Minimizing Carbon Emission And on-Time Delivery of Frozen Food Items Under Uncertain Environment With a Case Study

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Due to the sheer rising demand request for frozen food that requires less cooking time, the worldwide frozen food market is predicted to rise at a strong compound annual growth rate throughout the forecast time frame. Frozen food requires cold supply chain for its transportation which is a major contributor of carbon emissions. In this research work a new frozen food multi-objective transportation model is introduced that aims in minimizing carbon emissions and time taken for transportation and packaging of the frozen food item. To widen the horizon of application of model impreciseness or uncertainty in the environment of transportation is considered using triangular type-2 fuzzy variable. Fuzzy to crisp conversion is performed using the CV-based reduction technique with generalized credibility. The model is further implemented on a case study over city of Bangalore in India. Optimal solution using two different compromised programming techniques, i.e. GCM and FGP are obtained and compared. Lingo optimizer solver is used for soft computing of the model.

Keywords: Frozen food transportation model, cold supply chain, carbon emission, triangular type-2 fuzzy variable, global criterion method (GCM), fuzzy goal programming (FGP).

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1 Introduction

Frozen food distribution and holding come underneath the umbrella of cold chains of supply, in which products typically retained at a cold temperature to retain viability. Energy must be used adequately throughout storage and distribution to prevent any possible supplies from decomposing over duration, limiting value loss (for example, owing to rotting of perishable goods and providing excellent quality) [1]. Together with freshness, food's nutritional content, notably proteins in meat and vit C in certain foods, disintegrates if not properly sealed. The goal of cold chains is to retain integrity while somehow limiting value loss as the chain progresses from the farm towards the customer. The range of temperature for various form of items that avials cold chain transportation varies as seafood should be kept in the range from $-28^{o}C$ to -30^{o}, meat shoulde be held in from $-16^{o}C$ to -20^{o}, and fruits and vegetable from $2^{o}C$ to 8^{o} [2].

According to a research [2], food transport trucks are responsible for 40 % of the overall of worldwide greenhouse gas emissions, and they consume 15% of worldwide conventional fossil fuels. Alone in transportation sector almost 50% of carbon emission come from small and heavy duty trucks [3]. The cold food supply chain should increase it's attention towards sustainability [4]. Comprehensive researches are required to reconcile overall aim of power usage, which would be a framework for ensuring food standards, through managing heat, emission, and expenses throughout food preservation, shipping, and delivery [5]. A lot of research work on vehicle routing problems. As people's lifestyles have evolved, resulting in increased globalization and traffic congestion, which has been ignored for years, timing ought to be a significant problem in transportation. As a result, models featuring time-dependent transit time have indeed been established [6]. Research work showing how reduced trip lengths often correlate to longer journeys, adding additional unpredictable traffic circumstances and path flexibility, thus the goal value turns travel time minimization to be contrasted with the journey have been accomplished already [7]. The frozen supply food chain was outlined using a modeling that took under consideration food standards changes and even the environmental burden of the many circumstances studied [8]. Beyond these, there are a few additional research publications that aimed to reduce carbon emissions during transportation [9], [10], and [11]. However, because neither of those models took into account environmental variability, they had difficulty applying them to real-world circumstances. The ambiguity of the environment is studied in several factors in this study article, spanning from transit time to emission quantity. Any supply chain faces a variety of challenges, including transportation congestion, degraded road conditions, natural disasters, and inefficient human resources. As a result, modeling is more successful when examined in a fuzzy instead of a crisp setting.

The mathematical model considered in this research work is a solid transportation problem (STP) which has one added constraint than transportation problem i.e conveyance constraint. STP was given by Shell in 1955 [12]. Whereas in the year 1962 Haley [13] gave its solution. The current model employees uncertainty of level two often referred as Type-2 fuzzy set (T2FS). Before T2FS Type-1 fuzzy set came into existence which was proposed by Zadeh in 1965 [14]. Exactly ten years later Zadeh in 1975 came with T2FS to abolish uncertainty and challenges of T1FS [15]. In the research work [16], [17], and [18] it is shown how triangular and trapezoidal numbers are used to descripe uncertainty. However, in order to use the data attained in fuzzy form it must be first converted to respective crisp format. For that the relevant literature can be found in [19], [20], [21], and [22]. The input parameters considered in this paper taken as Triangular type -2 fuzzy variable (TT2FV) and the defuzzification for the same was given in the literature [21]. The frozen food supply chain model in this paper deals with minimization of carbon emission and time thus for optimal result compromised solution technique should be employed.

The rest of the paper is classified in following manner. The preliminaries of Type-2 fuzzy are given in section 2. The model formulation alongside the problem description is stated in section 3. The solution process is explained in detail in section 4 it includes defuzzification, compromised programming, and soft computing approach. The case study along with fuzzy inputs and all the set of results and managerial insights is presented in section 5. Finally conclusion and future work is mentioned in section 6.

2 Preliminary concepts of Type-2 fuzzy

2.1 Type-2 fuzzy set (T2FS)

T2FS deals with uncertainty of second order, in this the membership function lies in a range of $[0, 1]$ rather that having a fixed value [23]. Consider a T2FS $\widehat{Z}$ from universe of discourse U, y is an element of it and $0 \leq \bar{\mu}_Z(y, e)) \leq 1$. Then the membership function of this fuzzy set is itself a type-1 fuzzy set as shown below:

$$\widehat{Z} = \{((y, e), \bar{\mu}_Z(y, e)) \,:\, y \in U\}$$

2.2 Triangular type-2 fuzzy variable (TT2FV)

TT2FV is an augmentation of triangular type-1 fuzzy variable (TT1FV) [22]. The difference between the two lies in their grade of membership. In TT1FV, every point holds a fix value of the membership grade, whereas in TT2FV, the value lies in a range of [0,1].
Consider a TT2FV depicted by $\tilde{\tau} = (m_1, m_2, m_3, \varsigma_l, \varsigma_r)$, here m_1, m_2, m_3 are from real numbers and degree of uncertainty is specified by $(\varsigma_l, \varsigma_r) \in [0, 1]$. The secondary possibility distribution of the $\tilde{\tau}$ on value y is denoted by $\phi_{\tilde{\tau}}(y)$ and is defined for range $y \in [m_1, m_2]$ and for $y \in ((m_2, m_3])$ in the following equations:

$$\phi_{\tilde{\tau}}(y) = \left(\frac{y - m_1}{m_2 - m_1} - \varsigma_l min\left\{ \frac{y - m_1}{m_2 - m_1}, \frac{m_2 - y}{m_2 - m_1} \right\}, \frac{y - m_1}{m_2 - m_1}, \frac{y - m_1}{m_2 - m_1} + \varsigma_r min\left\{ \frac{y - m_1}{m_2 - m_1}, \frac{m_2 - y}{m_2 - m_1} \right\} \right)$$

$$\phi_{\tilde{\tau}}(y) = \left(\frac{m_3 - y}{m_3 - m_2} - \varsigma_l min\left\{ \frac{m_3 - y}{m_3 - m_2}, \frac{y - m_2}{m_3 - m_2} \right\}, \frac{m_3 - y}{m_3 - m_2}, \frac{m_3 - y}{m_3 - m_2} + \varsigma_r min\left\{ \frac{m_3 - y}{m_3 - m_2}, \frac{y - m_2}{m_3 - m_2} \right\} \right)$$

2.3 Defuzzification

Defuzzification of type 2 fuzzy variable (T2FV) is a two step operation in the course of which the first step includes type reduction and the second one is eventually responsible for crisp conversion. CV-based reduction [22] is one of the finest method used for conversion of T2FV into T1FV as it avails optimistic CV, CV reduction, and pessimistic CV values to attain reduced form as shown below:

Theorem 2.1 *Let $\tilde{\tau} = (m_1, m_2, m_3, \varsigma_l, \varsigma_r)$ be a TT2FV. Consider the reduction of $\tilde{\tau}$ using optimistic, pessimistic, and CV reduction to be τ_1, τ_2, and τ_3 then their possibility distribution are given as follows [22]:*

$$\phi' \tau_1(y) = \begin{cases} \frac{(1+\varsigma_r)(y-m_1)}{m_2-m_1+\varsigma_r(y-m_1)} & if\ y \in [m_1, \frac{m_1+m_2}{2}] \\ \frac{(1-\varsigma_r)y+\varsigma_r m_2-m_1}{m_2-m_1+\varsigma_r(m_2-m_1)} & if\ y \in (\frac{m_1+m_2}{2}, m_2] \\ \frac{(-1+\varsigma_r)y-\varsigma_r m_2+m_3}{m_3-m_2+\varsigma_r(y-m_2)} & if\ y \in [m_2, \frac{m_2+m_3}{2}] \\ \frac{(1+\varsigma_r)(m_3-y)}{m_3-m_2+\varsigma_r(m_3-y)} & if\ y \in (\frac{m_2+m_3}{2}, m_3) \end{cases}$$

$$\phi' \tau_2(y) = \begin{cases} \frac{y-m_1}{m_2-m_1+\varsigma_l(y-m_1)} & if\ y \in [m_1, \frac{m_1+m_2}{2}] \\ \frac{y-m_1}{m_2-m_1+\varsigma_l(m_2-y)} & if\ y \in (\frac{m_1+m_2}{2}, m_2] \\ \frac{m_3-y}{m_3-m_2+\varsigma_l(y-m_2)} & if\ y \in [m_2, \frac{m_2+m_3}{2}] \\ \frac{(m_3-y)}{m_3-m_2+\varsigma_l(m_3-y)} & if\ y \in (\frac{m_2+m_3}{2}, m_3) \end{cases}$$

$$\phi'\tau_3(y) = \begin{cases} \frac{(1+\varsigma_r)(y-m_1)}{m_2-m_1+2\varsigma_r(y-m_1)} & \text{if } y \in [m_1, \frac{m_1+m_2}{2}] \\ \frac{(1-\varsigma_r)y+\varsigma_r m_2-m_1}{m_2-m_1+2\varsigma_l(m_2-y)} & \text{if } y \in (\frac{m_1+m_2}{2}, m_2] \\ \frac{(-1+\varsigma_l)y-\varsigma_l m_2+m_3}{m_3-m_2+2\varsigma_l(y-m_2)} & \text{if } y \in [m_2, \frac{m_2+m_3}{2}] \\ \frac{(1+\varsigma_r)(m_3-y)}{m_3-m_2+\varsigma_r(m_3-y)} & \text{if } y \in (\frac{m_2+m_3}{2}, m_3) \end{cases}$$

From the reduced fuzzy parameters derived in theorem 2.1 chance constrain programming model is developed. Type reduced fuzzy variables i.e TT1FV are not always obtained in normalized form, thus out of usual and generalized credibility measure the later one is preferred to provide a more generic solution. Theorem 2.2 shows implication of generalized credibility in crisp conversion from reduced variable attained in theorem 2.1.

Theorem 2.2 *Consider $\tilde{\tau}_i = (m_1^i, m_2^i, m_3^i, \varsigma_{l,i}, \varsigma_{r,i})$ as TT2FV and τ_i as the type reduction of $\tilde{\tau}_i$ attained from CV reduction technique. Here, $i = 1, 2, ..., I$, $\tau_1, \tau_2, ..., \tau_I$ are not mutually dependent and $g_i \geq 0\ \forall i$.*

(i) *For the generalized credibility level $\psi \in (0, 0.25]$: $\tilde{Cr}\{\sum_{i=1}^I g_i\tau_i \leq s\} \geq \psi$ is equal to,*
$$\sum_{i=1}^I \left[\frac{(1-2\psi+(1-4\psi)\varsigma_{r,i})g_i m_1^i + 2\psi g_i m_2^i}{1+(1-4\psi)\varsigma_{r,i}}\right] \leq s$$

(ii) *For the generalized credibility level $\psi \in (0.25, 0.5]$: $\tilde{Cr}\{\sum_{i=1}^I g_i\tau_i \leq s\} \geq \psi$ is equal to,*
$$\sum_{i=1}^I \left[\frac{(1-2\psi)g_i m_1^i + (2\psi+(4\psi-1)\varsigma_{l,i})g_i m_2^i}{1+(4\psi-1)\varsigma_{l,i}}\right] \leq s$$

(iii) *For the generalized credibility level $\psi \in (0.5, 0.75]$: $\tilde{Cr}\{\sum_{i=1}^I g_i\tau_i \leq s\} \geq \psi$ is equal to,*
$$\sum_{i=1}^I \left[\frac{(2\psi-1)g_i m_3^i + (2(1-\psi)+(3-4\psi)\varsigma_{l,i})g_i m_2^i}{1+(3-4\psi)\varsigma_{l,i}}\right] \leq s$$

(iv) *For the generalized credibility level $\psi \in (0.75, 1]$: $\tilde{Cr}\{\sum_{i=1}^I g_i\tau_i \leq s\} \geq \psi$ is equal to,*
$$\sum_{i=1}^I \left[\frac{(2\psi-1+(4\psi-3)\varsigma_{r,i})g_i m_3^i + 2(1-\psi)g_i m_2^i}{1+(4\psi-3)\varsigma_{r,i}}\right] \leq s$$

3 Problem description and model formulation

3.1 Description of problem

In today's society, frozen food is already in growing market. Cold chain supply has shown to be crucial in improving the market dominance for frozen meals in whatsoever country. Advanced economies, still lack a cold chain infrastructure and therefore unable to high standard frozen food to their populations. Internet shopping and the launch of new applications, which make it easier for customers to choose their chosen items, are two of the most recent trends propelling the business. But at the same time the transportation of these frozen food needs refrigerated trucks which are heavy contributor of carbon emission. Customer satisfaction plays a key role in frozen food industry thus delivery time constraint plays a vital role. Keeping these factors in mind the mathematical model is developed as shown in subsection 3.5. The objective function dealing with minimization of carbon emission considers parameters ranging from speed of transportation vehicle to the carbon emission while transporting, loading, and unloading along with speed of loading and unloading as triangular type-2 fuzzy numbers. Similarly for the objective dealing with time minimization considers travel time and packaging time as triangular type-2 fuzzy numbers. Type-2 set is generalized form of type-1 fuzzy set and can take over higher order of uncertainty. The visualization of model can be done through figure 1.

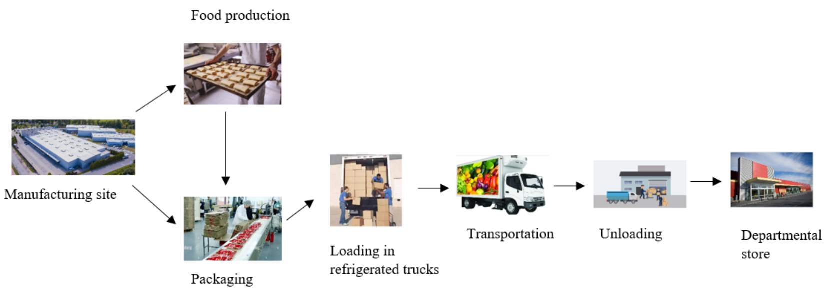

Figure 1: Pictorial visualization of frozen food transportation model

3.2 Assumptions

- Problem referred in research work is unbalanced solid transportation problem
- Frozen food is being transported
- The factor that affects the quality or the caliber of the frozen food is temperature
- Overloading of vehicles is strictly prohibited
- Refrigerated vans are availed for transportation of frozen food

3.3 Indices

- J is a batch of manufacturing units indexed by j
- L is a batch of departmental store indexed by l
- K is a batch of vehicles that are indexed by k

3.4 Parameters

p_{jlk} amount of frozen food units transported from $j-$th manufacturing unit to $l-$th departmental store availing $k-$ th vehicle
m weight of each frozen food item
$\widetilde{vel_k}$ velocity of k-th vehicle denoted by a fuzzy number
$\widetilde{VE_k}$ fuzzy number representing amount of carbon emitted by the k-th vehicle
$\widetilde{EL_j}$ carbon emission for maintaining temperature of vehicle while loading at j-th manufacturing unit represented by fuzzy number
$\widetilde{SL_j}$ speed at which frozen food packets are loaded into the vehicle at j-th manufacturing site in fuzzy number
$\widetilde{EU_l}$ fuzzy number representing carbon emission at the time of unloading to maintain temperature of vehicle at l-th departmental store
$\widetilde{SU_l}$ speed at which frozen food packets are unloaded from the vehicle at l-th departmental store in fuzzy number
d_{jl} distance between $j-$th manufacturing site and $l-$th departmental store
$\widetilde{T^a_{jlk}}$ travel time taken by $k-$th vehicle to transport items from $j-$th manufacturing site to $k-$th departmental store
$\widetilde{T^b_{jlk}}$ packaging time of each item being transported from $j-$th manufacturing site to $k-$th departmental store using $k-$th vehicle
$\widetilde{CM_j}$ capacity of $j-$th manufacturing site represented by fuzzy number
$\widetilde{DD_l}$ demand of $l-$th departmental store represented by fuzzy number
$\widetilde{VC_k}$ capacity of $k-$th vehicle represented by fuzzy number
$\widetilde{\rho_j}$ carbon cap on j manufacturing site represented by fuzzy number
$\widetilde{\tau_l}$ carbon cap on l-th departmental store represented by fuzzy number
z_{jlk} $\begin{cases} 1 & \text{if} \quad x_{jlk} \geq 0 \\ 0 & otherwise \end{cases}$

3.5 Mathematical model

$$Min\ CE = \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{l=1}^{L}\left(p_{jlk}m\widetilde{VE_k}\frac{d_{jl}}{\widetilde{vel_k}} + \widetilde{EL_j}\frac{p_{jlk}}{\widetilde{SL_j}} + \widetilde{EU_l}\frac{p_{jlk}}{\widetilde{SU_l}}\right) \tag{92.1}$$

$$Min\ Time = \sum_{j=1}^{J}\sum_{l=1}^{K}\sum_{k=1}^{K}\left(\widetilde{T^a_{jlk}}z_{jlk} + \widetilde{T^b_{jlk}}p_{jlk}\right) \tag{92.2}$$

s.t.

$$\sum_{j=1}^{J}\sum_{l=1}^{L} p_{jlk} \leq \widetilde{VC_k} \qquad k = 1, 2, ..., K, \tag{92.3}$$

$$\sum_{k=1}^{K}\sum_{l=1}^{L} p_{jlk}m\widetilde{VE_k}\frac{d_{jl}}{\tilde{v}_k} + \sum_{k=1}^{K}\sum_{l=1}^{L}\widetilde{EL_j}\frac{p_{jlk}}{\widetilde{SL_j}} \leq \tilde{\rho}_j \ j = 1, 2, ..., J, \tag{92.4}$$

$$\sum_{k=1}^{K}\sum_{j=1}^{J} EU_l\frac{p_{jlk}}{\widetilde{SU_l}} \leq \tilde{\tau}_l \qquad l = 1, 2, ..., L, \tag{92.5}$$

$$p_{jlk} \geq 0 \ \ \forall j, l, k \tag{92.6}$$

3.6 Interpretation of model

The model presented under subsection 3.5 deals with two objective functions. The first objective function 92.1 is responsible for minimizing carbon emission from the vehicle during the course of traveling along with extra emission at the time of loading and unloading of frozen food items. The first part of the function evaluate the emission based on load of the vehicle. The second part of model formulates emission due to loss of cooling in the refrigerator while loading of the frozen item, and the third part gives emission value at the unloading of product in departmental store. The second objective function 92.2 minimizes time of transportation of frozen food product alongside the time taken in packaging of the item as packaging plays a vital role in quality maintenance of frozen item.

The constraint **??** is placed to make sure that the capacity of each manufacturing site is not violated. Constraint **??** is responsible to make sure that demand of each departmental store is met. Over loading of any vehicle should not be allowed is made sure by constraint 92.3. Each manufacturing unit has a carbon cap based on the locality it is established on violation of which the site is heavily fined and sometime even asked to shut down, this carbon cap check is stated by constraint 92.4. Similarly the carbon cap constraint for departmental store is mentioned in constraint 92.5. Constraint 92.6 is a non negative constraint that states that negative quantity can't be transported.

4 Solution of Model

The model contemplated in research work is a multi objective model whose parameters are TT2FV. In order to obtain the solution of model primarily all the fuzzy variable should be transformed to correspondent crisp form. Later a compromised programming technique is employed as multi objective can't be optimized concurrently.

4.1 Defuzzification of the model

The first step is to develop chance constraint model with generalized credibility and later based on the range of credibility four different crisp equivalent forms are evaluated.

$$
\begin{aligned}
& Min_p(Min\bar{f}_1^*, Min\bar{f}_2^*) \\
\text{s.t.} \quad & \\
& \widetilde{Cr}\left\{\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{l=1}^{L}\left(p_{jlk} m\widetilde{VE}_k \frac{d_{jl}}{\widetilde{vel}_k} + \widetilde{EL}_j \frac{p_{jlk}}{\widetilde{SL}_j} + \widetilde{EU}_l \frac{p_{jlk}}{\widetilde{SU}_l}\right) \le \bar{f}_1^*\right\} \ge \alpha_*^E \\
& \widetilde{Cr}\left\{\sum_{j=1}^{J}\sum_{l=1}^{K}\sum_{k=1}^{K}\left(\widetilde{T_{jlk}^a} z_{jlk} + \widetilde{T_{jlk}^b} p_{jlk}\right) \le \bar{f}_2^*\right\} \ge \alpha_*^T \\
& \widetilde{Cr}\left\{\sum_{k=1}^{K}\sum_{l=1}^{L}(p_{jlk}) \le \widetilde{CM}_j\right\} \ge \kappa_1^* \quad j = 1, 2, ..., J, \\
& \widetilde{Cr}\left\{\sum_{k=1}^{K}\sum_{j=1}^{J} p_{jlk} \ge \widetilde{DD}_l\right\} \ge \kappa_2^* \quad l = 1, 2, ..., L, \\
& \widetilde{Cr}\left\{\sum_{j=1}^{J}\sum_{l=1}^{L} p_{jlk} \le \widetilde{VC}_k\right\} \ge \kappa_3^* \quad k = 1, 2, ..., K, \\
& \widetilde{Cr}\left\{\sum_{k=1}^{K}\sum_{l=1}^{L} p_{jlk} m\widetilde{VE}_k \frac{d_{jl}}{\tilde{v}_k} + \sum_{k=1}^{K}\sum_{l=1}^{L} \widetilde{EL}_j \frac{p_{jlk}}{\widetilde{SL}_j} \le \tilde{\rho}_j\right\} \ge \kappa_4^* \; j = 1, 2, ..., J, \\
& \widetilde{Cr}\left\{\sum_{k=1}^{K}\sum_{j=1}^{J} EU_l \frac{p_{jlk}}{\widetilde{SU}_l} \le \tilde{\tau}_l\right\} \ge \kappa_5^* \quad l = 1, 2, ..., L, \\
& p_{jlk} \ge 0 \;\; \forall j, l, k
\end{aligned}
$$

here, $Min_p(Min\bar{f}_1^*, Min\bar{f}_2^*)$ represent the minimum value of the objective function that is attained when the credibility of carbon emission and time objective function is at least α_*^E and α_*^T, along with the minimum credibility of supply, demand, conveyance, and carbon emission constraint (manufacturing site and departmental store) as $\kappa_1^*, \kappa_2^*, \kappa_3^*, \kappa_4^*, \kappa_5^*$ respectively.

4.2 Equivalent crisp model

Consider all the TT2FV present in the model are not mutually dependent and have following representation:
The crsip equivalent model is as follows:

$$Min\ CE = \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{l=1}^{L}\left(p_{jlk}mF_{VE_k}\frac{d_{jl}}{F_{vel_k}} + F_{EL_j}\frac{p_{jlk}}{F_{SL_j}} + F_{EU_l}\frac{p_{jlk}}{F_{SU_l}}\right)$$

$$Min\ Time = \sum_{j=1}^{J}\sum_{l=1}^{K}\sum_{k=1}^{K}\left(F_{T^a_{jlk}}z_{jlk} + F_{T^b_{jlk}}p_{jlk}\right)$$

s.t.

$$\sum_{k=1}^{K}\sum_{l=1}^{L}p_{jlk} \leq F_{CM_j} \qquad j = 1, 2, ..., J,$$

$$\sum_{k=1}^{K}\sum_{j=1}^{J}p_{jlk} \geq F_{DD_l} \qquad l = 1, 2, ..., L,$$

$$\sum_{j=1}^{J}\sum_{l=1}^{L}p_{jlk} \leq F_{VC_k} \qquad k = 1, 2, ..., K,$$

$$\sum_{k=1}^{K}\sum_{l=1}^{L}p_{jlk}mF_{VE_k}\frac{d_{jl}}{F_{v_k}} + \sum_{k=1}^{K}\sum_{l=1}^{L}F_{EL_j}\frac{p_{jlk}}{F_{SL_j}} \leq \tilde{\rho}_j \ \ j = 1, 2, ..., J,$$

$$\sum_{k=1}^{K}\sum_{j=1}^{J}EU_l\frac{p_{jlk}}{F_{SU_l}} \leq \tilde{\tau}_l \qquad l = 1, 2, ..., L,$$

$$p_{jlk} \geq 0 \ \ \forall j, l, k$$

The TT2FV representation of all the fuzzy variables in the model is shown below:

$\widetilde{vel_k} = (vel_k^1, vel_k^2, vel_k^3; \varsigma_{l,k}^1, \varsigma_{r,k}^1)$,
$\widetilde{VE_k} = (VE_k^1, VE_k^2, VE_k^3; \varsigma_{l,k}^2, \varsigma_{r,k}^2)$,
$\widetilde{EL_j} = (EL_j^1, EL_j^2, EL_j^3; \varsigma_{l,j}^3, \varsigma_{r,j}^3)$,
$\widetilde{SL_j} = (SL_j^1, SL_j^2, SL_j^3; \varsigma_{l,j}^4, \varsigma_{r,j}^4)$,
$\widetilde{EU_l} = (EU_l^1, EU_l^2, EU_l^3; \varsigma_{l,l}^5, \varsigma_{r,l}^5)$
$\widetilde{SU_l} = (SU_l^1, SU_l^2, SU_l^3; \varsigma_{l,l}^6, \varsigma_{r,l}^6)$,
$\widetilde{T^a_{jlk}} = ({T^a_{jlk}}^1, {T^a_{jlk}}^2, {T^a_{jlk}}^3; \varsigma_{l,jlk}^7, \varsigma_{r,jlk}^7)$,
$\widetilde{T^b_{jlk}} = ({T^b_{jlk}}^1, {T^b_{jlk}}^2, {T^b_{jlk}}^3; \varsigma_{l,jlk}^8, \varsigma_{r,jlk}^8)$,
$\widetilde{CM_j} = (CM_j^1, CM_j^2, CM_j^3; \varsigma_{l,j}^9, \varsigma_{r,j}^9)$,
$\widetilde{DD_l} = (DD_l^1, DD_l^2, DD_l^3; \varsigma_{l,j}^1 0, \varsigma_{r,j}^1 0)$,
$\widetilde{VC_k} = (VC_k^1, VC_k^2, VC_k^3; \varsigma_{l,k}^1 1, \varsigma_{r,k}^1 1)$

Note: The crisp conversion of one of the TT2FV $\widetilde{vel_k} = (vel_k^1, vel_k^2, vel_k^3; \varsigma_{l,k}^1, \varsigma_{r,k}^1)$ for a generalized credibility is shown below and the crisp conversion of remaining variable can be carried in the similar manner:

- If credibility lies in range $0 < \alpha_*^E \leq 0.25$:

$$F_{vel_k} = \frac{((1-2\alpha_*^E) + (1-4\alpha_*^E)\varsigma_{l,k}^1)vel_k^1 + 2\alpha_*^E vel_k^2}{1 + (1-4\alpha_*^E)\varsigma_{r,k}^1}$$

- If credibility lies in range $0.25 < \alpha_*^E \leq 0.5$:

$$F_{vel_k} = \frac{(1-2\alpha_*^E)vel_K^1 + ((2\alpha_*^E + (4\alpha_*^E - 1)\varsigma_{l,k}^1)vel_k^2)}{1 + (4\alpha_*^E - 1)\varsigma_{l,k}^1}$$

- If credibility lies in range $0.5 < \alpha_*^E \leq 0.75$:

$$F_{vel_k} = \frac{(2\alpha_*^E - 1)vel_k^3 + (2(1-\alpha_*^E) + (3-4\alpha_*^E)\varsigma_{l,k}^1)vel_k^2}{1 + (3-4\alpha_* E)\varsigma_{l,k}^1}$$

- If credibility lies in range $0.75 < \alpha_*^E \leq 1$:

$$F_{vel_k} = \frac{(2\alpha_* E - 1 + (4\alpha_* E - 3)\varsigma_{r,k}^1)vel_k^3 + 2(1-\alpha_* E)vel_k^2}{1 + (4\alpha_* E - 3)\varsigma_{r,k}^1}$$

4.3 Implication of compromised programming approaches to the model

As the model deals with multiple objectives, the first one minimizes carbon emission, and the second is responsible for the minimization of time; thus compromised programming technique is utilized since both the objectives cannot be optimized simultaneously. Here, two techniques, namely the GCM and FGP are availed as shown below:

4.3.1 Global criterion method

In this method the compromised solution is obtained by reducing all the objectives to single objective which holds a metric function that comprises of relative deviation of all the objective function of the models to their corresponding ideal solutions. For detail explanation of the method readers can refer [24]. This method is often preferred over other methods as it is exempted from pareto ranking mechanism [25]. The steps to obtain the compromised solution of the model displayed in section 3.5 are as follows:

Step 1: Solve the model given in section 3.5 for both of the objectives individually i.e. while solving minimization of carbon emission objective ignore the minimization of time and similarly for the other objective.

Step 2: Store the minimum value of objective 92.1 as CE^{min} and $Time^{min}$.

Step 3: The corresponding reduced model using GCM is as follows:

$$\text{Min} \left\{ \left(\frac{CE - CE^{min}}{CE^{min}} \right)^{\xi} + \left(\frac{Time - Time^{min}}{Time^{min}} \right)^{\xi} \right\}^{\frac{1}{\xi}}$$

s.t.

constraints (??)-(92.6)

$1 \leq \xi \leq \infty$

here, ξ is an exponent that hold only integer values. For different value of ξ the relation in weights assigned to objective function varies. If the weight is to be assigned based on the deviation [26] then $\xi > 1$ and for permitting equal moment to each deviation $\xi = 1$ [27].

4.3.2 Fuzzy goal programming

This procedure takes into consideration the level of aspiration of each objective function which is defined by the decision maker [28]. The idea is to minimize the distance between objective function and aspiration level. Positive deviation (d^+_{CE}, d^+_{Time}) and negative deviation (d^-_{CE}, d^-_{Time}) are used to define this distance [29]. For detail explanation of this readers can refer [28]. It can be implemented to the model in section 3.5 as shown below:

Step 1: Solve the objective function 92.1 and 92.2 alone without bothering the other and store the value of unknowns obtained in P_1 and P_2.

Step 2: Determine the upper (U_{CE}, U_{time}) and lower limit (L_{CE}, L_{time}) of both the objective function

$$U_{CE} = max(CE(P_1), CE(P_2)) \text{ and } U_{time} = max(Time(P_1), Time(P_2))$$

$$L_{CE} = min(CE(P_1), CE(P_2)) \text{ and } L_{Time} = min(Time(P_1), Time(P_2))$$

Step 3: Determine the value of $d^+_{CE}, d^-_{CE}, d^+_{Time}$, and d^-_{Time} as follows:

$$d_{CE}^{+} = \max\left(0, CE - \overline{CE}\right) = \frac{1}{2}\left\{\left(CE - \overline{CE}\right) + \left|CE - \overline{CE}\right|\right\}$$

$$d_{CE}^{-} = \max\left(0, \overline{CE} - CE\right) = \frac{1}{2}\left\{\left(\overline{CE} - CE\right) + \left|\overline{CE} - CE\right|\right\}$$

$$d_{Time}^{+} = \max\left(0, Time - \overline{Time}\right) = \frac{1}{2}\left\{\left(Time - \overline{Time}\right) + \left|Time - \overline{Time}\right|\right\}$$

$$d_{Time}^{-} = \max\left(0, \overline{Time} - Time\right) = \frac{1}{2}\left\{\left(\overline{Time} - Time\right) + \left|\overline{Time} - Time\right|\right\}$$

here, $\overline{CE}$, $\overline{Time}$ is the aspiration level of the two objective functions of the model 3.5.

Step 4: The corresponding goal programming model of 3.5 is as follows:

$$\begin{aligned}
&\min X\\
&\text{s.t.}\\
&\frac{1}{2} + \frac{1}{2}\,\frac{e^{\left\{\frac{(L_{CE}+U_{CE})}{2} - CE\right\}\eta_{CE}} - e^{-\left\{\frac{(L_{CE}+U_{CE})}{2} - CE\right\}\eta_{CE}}}{e^{\left\{\frac{(L_{CE}+U_{CE})}{2} - CE\right\}\eta_{CE}} + e^{-\left\{\frac{(L_{CE}+U_{CE})}{2} - CE\right\}\eta_{CE}}} - d_{CE}^{+} + d_{CE}^{-} = 1\\
&\frac{1}{2} + \frac{1}{2}\,\frac{e^{\left\{\frac{(L_{Time}+U_{Time})}{2} - Time\right\}\zeta_{Time}} - e^{-\left\{\frac{(L_{Time}+U_{Time})}{2} - Time\right\}\zeta_{Time}}}{e^{\left\{\frac{(L_{Time}+U_{Time})}{2} - Time\right\}\zeta_{Time}} + e^{-\left\{\frac{(L_{Time}+U_{Time})}{2} - Time\right\}\zeta_{Time}}} - d_{Time}^{+} + d_{Time}^{-} = 1\\
&X \geq d_{CE}^{-}\\
&X \geq d_{Time}^{-}\\
&d_{CE}^{+} d_{CE}^{-} = 0\\
&d_{Time}^{+} d_{Time}^{-} = 0\\
&\text{constraints } (??) - (92.6)\\
&0 \leq X \leq 1\\
&\eta_{CE} = \frac{6}{U_{CE} - L_{CE}}\\
&\eta_{Time} = \frac{6}{U_{Time} - L_{Time}}
\end{aligned}$$

4.4 Soft computing approach to solve the model

The optimization of the multi objective problem availing compromised programming technique is performed via Lingo optimizer software. The software was developed by LINDO company. The modification of program in this is convenient. It works on reduced gradient technique. This software can handle wide range of variables and constraints i.e around eight thousand [30].

5 Quantitative experimentation through a case study

The demand of frozen food has increased in past few years in metropolitan cities like Bangalore. Some of the predominant reason for the spike in this demand are given below :

- Due to the hectic work-life schedule of people in the city, there is an inadequacy of time to cook, and frozen food hardly takes any time to cook
- Shelf life of frozen food is much higher than fresh food items; thus after the attack of Coronavirus, food products with higher shelf life were preferred
- Availability of a wide variety of health benefiting food products in frozen form has further added to the demand
- Disposable income is a crucial factor in increasing the demand for frozen foods

For the quantitative experiment the city of Bangalore is considered, also the vehicle count and traffic congestion of the city is not a hidden issue. Carbon emission and on-time delivery are two significant concerns often faced in this city. Thus, the idea is to develop a cold supply chain model fulfilling the demands of frozen food of the residents of Bangalore while keeping in check the carbon emission and in-time delivery. The geographical placement of manufacturing sites and departmental store considered in the case study are shown in figure 2.

5.1 Inputs for the quantitative experiment

Two manufacturing sites responsible for manufacturing of frozen food are located in Bommasandra and HBR layout. The three departmental stores are based out of Koramangala, Yeshwantpur, and JP Nagar. Three different variety of vehicles are used for transportation. Manufacturing sites, departmental stores, and conveyance are represented by $j, l,$ and$k$ respectively. Distance is given by $d11 = 35, d12 = 43, d13 = 56, d21 = 38, d22 = 56,$ and $d23 = 49$. The TT2FV input for vehicle speed ($\widetilde{vel_k}$), emission from $k-$ th vehicle ($\widetilde{VE_k}$), speed of loading ($\widetilde{SL_j}$), unloading($\widetilde{SU_l}$), emission while loading ($\widetilde{EL_j}$), unloading ($\widetilde{EU_l}$), demand of departmental store ($\widetilde{DD_l}$), supply capacity of manufacturing site ($\widetilde{CM_j}$), transporting

Figure 2: Location of manufacturing sites and departmental stores in the city of Bangalore considered in the case study

vehicle capacity ($\widetilde{VC_k}$), carbon cab on manufacturing site ($\widetilde{\rho_j}$), on departmental store ($\widetilde{\tau_l}$) are provide in table 1. The TT2FV inputs for transportation time and packaging time of the frozen food items are mentioned in table 2.

Table 1: TT2FV inputs for parameters and constraints

j	$\widetilde{EL_j}$	$\widetilde{SL_j}$	$\widetilde{CM_j}$	$\widetilde{\rho_j}$
1	(4.39,7.2,9;0.2,0.7)	(48.49,55,58;0.4,0.9)	(1017.9,1026.54,1032;0.2,0.5)	(11682.43,14522.24,12358;0.3,0.7)
2	(5.7,7.13,9;0.2,0.7)	(64.44,67.1,69;0.4,0.9)	(1037.39,1047.9,1051;0.2,0.5)	(15640.57,15672.35,15676;0.3,0.7)
l	$\widetilde{EU_l}$	$\widetilde{SU_l}$	$\widetilde{DD_l}$	$\widetilde{\tau_l}$
1	(2.91,6.99,9;0.2,0.3)	(66.1,70.26,72;0.3,0.9)	(299.11,303.23,340;0.4,0.9)	(2762.51,2769.34,2780;0.2,0.8)
2	(4.2,7.22,10;0.2,0.3)	(54.1,57.1,61;0.3,0.9)	(262.11,275.4,279;0.4,0.9)	(2436.36,2442.46,2447;0.2,0.8)
3	(2.2,5.21,8;0.2,0.3)	(81.12,85.21,87;0.3,0.9)	(408.89,414.14,420;0.4,0.9)	(2762.23,2770.18,2778;0.2,0.8)
k	$\widetilde{Vel_k}$	$\widetilde{VE_k}$	$\widetilde{VC_k}$	
1	(44.04,48.03,52.56;0.1,0.6)	(21.89,26.11,28;0.3,0.3)	(555.82,556.67,559;0.2,0.5)	
2	(45.27,52.45,55;0.1,0.6)	(32.92,37.12,39;0.3,0.2)	(484.35,487.22,490;0.2,0.5)	
3	(46.9,55.65,58;0.1,0.6)	(26.85,31.2,33;0.3,0.2)	(577.45,579.92,582;0.2,0.5)	

5.2 Optimal result discussion and managerial insight

The transportation of frozen food from manufacturing sites in the outskirt of Bangalore to the departmental stores located in the city is portrayed availing the model presented in section 3.5. The inputs for the corresponding model are propounded in 5.1. To handle higher degree of uncertainty TT2FV variables are

Table 2: TT2FV inputs of time for transportation and packaging

	l	$k=1$	$k=2$	$k=3$	
	1	(3.29,6.35,8.23;0.1,0.7)	(4.56,6.46,9;0.1,0.7)	(6.88,11.67,14;0.1,0.7)	
$\widetilde{T^a_{jlk}}$	2	(5.5,7.67,9;0.1,0.7)	(2.11,5.92,8;0.1,0.7)	(4.56,6.46,9;0.1,0.7)	$j=1$
	3	(4.56,6.46,9;0.1,0.7)	(6.36,9.11,12;0.1,0.7)	(2.19,5.67,8;0.1,0.7)	
	1	(2.19,5.67,8;0.1,0.7)	(4.56,6.46,9;0.1,0.7)	(6.36,9.11,12;0.1,0.7)	
$\widetilde{T^a_{jlk}}$	2	(6.36,9.11,12;0.1,0.7)	(2.19,5.67,8;0.1,0.7)	(2.92,7.54,9;0.1,0.7)	$j=2$
	3	(4.56,6.46,9;0.1,0.7)	(5.5,7.67,9;0.1,0.7)	(2.92,7.54,9;0.1,0.7)	
	1	(0.12,0.17,0.8;0.3,0.6)	(0.2,0.24,0.5;0.3,0.6)	(0.14,0.19,0.25;0.3,0.6)	
$\widetilde{T^b_{jlk}}$	2	(0.22,0.27,0.27;0.3,0.6)	(0.32,0.37,0.41;0.3,0.6)	(0.12,0.14,0.18;0.3,0.6)	$j=1$
	3	(0.22,0.24,0.26;0.3,0.6)	(0.23,0.28,0.29;0.3,0.6)	(0.18,0.19,0.21;0.3,0.6)	
	1	(0.21,0.22,0.27;0.3,0.6)	(0.22,0.24,0.26;0.3,0.6)	(0.25,0.29,0.27;0.3,0.6)	
$\widetilde{T^b_{jlk}}$	2	(0.31,0.32,0.35;0.3,0.6)	(0.18,0.19,0.21;0.3,0.6)	(0.27,0.28,0.27;0.3,0.6)	$j=2$
	3	(0.25,0.29,0.27;0.3,0.6)	(0.28,0.33,0.32;0.3,0.6)	(0.30,0.32,0.36;0.3,0.6)	

considered in parameters and constraints. However, in order to solve the model TT2FV need to be converted to equivalent crisp numbers which is done by implementing methodology shown in subsection 4.1 and 4.2. To solve multiple objective problem compromised programming technique from subsection 4.3 are procured.

5.2.1 Result

Using GCM the range of overall CE and time varies. It can be seen from the graphical representation of solution in figure 3 that emission is highest 12332.66 and time is minimum 160.2 when $\xi = 1$. The corresponding allocation of unknowns in this are $p111 = 300, p123 = 265, p131 = 190,$ and $p133 = 220$. For $\xi = 2$ emission and time are 11991.31 and 167.8 respectively, with allocations as $p111 = 300, p123 = 265, p133 = 220$and $p231 = 190$. For $\xi = 3$ emission and time are 12221.19 and 162.84 respectively, with allocations as $p111 = 300, p123 = 265, p131 = 256$ and $p133 = 154$.
Whereas the results from FGP are bit diverse from GCM as the value of carbon emission is 11387.06 and time is 198.1, set of corresponding allocations are $p111 = 146, p113 = 154, p123 = 265$ and $p231 = 410$. The graphical view of the results can be seen in figure 3

5.2.2 Managerial insights

- The mathematical model developed in this paper takes into consideration the carbon emission and time taken in the process of delivery of frozen

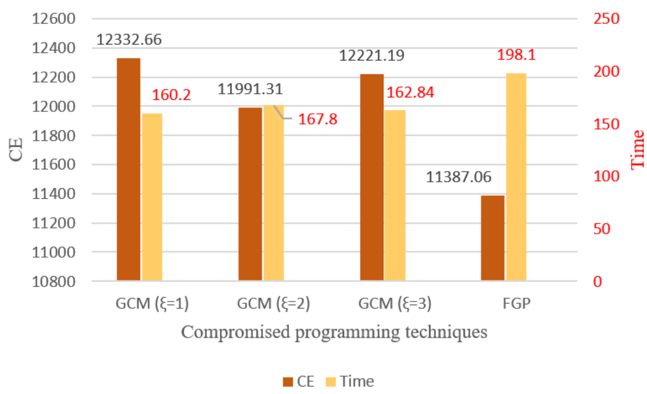

Figure 3: Location of manufacturing sites and departmental stores in the city of Bangalore considered in the case study

food from manufacturing site to the departmental store, it aims to optimize emission as frozen food is transported using vehicles with refrigeration capacity and are huge contributor of green house gases.

- The condition at time of transportation is not uniform always and to capture that uncertainty of environment it takes input in TT2FV which accounts for high scalability of model in other industries as well.
- The solution of the multi objective model is presented via various options i.e three cases from GCM and one from FGP, thus model can be availed by different industries based on their priorities.
- If the delivery of the product has critical time bound and due to some irregularities in the manufacturing process order preparation has taken more time than GCM $\xi = 1$ can be availed for delivery.
- If the manufacturing or departmental site lies in a zone that has high carbon cap breakage price that the user may opt for FGP. Similarly, other solution approaches can be availed as per the need of the hour.

6 Conclusion and future work

Transportation of frozen foods necessitates a cool supply network. The cold supply chain transports items in a chilled state, resulting in a significant emission of carbon emissions all across the transaction. In order to enhance customer contentment and preserve the quality and safety of food item, on-time transportation is vital. Throughout this study, a mathematical framework is designed with the intention of minimizing carbon emissions throughout transportation, as well as emissions through merchandise transition from the point of manufacture to the vehicle, and ultimately from the vehicle to the end destination. Considering frozen food must always be packaged with both the utmost care and quality, packing time is factored into the equation alongside transportation time. The research work takes into account a situational analysis of the Bangalore environment. The parameters are deemed fuzzy because of the ambiguity with in environment. To accommodate for the possibility that decision makers' opinions may differ, TT2FV is evaluated. GCM and FGP compromised programming techniques are being examined to maximize both carbon emissions and time. The findings given in this study, together with management insights, aim to provide solutions to industries in a variety of situations.

Hereafter, the study could be broadened to include a range of items in a single fleet of transportation. The very same model may indeed be analyzed in various fuzzy environments. In the case of frozen food shipping, cost is indeed an essential component to consider. The framework may be upgraded to include a larger number of production facilities and department stores.

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