m	×	×
Majumder et al. [44]	UT	m	✓	✓	✓	m	✓	×
Proposed model	UT	m	✓	✓	✓	m	✓	✓

In the current study, we have taken into account uncertain multi objective fixed charge STP with budget constraint UFSTPCEBC at destinations, within the framework of UT [13], to solve the aforementioned gaps. The model with expect-chance constraints ECCM is used to formulate the problem. Consequently, the fuzzy goal programming method is used to solve the model.

The remainder of this study is divided into the following sections. In Section 2, the foundational ideas underlying our research are presented. Section 3 contains the notations which are sued in the proposed work. The proposed UFSTPCEBC uncertain programming model, or ECCM, is provided in Section 4. In Section 5, the crisp equivalent is developed for the proposed model. Sect.6 explains the goal programming technique. Section 7 explains the compromise multi-objective solution methodology. We provide a numerical example to demonstrate the model in section 8, and the findings are analyzed. Finally, Section 9 presents our study's epilogue.

2. PRELIMINARIES

This section contains some concepts on uncertainty theory that have been used in the research work.

Definition 2.1 [13]:

Let $\mathcal{L}$ be a σ- algebra of collection of events Λ of a universal set Γ. A set function M is said to be an uncertain measure [UM]defined on the σ- algebra where M{Λ} indicates the belief degree with which we believe that the event will happen and satisfies the following four axioms:

1. For the universal set Γ. we have:

$$\mathrm{M}\{\Gamma\} = 1 \tag{1}$$

2. For any event Λ, we have:

$$\mathrm{M}\{\Lambda\} + \mathrm{M}\{\Lambda^c\} = 1 \tag{2}$$

3. For every countable sequence of events Λ_1, Λ_2,... we have:

$$\mathrm{M}\left\{\cup_{j=1}^{\infty} \Lambda\right\} \leq \sum_{j=1}^{\infty} \mathrm{M}\left\{\Lambda_j\right\} \tag{3}$$

4. Let $(\Gamma_j, \mathcal{L}_j, \mathrm{M}_j)$ be uncertainty spaces for. The product UM measure is a UM holds:

$$\mathrm{M}\left\{\prod_{j=1}^{\infty} \Lambda_j\right\} = \wedge_{j=1}^{\infty} \mathrm{M}\left\{\Lambda_j\right\} \tag{4}$$

where, $\Lambda_j \in \mathcal{L}_j$ fo $j = 1,2, \dots, \infty$r.

Definition 2.2 [13]:

A function $\xi: (\Gamma, \mathcal{L}, \mathrm{M}) \to$R is known as an uncertain variable [UV] such that:

$$\{\xi \in B\} = \{\gamma \in \Gamma / \xi(\gamma) \in B\} \tag{5}$$

is an event for any Borel set B of real numbers.

Definition 2.3 [13]:

The uncertainty distribution [UD] $\rho(y)$ of a UV ξ for any real number y is defined by:

$$\rho(y) = \mathrm{M}\{\xi \leq y\} \tag{6}$$

Definition 2.4:

An uncertainty distribution [UD] $\rho(y)$ is said to be regular uncertainty distribution [RUD] if it is a strictly increasing and continuous function with respect to y at which $0<\rho(y)<1$ and:

$$\lim_{y \to -\infty} \varphi(y) = 0 \tag{7}$$

$$\lim_{y \to \infty} \varphi(y) = 1 \tag{8}$$

Definition 2.5:

Let $\rho(y)$ be the RUD of an uncertain variable ξ. Then $\rho^{-1}(y)$ is called an inverse uncertainty distribution [IUD] of ξ and it exists on (0, 1).

Definition 2.6 [13]:

The UV ξ_t $(t = 1,2, \dots, T)$ are said to be independent if:

$$\mathrm{M}\{\cap_{t=1}^{T} (\xi_t \in B_t)\} = \wedge_{t=1}^{T} \mathrm{M}(\xi_t \in B_t) \tag{9}$$

where, B_t (t=1,2,..,T) are the Borel sets with real numbers.

Theorem 2.7 [13]:

The RUD of independent UV ξ_t $(t = 1,2, \dots, T)$are ρ_t $(t = 1,2, \dots, T)$ respectively. If the function $h(y_1, y_2, \dots, y_t)$ is strictly increasing and strictly decreasing with respect to $y_1, y_2, \dots, y_s$ and $y_{s+1}, y_{s+2}, \dots, y_t$ respectively then the uncertain variable $\xi = h(\xi_1, \xi_2, \dots, \xi_s, \dots, \xi_t)$ has an IUD:

$$\rho^{-1}(\gamma) = h(\rho_1^{-1}(\gamma), \rho_2^{-1}(\gamma), \dots, \rho_s^{-1}(\gamma), f(\rho_{s+1}^{-1}(1 - \gamma), \rho_{s+2}^{-1}(1 - \gamma), \dots, \rho_t^{-1}(1 - \gamma)) \tag{10}$$

Definition 2.8 [13]:

The expected value of UV ξ is given by:

$$E(\xi) = \int_0^{\infty} \mathrm{M}\{\xi \geq y\}\, dy - \int_{-\infty}^{0} \mathrm{M}\{\xi \leq y\}\, dy \tag{11}$$

This is valid only if at least one of the integrals is finite.

Theorem 2.9 [38]:

Let $\rho_t(t = 1,2, \dots, T)$ be RUD of independent ξ_t $(t = 1,2, \dots, T)$ with respectively. If the function $h(y_1, y_2, \dots, y_t)$ is strictly increasing and strictly decreasing w.r.to $y_1, y, \dots, y_s$ and $y_{s+1}, y_{s+2}, \dots, y_t$ respectively, then:

$$E(\xi) = \int_0^1 h(\rho_1^{-1}(\gamma), \dots, \rho_s^{-1}(\gamma), \rho_{s+1}^{-1}(1 - \gamma), \dots, \rho_t^{-1}(1 - \gamma)) d\gamma \tag{12}$$

From this theorem, we have,

$$E(\xi) = \int_0^1 \rho^{-1}(\gamma) d\gamma \tag{13}$$

here ξ is a UV with RUD ρ.

Definition 2.10 [13]:

The distribution function of a normal uncertain variable [NUV] is:

$$\rho(x) = \left[1 + exp^{\left[\frac{\pi(\mu - x)}{\sigma\sqrt{3}}\right]}\right]^{-1}, \ x \geq 0 \tag{14}$$

and represented by $N(\mu, \sigma)$; $\mu, \ \sigma \in R \ with \ \sigma > 0$. The IUD and the expected value of N(μ,σ) are given as follows:

$$\rho^{-1}(\gamma) = \mu + \frac{\sigma\sqrt{3}}{\pi} ln \frac{\gamma}{1-\gamma} \quad (15)$$

$$E[\xi] = \mu \quad (16)$$

3. NOMENCLATURE

The following notations have been used for formulating the proposed model:

m	origins indexed
n	destinations indexed
v	indexed by the type of transport
$\tilde{Z}_i$	uncertain objective functions, where i=1,2,3.
$\tilde{P}_m$	the product's purchasing price per unit at m[th] origin
$\widetilde{S_n}$	the product's selling price per unit at n[th] destination
$\tilde{c}_{mnv}$	the unit transportation cost of the product from m[th] origin to n[th] destination by v[th] conveyance per unit distance
$\tilde{d}_{mnv}$	deterioration rate for unit quantity of the product from m[th] origin to n[th] destination with v[th] conveyance
x_{mnv}	number of units that to be transported from m[th] origin to n[th] destination by v[th] transport
$\tilde{E}_v$	fixed carbon capacity
$\tilde{\gamma}_{mnv}$	average of carbon emission per unit
$\tilde{t}_{mnv}$	transportation time of the product from m[th] origin to n[th] destination by v[th] transport
$\tilde{a}_m$	quantity of the good available at m[th] origin
$\tilde{b}_n$	the requirement of the good at n[th] destination
$\tilde{e}_v$	the capacity of a single-vehicle of v[th] transport
$\tilde{f}_{mnv}$	the fixed charge, which must be paid when the transportation activity happens from m[th] origin to n[th] destination by v[th] transport
$\widetilde{Bud_n}$	total budget at the n[th] destination
$\tilde{\alpha}$	carbon tax per unit of its carbon emission
Y_{mnv}	binary indicator takes the value 0 and 1 if $x_{(mnv)}\neq 0$ "and" $x_{(mnv)}=0$ respectively
N_i^-	negative deviational value
P_i^+	positive deviational value

4. MATHEMATICAL MODEL

The general model for UFSTPCEBC is presented below in (17).

Definition 4.1:

A feasible solution $Y^* = \{Y^*_{mnv}\} \in S$ is an efficient (no dominated) solution for UFSTPCEBC if there does not exist another $Y = \{y_{mdwvg}\} \in S$ such that $Z_i(Y) \le Z_i(Y^*), 1 \le i \le I$ and $Z_i(Y) \neq Z_i(Y^*)$ for some l, $1 \le i \le I$.

$$\begin{cases} \text{Max } \tilde{Z}_1 = \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}(\widetilde{S_n} - \tilde{c}_{mnv} - \tilde{\alpha}\ \tilde{\gamma}_{mnv} - \tilde{P}_m)x_{mnv} - \tilde{f}_{mnv}Y(x_{mnv}) \\ \text{Min } \tilde{Z}_2 = \sum_{m=1}^{M}\sum_{n}^{N}\sum_{v=1}^{V}\tilde{d}_{mnv}\ x_{mnv} \\ Min\ \tilde{Z}_3 = \sum_{m=1}^{M}\sum_{n}^{N}\sum_{v=1}^{V}\tilde{t}_{mnv}\ Y(x_{mnv}) \\ \text{Subject to} \\ \sum_{n=1}^{N}\sum_{v=1}^{V}x_{mnv} \le \tilde{a}_m, \quad m = 1 \text{ to } M \\ \sum_{m=1}^{M}\sum_{v=1}^{V}x_{mnv} \le \tilde{b}_n, \quad \text{n = 1 to N} \\ \sum_{m=1}^{M}\sum_{n=1}^{N}x_{mnv} \le \tilde{e}_v, \quad v = 1 \text{ to } V \\ \sum_{m=1}^{M}\sum_{v=1}^{V}(\tilde{c}_{mnv} + \tilde{\alpha}\ \tilde{\gamma}_{mnv} + \tilde{P}_m)x_{mnv} \le \tilde{B}_n, \text{n = 1 to N} \\ \sum_{m=1}^{M}\sum_{n=1}^{N}\tilde{\gamma}_{mnv}x_{mnv} \le \tilde{E}_v\ , v = 1 \text{ to } V, \\ x_{mnv} \ge 0, \forall\ m,n,v \\ Y(x_{mnv}) = \begin{cases} 1 & \text{if } x_{mnv} > 0 \\ 0 & \text{otherwise} \end{cases} \end{cases} \quad (17)$$

5. EQUIVALENT DETERMINISTIC MODEL FOR UFSTPCEBC

This section presents a comparable deterministic model for UFSTPCEBC.

Suppose that $\tilde{E}_v, \tilde{P}_m, \tilde{C}_{mnv}, \tilde{\gamma}_{mnv}, \tilde{a}_m, \tilde{b}_n, \tilde{e}_v, \tilde{B}_n, \tilde{\alpha}$ are uncertain variables with RUD $\beta_v, \mu_m, \theta_{mnv}, \eta_{mnv},, \psi_m, \varphi_n, \chi_v, \omega_n \& \tilde{\sigma}$ respectively. Using the expected–chance constraint method for NUVs and their properties, the Equivalent deterministic model of UFSTPCEBC is given in Eq. (18).

$$\begin{gathered} \text{Max } Z_1 = E(\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}(\widetilde{S_n} - \tilde{c}_{mnv} - \tilde{\alpha}\ \tilde{\gamma}_{mnv} - \tilde{P}_m)x_{mnv} - \tilde{f}_{mnv}Y(x_{mnv})) \\ \text{Min } \tilde{Z}_2 = E\left(\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}\tilde{d}_{mnv}\ x_{mnv}\right) \\ \text{Min } \tilde{Z}_3 = E\left(\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}\tilde{t}_{mnv}\ Y(x_{mnv})\right) \\ Subject\ to \\ \sum_{n=1}^{N}\sum_{v=1}^{V}x_{mnv} \le \psi_m^{-1}(1-\delta_m), m = 1 \text{ to } M \\ \sum_{m=1}^{M}\sum_{v=1}^{V}x_{mnv} \ge \varphi_n^{-1}(\sigma_n), n = 1 \text{ to } N \\ \sum_{m=1}^{M}\sum_{n=1}^{N}x_{mnv} \le \chi_v^{-1}(1-\tau_v), v = 1 \text{ to } V \\ \sum_{m=1}^{M}\sum_{v=1}^{V}(\theta_{mnv}^{-1}(\alpha_1) + \sigma^{-1}(\alpha_2)\ \eta_{mnv}^{-1}(\alpha_3) + \mu_m^{-1}((\alpha_4))x_{mnv} \le \varphi_m^{-1}(\alpha_5), m = 1 \text{ to } M \\ \sum_{m=1}^{M}\sum_{n=1}^{N}\tilde{\gamma}_{mnv}x_{mnv} \le \beta_v^{-1}(1-\varepsilon_v), v = 1\ to\ V \\ x_{mnv} \ge 0, \forall\ m,n,v \\ Y(x_{mnv}) = \begin{cases} 1 & \text{if } x_{mnv} > 0 \\ 0 & \text{otherwise} \end{cases} \end{gathered} \quad (18)$$

Here, $\delta_m, \sigma_{n,} \tau_v, \epsilon_m, \alpha_q \forall$ q=1 to 5, are predetermined chance levels which takes values from 0 to 9.

By using the expected-chance constraint method's property on uncertainty on (18), we have

$$\left\{\begin{array}{c}
\max \boldsymbol{Z_1} = \boldsymbol{E}(\sum_{m=1}^{M} \sum_{n=1}^{N} \sum_{v=1}^{V} [\![(\widetilde{\boldsymbol{S_n}}]\!] - \tilde{\boldsymbol{c}}_{\boldsymbol{mnv}} - \widetilde{\boldsymbol{\alpha}}\ \widetilde{\boldsymbol{\gamma}}_{\boldsymbol{mnv}} - \widetilde{\boldsymbol{P}}_{\boldsymbol{m}})\boldsymbol{x_{mnv}} - \tilde{\boldsymbol{f}}_{\boldsymbol{mnv}} \boldsymbol{Y}(\boldsymbol{x_{mnv}})) \\
\min \boldsymbol{Z_2} = \boldsymbol{E}\left(\sum_{m=1}^{M} \sum_{n=1}^{N} \sum_{v=1}^{V} \widetilde{\boldsymbol{d}}_{\boldsymbol{mnv}}\ \boldsymbol{x_{mnv}}\right) \\
\min \boldsymbol{Z_3} = \boldsymbol{E}\left(\sum_{m=1}^{M} \sum_{n=1}^{N} \sum_{v=1}^{V} \tilde{\boldsymbol{t}}_{\boldsymbol{mnv}}\ \boldsymbol{Y}(\boldsymbol{x_{mnv}})\right) \\
\textbf{\textit{Subject to}} \\
\sum_{n=1}^{N} \sum_{v=1}^{V} \boldsymbol{x_{mnv}} \le \boldsymbol{e_m} + \frac{\sigma_m}{\pi} * \sqrt{3} \quad \boldsymbol{log}\frac{1-\delta_m}{\delta_m}, \boldsymbol{m} = \boldsymbol{1} \text{ to } \boldsymbol{M} \\
\sum_{m=1}^{M} \sum_{v=1}^{V} \boldsymbol{x_{mnv}} \ge \boldsymbol{e_n} + \frac{\sigma_n}{\pi} * \sqrt{3} \quad \boldsymbol{log}\frac{\sigma_n}{1-\sigma_n},\ \mathbf{n} = \mathbf{1 \text{ to } N} \\
\sum_{m=1}^{M} \sum_{n=1}^{N} \boldsymbol{x_{mnv}} \le \boldsymbol{e_v} + \frac{\sigma_v}{\pi} * \sqrt{3} \quad \boldsymbol{log}\frac{1-\tau_v}{\tau_v}, \boldsymbol{v} = \boldsymbol{1} \text{ to } \boldsymbol{V} \\
\sum_{m=1}^{M} \sum_{v=1}^{V} (\boldsymbol{\theta}_{\boldsymbol{mnv}}^{-1}(\boldsymbol{\alpha_1}) + \boldsymbol{\sigma}^{-1}(\boldsymbol{\alpha_2})\ \boldsymbol{\eta}_{\boldsymbol{mnv}}^{-1}(\boldsymbol{\alpha_3}) + \boldsymbol{\mu}_{\boldsymbol{m}}^{-1}((\boldsymbol{\alpha_4}))\boldsymbol{x_{mnv}} \le \boldsymbol{e_n} + \frac{\sigma_n}{\pi} * \sqrt{3} \quad \boldsymbol{log}\frac{1-\alpha_5}{\alpha_5}, \boldsymbol{n} = \boldsymbol{1} \text{to } \boldsymbol{N} \\
\sum_{m=1}^{M} \sum_{n=1}^{N} \widetilde{\boldsymbol{\gamma}}_{\boldsymbol{mnv}} \boldsymbol{x_{mnv}} \le \boldsymbol{e_v} + \frac{\sigma_v}{\pi} * \sqrt{3} \quad \boldsymbol{log}\frac{1-\epsilon_v}{\epsilon_v}, \boldsymbol{v} = \boldsymbol{1} \text{ to } \boldsymbol{V} \\
\boldsymbol{x_{mnv}} \ge \boldsymbol{0}, \forall\ \boldsymbol{m}, \boldsymbol{n}, \boldsymbol{v} \\
\boldsymbol{Y}(\boldsymbol{x_{mnv}}) = \begin{cases} \boldsymbol{1} & \boldsymbol{if\ x_{mnv} > 0} \\ \boldsymbol{0} & \boldsymbol{otherwise} \end{cases}
\end{array}\right. \tag{19}$$

Here, $\delta_m, \sigma_{n,} \tau_v, \epsilon_m, \alpha_q, \forall$ q=1 to 5, are predetermined chance levels which takes values from 0 to 9.

6. GOAL PROGRAMMING APPROACH

The Charnes clan cooper [45] proposed the GPT to find a workable solution when there were multiple objectives. Numerous authors, including Chang [46] and others, have researched and developed the GPT further. Mohammed [47] proposed the Fuzzy GP method for solving MOTP, and Zangiabadi et al. [48, 49] used it later to solve MOTP using both linear and nonlinear membership functions. The goal of GP is to minimizing the distance between $Z = (Z_1, Z_2, Z_3, \dots \dots Z_i)$, and aspiration (or) target level $\bar{Z} = (\bar{Z}_1, \bar{Z}_2, \bar{Z}_3, \dots \dots \bar{Z}_i)$, which are set by the DM. To apply GP in this proposed model, we introduce the negative and positive deviational variables.

$$P_i^{+} = \max(0, Z_i - \bar{Z}_i)$$
$$N_i^{-} = \max(0, \bar{Z}_i - Z_i)$$

We must reduce either P_i^+, N_i^- or $P_i^+ + N_i^-$ in order to reduce the distance between Z_i and $\bar{Z}_i$. If Z_i must be maximized, then $h_i(P_i^+, N_i^-) = N_i^-$. When minimizing Z_i, however, $h_i(P_i^+, N_i^-) = P_i^+$. When we require $Z_i = \bar{Z}_i$, $h_i(P_i^+, N_i^-) = P_i^+ + N_i^-$.

In addition to the solution, the membership functions are described below in order to convey the decision-maker's satisfaction.

$$\mu_i(Z_i) = \begin{cases} 1 & if\ Z_i \le L_{Z_i} \\ 1 - \frac{Z_i - L_{Z_i}}{U_{Z_i} - L_{Z_i}} & if\ L_{Z_i} < Z_i < U_{Z_i} \\ 0 & if\ Z_i \ge U_{Z_i} \end{cases} \tag{20}$$

The DM's satisfaction is represented by $\mu_n(Z_n)$. As a result, it needs to be maximized i.e., max $\left(\mu_1(Z_1(x)), \mu_2(Z_2(x)), \mu_3(Z_3(x)), \dots \dots \dots .. \mu_i(Z_i(x))\right)$. The highest acceptable and desired levels of performance for the $\widetilde{Z}_i$, $(i = 1,2,3)$ objective function are shown here as U_{Z_i} and L_{Z_i}.

We reduce its negative deviation from 1 to bring them as close to 1 as possible in order to maximize any of the membership functions since the maximum value of the membership function cannot be more than one. The LPP can be written down as follows:

$$\min\left(\max\left(h_i(P_i^+, N_i^-)\right)\right)$$

i.e, Min Q.

Subject to:

$$\begin{array}{l} \frac{U_{Z_i} - Z_i}{U_{Z_i} - L_{Z_i}} + N_i^- - P_i^+ = 1, \\ Q \ge N_i^-, \text{where } i = 1,2,3. \\ P_i^+ . N_i^- = 0. \end{array} \tag{21}$$

$N_i^-, P_i^+ \ge 0, 0 \le Q \le 1.$ and with given constraints. Here, we have considered UFSTPCEBC type of problem; GPT will be the most suitable methodology for getting the most acceptable compromise solution.

7. ALGORITHM FOR SOLVING UFSTPCEBC UNDER BUDGET CONSTRAINTS

The following algorithm is used to solve the proposed UFSTPWCE model under budget constraint.

Step 1: Formulate uncertain FSTPWCEBC model with the given data as of (17).

Step 2: Applying the characteristics of the expected-chance constraint model as of (19), transform UFSTPWCEBC model into the deterministic model.

Step 3: Compute the deterioration objective, time objective and profit functions Z_i, (i = 1,2,3) individually with the considered constraints.

Step 4: Obtain the values of each objective function Z_i, with (i= 1,2,3) at each solution obtained in step 3.

Step 5: From the set of solutions calculated from step 3, obtained the upper U_{Z_i} and lower L_{Z_i} bounds for each objective function. Here U_{Z_i} and L_{Z_i} are the most acceptable and aspired level of achievement for Z_i, (i = 1,2,3).

Step 6: For the given UFSTPWCEBC model, use the GPT to obtain the following LPP model Min Q.

Subject to:

$$\frac{U_{Z_i} - Z_i}{U_{Z_i} - L_{Z_i}} + N_i^- - P_i^+ = 1,$$
$$Q \geq N_i^-, \text{where } i = 1,2,3. \quad (22)$$
$$P_i^+ . N_i^- = 0.$$
$$N_i^-, P_i^+ \geq 0, 0 \leq Q \leq 1$$

and with constraints given in the respective model.

Step 7: By applying the generalized reduced gradient technique [GRG] (LINGO-18.0 Suite Solver), solve the model obtained in step 6 to have the compromise solution.

8. NUMERICAL EXAMPLE

To illustrate the effectiveness and efficiency of the proposed UFSTPWCE under the budget constraints model, a numerical example is presented in this section, whose parameters are NUV. Two different customers (destinations), sources (origins) and conveyances each are considered in this model. i.e m=n=v=2.

Selling price=($\tilde{S}_n$: {$\tilde{S}_1$=(50,4); $\tilde{S}_2$=(60,4)}; Purchasing cost=($\tilde{P}_m$): {$\tilde{P}_1$=(5,1); $\tilde{P}_2$=(6,2)}; Carbon tax=($\tilde{\alpha}$): {α=(2,0.5)}; Source=($\tilde{a}_m$): {$\tilde{a}_1$=(230,5); $\tilde{a}_2$=(240,10)}; Demand=($\tilde{b}_n$): {$\tilde{b}_1$=(90,5); $\tilde{b}_2$=(220,10)}; Conveyance=($\tilde{e}_v$): {$\tilde{e}_1$=(270,5); $\tilde{e}_2$=(290,10}; Budget=($\tilde{b}_n$): {$\tilde{b}_1$=(3900,100); $\tilde{b}_2$=(3500,100)}; Carbon capacity=(E_v): {E_1=(360,40); E_2=(420,40)}.

Table 2 contains the transportation cost per unit and fixed cost of the products.

Table 2. Transportation cost per unit and fixed charge

	D_1	D_2	a_1
	v=1	v=2	
$\tilde{C}_{11v}$	(6,4)	(8,3)	(230,5)
$\tilde{C}_{12v}$	(15,2)	(4,1)	
f_{11v}	(10,8)	(9,7)	
f_{12v}	(25,2)	(7,2)	
C_{21v}	(4,2)	(10,4)	(240,10)
C_{22v}	(3,1)	(5,2)	
f_{21v}	(6,2)	(13,10)	
f_{22v}	(7,2)	(15,2)	

Table 3 contains deterioration cost per unit.

Table 3. Deterioration cost d_{mnv}

	D_1	D_2	a_1
	v=1	v=2	
d_{11v}	(4,2)	(5,2)	(230,5)
d_{12v}	(5,1)	(3,2)	
d_{21v}	(3,1)	(4,2)	(240,10)
d_{22v}	(2,1)	(2,1)	
b_n	(90,5)	2120,10)	

Table 4 contains the transportation time of the product.

Table 4. The transportation time

	D_1	D_2	a_1
	v=1	v=2	
t_{11v}	(12,3)	(15,5)	(230,5)
t_{12v}	(8,2)	(11,4)	
t_{21v}	(6,4)	(9,5)	(240,10)
t_{22v}	(10,5)	(14,6)	
b_n	(90,5)	(220,10)	

Average carbon emission is presented in Table 5.

Table 5. Average carbon emission per unit

	D_1	D_2	a_1
	v=1	v=2	
γ_{11v}	(2,4)	(3,3)	(230,5)
γ_{12v}	(3,2)	(2,1)	
γ_{21v}	(2,3)	(2,1)	(240,10)
γ_{22v}	(2,2)	(3,2)	
b_n	(90,5)	(220,10)	

The steps involved in using the aforementioned algorithm to solve the problem are as follows:

Step 1: For the above data, the deterministic problem of the considered UFSTPWCE model is obtained using the ECCM as of (19) and solved.

Step 2: Solving the considered objectives separately, we have $Z_1 = 14976.72$, $Z_2 = 897.98$ and $Z_3 = 36$.

By using these solutions, the value of each objective function is found as follows:

$$Z_1(X_1) = 14976.72, Z_1(X_2) = 13890.77 \text{ and } Z_1(X_3) = 13902.7$$
$$Z_2(X_1) = 964.93, Z_2(X_2) = 897.05 \text{ and } Z_2(X_3) = 924.9$$
$$Z_3(X_1) = 27,\ Z_3(X_2) = 34 \text{ and } Z_3(X_3) = 36$$

The boundary values of Z_1, Z_2 and $Z_3$are given as follows;

$$U_{Z_1} = 14976.72, L_{Z_1} = 13890.77$$
$$U_{Z_2} = 964.93, L_{Z_2} = 897.05$$
$$U_{Z_3} = 36, U_{Z_3} = 27$$

Step 3: The GP ECCM for the proposed model is defined as follows using the GPT.

Min Q

Subject to

$$\boldsymbol{E}\left(\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}[\![(\widetilde{S_n})]\!] - \tilde{c}_{mnv} - \tilde{\alpha}\ \tilde{\gamma}_{mnv} - \tilde{P}_m)x_{mnv} - \tilde{f}_{mnv}Y(x_{mnv})\right) + 1085.95(N_1^- — P_1^+) = 14976.72$$

$$E\left(\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}\tilde{d}_{mnv}\ x_{mnv}\right) = 897.05 + 67.88 * (N_2^- — P_2^+)$$

$$E(\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{v=1}^{V}\tilde{t}_{mnv}\ Y(x_{mnv})) = 27 - 9(N_3^- — P_3^+);$$

where, $Y(x_{mnv}) = \begin{cases} 1 & \text{if } x_{mnv} > 0 \\ 0 & \text{otherwise} \end{cases}$.

$$\sum_{n=1}^{N}\sum_{v=1}^{V}x_{mnv} \leq e_m + \frac{\sigma_m}{\pi} * \sqrt{3}\ \log\frac{1-\delta_m}{\delta_m}, m = 1 \text{ to } M$$
$$\sum_{m=1}^{M}\sum_{v=1}^{V}x_{mnv} \geq e_n + \frac{\sigma_n}{\pi} * \sqrt{3}\ \log\frac{\sigma_n}{1-\sigma_n},\ n = 1 \text{ to N}$$
$$\sum_{m=1}^{M}\sum_{n=1}^{N}x_{mnv} \leq e_v + \frac{\sigma_v}{\pi} * \sqrt{3}\ \log\frac{1-\tau_v}{\tau_v}, v = 1 \text{ to } V$$
$$\sum_{m=1}^{M}\sum_{v=1}^{V}(\theta_{mnv}^{-1}(\alpha_1) + \sigma^{-1}(\alpha_2)\,\eta_{mnv}^{-1}(\alpha_3) + \mu_m^{-1}((\alpha_4))x_{mnv} \leq e_n + \frac{\sigma_n}{\pi} * \sqrt{3}\ \log\frac{1-\alpha_5}{\alpha_5}, n = 1\text{to } N$$
$$\sum_{m=1}^{M}\sum_{n=1}^{N}\tilde{\gamma}_{mnv}x_{mnv} \leq e_v + \frac{\sigma_v}{\pi} * \sqrt{3}\ \log\frac{1-\epsilon_v}{\epsilon_v}, v = 1 \text{ to } V$$
$$x_{mnv} \geq 0, \forall\, m, n, v, Q \geq N_i^-,$$

where, *n=1,2,3.*

$$P_i^+ . N_i^- = 0.$$
$$N_i^-, P_i^+ \geq 0, 0 \leq Q \leq 1. \quad (23)$$

Step 4: With the use of the GRG technique (LINGO-18.0 Suite Solver), we obtain the efficient value of Q = 1 and the associated transportation plan is $P_1^+ = 0, N_1^- = 1, P_2^+ = 0, N_2^- = 0.27$, $P_3^+ = 0, N_3^- = 1$, Max $Z_1 = 13876.99$, Min $Z_2 = 942.45$, Min $Z_3 = 36\, x_{111} = 17.75$, $x_{122} = 95.01$, $x_{211} = 27.7$, $x_{212} = 50.5$, $x_{221} = 110.3$, $x_{222} = 26.79$, $y_{111} = y_{121} = y_{211} = y_{221} = 1$ and the other decision variables have values of 0. We can see that DM's goals have been met to a satisfactory extent.

9. RESULT ANALYSIS

In our work, we used the goal programming expect-chance constraint method to get the compromise solution of UFSTPCEBC. Utilizing goal programming approaches, the efficient solution of the proposed model UFSTPCEBC is produced and is provided in Step 4. Thus, the goal programming technique is a suitable approach for resolving transportation problems with multiple objectives. We can get different suitable solutions in the EC- constraint model, resulting in optimistic and pessimistic conclusions, depending on the condition that is given greater weight as requested by the decision maker as derived from the solutions. Even while taking into account multiple parameters, the decision-maker may still get the maximum profit with minimum time taken here.

10. CONCLUSION

In this work, Fixed charge solid transportation problem based on carbon emission with budget constraints in uncertain environment (UFSTPCEBC) has been presented. For the first time, unlike other transportation models, we have taken into consideration the cost of the fixed charge, budget constraint, and the carbon emission charge. We have obtained the equivalent deterministic model for UFSTPCEBC by using ECCM and then we applied GPT to reach a compromise solution. The suggested model is very simple to use, simple to comprehend, and profitable economically for the company since it boosts earnings, reduces air pollution, and greatly shortens delivery times. The DM can thus make better managerial decisions. The ease of application of this method's effectiveness in solution for UFSTPCEBC has been demonstrated in the numerical example.

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NOMENCLATURE

S	Single
M	Multi
F	Fuzzy
T2F	Type 2 fuzzy
IT2F	Interval type 2Fuzzy
R	Rough
RI	Rough Interval
UT	Uncertainty theory
RAN	Random
RAN F	random Fuzzy
ECCM	expected-chance constrained model
GP	Goal programming