International Journal of Recent Engineering Research and Development (IJRERD)
ISSN: 2455-8761
www.ijrerd.com || Volume 06 – Issue 04 || April 2021 || PP. 01-20

Evaluating the Impact of Tariffs on Designing a Sustainable Closed-Loop Supply Chain

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Abstract: The government regulations could have a significant impact on the supply chain management and the stakeholders' long and short-term investment decisions. Ever-changing restrictions, mandates, and tax policies can affect corporation's competitive advantage, market share, operational costs, and in extreme cases, the overall livelihood of the companies. The concerns on growth in the volume of waste tires and new strict government legislations to reduce the environmental impact of the end of life (EOL) tires has increased interests among companies to design a sustainable, efficient, and environmentally-friendly closed-loop supply chain (CLSC) network. This study proposes a sustainable, environmentally conscious closed-loop supply chain network for the tire industry under uncertainty and various recovery options. This study aims to assess the impact of imports and the government tariffs on the feasibility and performance of the network. To accomplish this goal, a multi-objective, multi-product, multi-echelon supply chain network is designed and solved using possibilistic programming. A numerical illustration of the tire industry is used to show the applicability of the proposed model under different tariff policies. The results indicate the applicability and feasibility of the proposed model; however, an appropriate government policy with regard to tariff rate and import cap is needed to create a fair competitive environment.

Keywords: Closed-loop supply chain, Tire industry, Multi-Objective criteria, Fuzzy uncertainty, Import tariffs

1. Introduction

In today's business world, an effective, efficient, and reliable closed-loop supply chain network (CLSCN) is an absolute necessity in order to compete in a competitive market. A closed-loop supply chain is a network consist of a forward and reverse logistics network combined. Reverse logistics is a network where selected products transfer up the stream from the end users for repair, remanufacturing, or recycling[1]. Environmental concerns, government regulations, and the potential economic benefits, and consumer's awareness and their responsibility against the environment are some of the motives for manufacturers for considering reverse logistics in addition to the traditional forward supply chain network[2][3].

Worldwide, more than a billion tires are manufactured every year which a significant number of them are thrown away after being used. According to U.S. Environmental Protection Agency (EPA), in the United States alone 280 million tires are being scraped every year. The average passenger tire weighs about 22 pounds, and the commercial semi-truck tire weighs about 110 pounds and contains oil and other combustible carbon compounds, which create a fire hazard. Tire fires are difficult to extinguish and can break the tire down into hazardous compounds, including gases, heavy metals, and oil. Tire piles can also create a breeding ground for pests such as rodents and mosquitos that contribute to the spread of diseases[4][5].

There are many factors being considered by the decision maker (DM) when designing a CLSC network, such as costs, competition and market share, governmental regulations, environmental impacts, social dimensions, uncertainty in the parameters, operational and disruption risks, reliability of the network, etc.

Government regulations and restrictions are some of the important elements being considered by the managers. Governments establish many regulations and policies that guide businesses. Businesses need to be flexible enough to respond to changing rules and policies. The government can implement a policy that changes the social behavior in the business environment. For example, the government can impose taxes on certain industries to direct investments in new technology that will bring the necessary change. Imposing on a particular sector more taxes or duties than are necessary will make the investors lose interest in that sector. Similarly, tax and duty exemptions on a particular sector trigger investment in it and may generate growth.

A tariff is a tax levied on an imported good with the intent to limit the volume of foreign imports, protect domestic employment, reduce competition among domestic industries, and increase government revenue. It is one of several trade policies that a country can enact.

One of the challenges facing the managers in the tire supply chain is the import of low-cost, low-quality tires into the United States. A surge of low-cost foreign manufacturers entering the tire market can significantly influence the industry. These budget imports have a short life span, some of the imported truck tire products have inconsistent construction quality, may actually wear more quickly, and the resultant casing from the tire does not have the same quality as that from a major brand. Therefore, fleets require more frequent tire replacements, which could increase the long-term cost of these budget im-port tires above that of premium tires. This issue can also raise some environmental concerns as the short life cycle of imported tires would result in more EOL tires exit the supply chain and more scrap tires to deal with. From a broader economic standpoint, these imports not only impact the market share and profitability of the domestic manufacturers but also can impact the tire retreading industry, as low-quality imported tires are not retread-able due to the low quality of tire casing. Also, considering that the imported tire cost half the price of a retread tire, leaves little to no interest in investing on retread tires by fleets.

Low-cost import tires might have an up-front prices advantage which provides short-term savings over the premium tire brands, but in reality, this does not make up for other deficiencies or necessarily equate to overall savings. Price is an important decision factor, though other factors, such as quality, availability, safety, service level, and consumer's desire to support domestic production, are just some of the factors that are considered.

In this study, we are designing a closed-loop supply chain network by considering the impact of import tires and government tariff policy on the profitability and performance of the network. Our model aims to maximize the total CLSC profit, minimize the overall cost of tire procurement for fleets, minimize the total greenhouse gas (GHG) generated along the CLSC and maximize the social responsibilities which are presented in the form of a total number of jobs created by expanding the network in the forward direction and establishing a new reverse logistics network.

To the author's best of knowledge, no previous research has been conducted on the design of the CLSC for tire industry with a focus on imports and government tariff policy.

The paper is structured as follows. In Section 2, the relevant literature on closed-loop supply chains network design and tire industry is reviewed; some works concerning government tax policy are also analyzed. In Section 3, the main problem characteristics, assumptions, and mathematical formulation are presented. In Section 4, a proposed Possibilistic Programming (PP) approach and augmented epsilon constraint method are described in detail. In Section 5, the proposed model is applied to an example problem. The computational results and the sensitivity analysis are also presented in this section. Finally, in Section 6 some conclusions and future work are discussed.

2. Literature Review

2.1. Closed-Loop Supply Chain

Designing a robust and flexible supply chain network that includes optimizing the number, capacity, and location of network facilities has received a lot of attention these days. A closed-loop supply chain network (CLSC) considers both forward and reverse supply chain networks in an integrated manner. There have been many papers published in this subject area. Govindan et al. (2014) and Devika et al. (2015) provided a comprehensive survey of CLSC network [6][7]. Also, a comprehensive review on environmentally conscious manufacturing and product recovery was provided by Ilgin and Gupta (2010) [8]. Dulman and Gupta (2018) studied the financial impact of sensors on closed-loop supply chain systems [9]. Zhou and Gupta (2019) provided a pricing strategy for new and remanufactured high-tech products. Their model aimed to maximize the profit associated with customer demand based on the manufacturer, retailer, and joint supply chain [10]. In another study, they proposed a partial least square method to explore the factors that affect value depreciation rate and price differentiation between new and remanufactured iPhone and iPad [11]. Aldoukhi and Gupta (2019) proposed a new model for designing a closed-loop supply chain network by considering a downward product substitution policy under four carbon emission regulation policies. They used robust optimization to deal with uncertainty related to product demand and the number of returned products [12]. In another study, they proposed a multi-objective model to design a Closed-Loop Supply Chain (CLSC) network with the aim of minimizing the total cost, minimizing the carbon emission, and maximizing the service level of the retailers. They used physical programing approach to model the problem [13]. Fadhel and Gupta (2019) evaluated the food waste valorization alternatives from a sustainability point of view. They estimated energy utilization and GHG emission reduction for each potential food waste processing technique [14]. Oliveira and Machado (2021) provided a literature review on the application of optimization methods in closed-loop supply chain [15].Vieira et al. (2020) studied the barriers in implementing reverse logistics for E-waste and investigated the widely applied multicriteria decision aid (MCDA) methods used to prioritize these barriers [16]. Gupta et al. (2020) presented a compilation of six recent papers on a variety of topics to demonstrate the pioneer research activity within responsible and sustainable manufacturing [17].

2.2. Closed-Loop Supply Chain Network Under Uncertainty

Inconsistent and inaccurate information and data are one of the major reasons for failure in the supply chain. This uncertainty and ambiguity have posed a significant challenge for decision makers in supply chain management [18]. Some of the most common uncertainties can be associated with customer demands, quality, and quantity of the returned products in reverse logistics and operational cost, which can include procurement costs, manufacturing costs, transportation costs, etc. [19]. A successful design of a supply chain network requires identification, evaluation and mitigation of the risk associated with these uncertainties. Two main types of uncertainty are randomness and epistemic [20][21]. Stochastic programming and Possibilistic programming are the most common methods to deal with randomness and Epistemic (fuzzy) uncertainty, respectively [22][23]. Mulvey et al. (1995) provided a flexible robust optimization approach for scenario-based stochastic programming models [24]. Their proposed approach was further developed by Yu and Li, 2000 [25]. Dutta et al. (2016) proposed a CLSC model under demand and capacity uncertainty and used chance constraint approach to deal with the uncertainty [26]. Zeballos et al. (2017) used stochastic programming models to design a CLSC network by considering multiple scenarios [27]. Mousazadeh et al. (2018) used robust possibilistic approach for health service network design [28]. Tozanli and Gupta et al. (2017) provided a literature review paper for environmentally concerned logistics operation (ECLO) in fuzzy environment by reviewing papers published between 1994 and 2017 [29]. Moshtagh et al. (2017) proposed an integrated manufacturing and remanufacturing CLSC model with quality based return rate distribution function [30]. Vahdat et al. (2017) provided a two-stage stochastic programming modeling to design a multi-period, multistage, and single-commodity CLSC network under uncertainty [31]. Yolmeh and Saif (2020) provided a supply chain network design with assembly and disassembly line balancing under uncertainty [32]. Wang et a. (2021) studied various incentive mechanisms in green supply chain under demand uncertainty [33]. Rafael et al. (2021) provided a review of simulation optimization methods for designing a resilient supply chain under uncertainty [34].

2.3 Closed-Loop supply chain & Government regulations

The government has an important role in decisions made by managers of the closed-loop supply chain. There have been many papers published in this area, most of which have focused on government subsidies. Latruffe et al. (2016) studied the impact of subsidies in performance agriculture production [35]. Fan et al. (2018) studied the effect of government subsidy selection strategy in low-carbon diffusion [36]. Bai et al. (2018) studied the impact of environmental subsidies on the green efficiency of thermal power firms by using classical Slacks-based Measure and Tobit model [37]. Hafezalkotob (2018) investigated the impact of different government intervention policies between two competitive green supply chains and found that the government regulation policies are beneficial for supply chain [38]. Wan and Hong (2019) examined the effects of transfer pricing and subsidy policies in a closed-loop supply chain. They considered two recyclers, one retailer, and one third-party in their model [39]. Subrata et al. (2019) studied a closed-loop supply chain under the influence of government incentives [40]. He et al. (2019) obtained the best channel structure and pricing strategies for the manufacturer and the optimal subsidy policies for the government. Their supply chain model consists of one manufacturer, one retailer, and one third-party [41]. Jinghua and Sun (2019) evaluated subsidies-based profit distribution pattern analysis in the closed-loop supply chain using game theory [42]. Ali and Aida (2021) studied a multi-product and multi-period closed-loop supply chain network design under take-back legislation [43].

There are also many papers published regarding government carbon tax policy. Yang et al. (2017) considered two competitive low carbon supply chains in which the manufacturers produce the substitutable products in the cap-and-trade scheme and found a suitable cooperation pattern for supply chain members [44]. Xu et al. (2017) also analyzed the influence of carbon trading price on production quantity and abatement level; they concluded that the optimal product quantity first decreases and then remains constant when the carbon trading price increases [45]. Gao et al. (2018) imposed a limitation (carbon cap) on the supreme allowable emission [46]. Manoranjan and Giri (2020) proposed a model for a closed supply chain with a heterogeneous fleet under a carbon emission reduction policy [47]. Yuyan et al. (2020) studied recycling decisions of low carbon e-commerce closed-loop supply chain under government subsidy mechanism [48].

2.4. Closed-Loop Supply Chain for tire

In 2019, 267.8 million new passenger tires, 37.9 new light truck tires, and 25.4 million new medium and heavy truck tires were shipped within the United States. EOL tires, due to the large quantities being manufactured and the durability of the material being used, pose a significant challenge for the government and the supply chain. Disposing scrap tires in landfills consumes valuable space and can also result in the penetration of pollutants and metal contents into the underground water. With recent research and advancement in the composition of the tire, tires have become even more durable. When the tire treads are worn out, the majority of the time, the tire casing is still in good condition and can be reused many times. Disposing of in the landfill or incineration for energy recovery only shortens the life span of the tire casing. There are a few recovery options available for EOL tires which some of them are as follows:

Reuse or repurposing the tire is the most environmentally friendly option that extends the life cycle of the tires. Tires with sufficient thread depth can be sold in the used tire market. Whole tires can also be used for a number of applications, including erosion control, playground equipment, crash barriers on the side of the highway, and boat bumpers at the docks.

Retread or recap is a process in which the worn thread of the tire is removed from the tire casing and replaced with new treads. Study shows 25 gallons of oil needed to produce a new truck tire compared to only 7 gallons of oil to retread a used one. That results in a significant reduction in greenhouse gas emission, preserving raw material, and minimizing the amount of waste disposed of in the landfills. With good tire management practices in the fleet and trucking industry, a tire can be retreaded three times. New tires are typically used in the steer position. The first retread tire is then used in the drive position, and the second and third retread tires are used in the trailer position. Fig.1

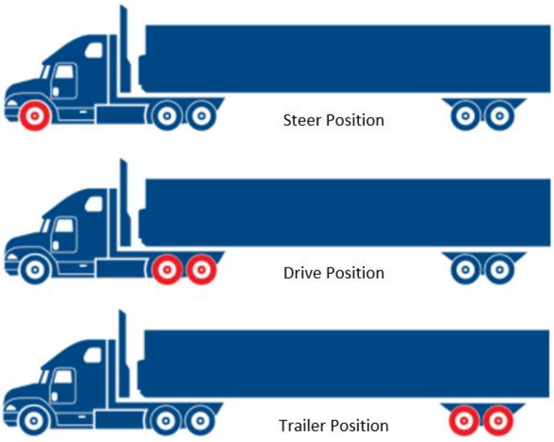

Fig.1. New and retread tire mounting position

Waste tires are typically shredded before they are recycled. Recycled tires can be used as crumb rubber in asphalt pavement or as an aggregate in Portland cement concrete. Tires are also cut up and used in garden beds to hold in the water and to prevent weeds from growing [49].

A large percentage of scrap tires are used as fuel. Tire-derived-fuel (TDF) is a fuel derived from scrap tires. Scrap tires, either shredded or as a whole, are used to supplement coal in power plants, cement kilns, paper mills, etc. Research has shown that atmospheric contamination dramatically increases when tire rubber is used as fuel [50-54].

Disposal in the landfill is the most harmful option due to the large volume and high percentage of void space inside the tire. Tires can trap gas that causes them to become buoyant and damage the landfill covers.

There has been some research on the tire CLSC network. In 1997, Ferrer published a paper and estimated the optimal number of times each tire can be retreaded [55]. Sasikumar et al. (2010) provided an optimization model for a tire remanufacturing case [56]. According to Chopra and Meindl (2015), between 2009 and 2011, only 3 percent of total sales by U.S. firms within the tire industry were retread tires [57]. One of the challenges facing the tire industry is the coordination of the entire forward and reverse logistics network and managing the flow of the new and used tires. Amin et al. (2017) examined a case study for CLSC network for the tire industry in Toronto, Canada. They developed a mixed-integer linear programming model under uncertainty with the goal of maximizing profit [58]. Subulan et al. (2015) examined a tire remanufacturing case study in Tur-key using a fuzzy mixed integer programming approach [59]. Derakhshan et al. (2017) presented a technique for recycling tire waste as well as reuse of the waste [60]. O'Brien and North (2017) investigated the emission of pollutants from tire waste. They studied the types of gases that are produced from car tire waste [61]. Fathollahi Fard et al. (2018) proposed a tri-level programming model for tire CLSC to identify the decision variable using real data sets [62]. Pedram et al. (2018) used stochastic programming to design a single objective tire CLSC network[63]. Lokesh et al. (2018a) studied tire retreading sup-ply chain network under carbon tax policy. In another study, Lokesh et al. (2018b) used a fuzzy goal programming approach for Brownfield tire retreading case study under carbon tax policy [64][65]. SahebJamnia et al. (2018) also modeled a robust closed-loop sup-ply chain of the tire industry and used hybrid metaheuristic algorithms to solve the model [66].

Abdolazimi et al. (2019) proposed a multi-objective closed-loop supply chain by integrating on-time delivery and cost [67]. Mehrjerdi et al. (2020) studied the sustainability and resiliency of a closed-loop supply chain using multiple sourcing strategies [68]. Lokesh et al. (2020) also designed a sustainable tire supply chain with a fuzzy goal planning approach [69].

Designing an economically optimized and environmentally friendly CLSC network is a prerequisite for tire manufacturers not only to earn a profit but also to decrease waste, preserve natural resources and save landfills and the environment with the ultimate goal of sustainable development. This has motivated this study to take a closer look at the challenges facing the tire industry and come up with a solution that creates a win-win situation for companies in the tire industry network and the environment.

3. Problem description and formulation

As shown in Fig.2, we are considering a multi-product and multi-echelon CLSCN consisting of suppliers, domestic manufacturers, international importers, distribution centers, collection centers, retreading centers, recycling, and energy recovery centers. In the forward flow, various raw materials are procured from the available choice of suppliers. After tires are manufactured at the domestic production facilities, they are distributed through the distribution centers and the retailers to the end users. The imported tires are assumed to be directly sent to the retailer. The location of retailers is fixed, and there might be unsatisfied demands due to uncertainty in demand. In the reverse flow, used tires are transferred to collection centers where the initial inspection is performed, and based on the condition of the tires, they are either routed to retreading center or the recycling centers.

The main objective in the CLSCN design problem is to maximize the total profit of the supply chain by choosing the optimal number and location of facilities, their capacities and the flow of products between the facilities. The second objective is from the customer's perspective, which aims to minimize the cost of procurement of tires by considering purchasing domestic and imported tires. The third and fourth objectives aim to minimize the environmental impact and maximize the social responsibilities, respectively. The demand, retreading rates, procurement, and production costs are fuzzy; therefore, a possibilistic approach has been utilized to deal with these parameters.

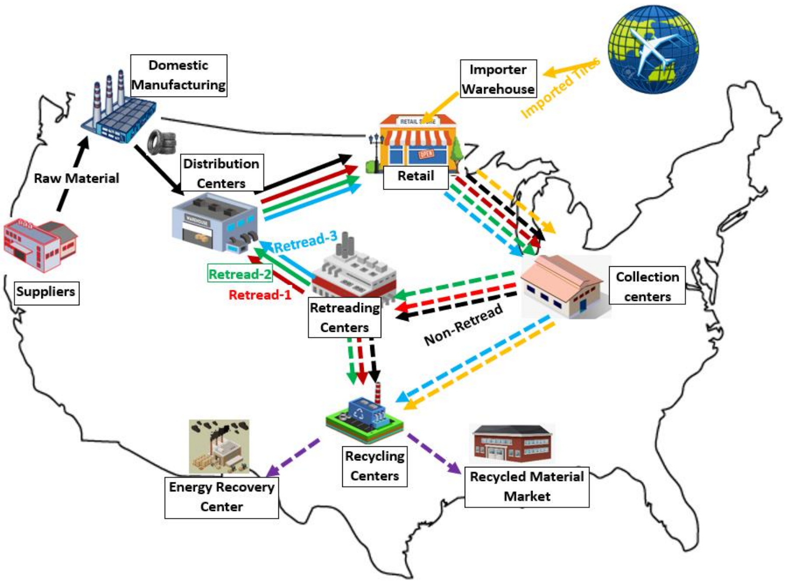

Fig.2. Schematic view of the proposed CLSC

3.1. Problem assumption and notation

The main characteristics and assumptions are as follows:

- The potential location of new manufacturing centers, distribution centers, retreading centers, and recycling centers are fixed and predefined.
- Production, distribution, retreading, and recycling capacity is limited, and all are subject to capacity level U.
- Capacity of the energy recovery centers is unlimited, but it has the most damaging environmental impacts
- The Demand, return, and retreading rate of new and retread tires are fuzzy.

- Raw material procurement costs and production costs are fuzzy, and their fuzzy expected value will be utilized.
- Ground transportation is the only transportation method used in the network.
- There is a buyback price paid to the customer for the returned products.
- Domestic tires can be retreaded three times, retread-1, retread-2 & retread-3, and each tire will be identified how many times it has been retreaded.
- Imported tires can not be retreaded due to the low quality of the tire casing.
- Value of the tires that have been retreaded once (retread-1) is greater than the value of the tires that have been retreaded two or three times (retread-2,3), and all are less than the value of the new tires.
- The demand for tires must be satisfied using a combination of new and retread tires.

Indices:

S	Set of raw material suppliers
M	Set of raw materials
P	Set of types of tires
F^a	Set of existing production centers
F^b	Set of potential production centers
G	Set of countries that tires are imported from
D^a	Set of existing distribution centers
D^b	Set of potential distribution centers
C	Set of customer delivery points
I	Set of collection centers
J	Set of recycling centers
K	Set of retreading centers
W	Set of energy recovery centers
U	Set of capacity levels

Parameters: Tilde symbol (~) is to distinguish the fuzzy parameters.

$fc_{f,u}^{F}$	Fixed opening cost of production center at location f at capacity level u
$fc_{d,u}^{D}$	Fixed opening cost of distribution center at location d at capacity level u
$fc_{i,u}^{I}$	Fixed opening cost of collection center at location i at capacity level u
$fc_{j,u}^{J}$	Fixed opening cost of recycling center at location j f at capacity level u
$fc_{k,u}^{K}$	Fixed opening cost of retreading center at location k at capacity level u
fc_{s}^{S}	Fixed ordering cost of raw material from supplier s
$\widetilde{mc_{m,s}^{S}}$	Unit cost of raw material m from supplier s (fuzzy)
$\widetilde{pc_{p,f}^{F}}$	Production cost of a unit of tire p at production center (fuzzy)
$Bbc_{p,c}$	Buyback price for EOL non-retread tire p from customer c
$Bbc1_{p,c}$	Buyback price for EOL retread-1 tire p from customer c
$Bbc2_{p,c}$	Buyback price for EOL retread-2 tire p from customer c
$Bbc3_{p,c}$	Buyback price for EOL retread-3 tire p from customer c
$BbcIMP_{p,c}$	Buyback price for EOL imported tire p from customer c
$rtc1_{p,k}^{k}$	Retreading cost of a unit of tire p for first time at retreading center k
$rtc2_{p,k}^{k}$	Retreading cost of a unit of tire p for second time at retreading center k
$rtc3_{p,k}^{k}$	Retreading cost of one unit tire for third time at retreading center k
$rc_{p,j}^{J}$	Recycling cost of a unit of tire p at recycling center j
$tr_{m,s,f}^{SF}$	Transportation cost for unit of raw material m from center s to center f
$tr_{p,f,d}^{FD}$	Transportation cost for a unit of tire p from center f and d
$tr_{p,d,c}^{DC}$	Transportation cost for a unit of tire p from center d and c
$tr_{p,c,i}^{CI}$	Transportation cost for a unit of tire p from center c and i
$tr_{p,i,j}^{IJ}$	Transportation cost for a unit of tire p from center i and j
$tr_{p,i,k}^{IK}$	Transportation cost for a unit of tire p from center i and k
$tr_{p,k,d}^{KD}$	Transportation cost for a unit of tire p from center k and d
$tr_{p,k,J}^{KJ}$	Transportation cost for a unit of tire p from center k and j
$tr_{p,j,W}^{JW}$	Transportation cost for a unit of tire p from center j and w
$cap_{m,s}^{S}$	Maximum capacity of the supplier s for material m
cap_{u}^{F}	Maximum capacity of production center f at capacity level u
$g_{f,u}^{F}$	Binary parameter defining capacity level of existing center f ∈ F^a
cap_{u}^{D}	Maximum capacity of distribution center d at capacity level u

cap^G	Import cap for country G
$g_{d,u}^D$	Binary parameter defining capacity level of existing center $d \in D^a$
cap_u^I	Maximum capacity of collection center i at capacity level u
cap_u^K	Maximum capacity of retreading center k at capacity level u
cap_u^J	Maximum capacity of recycling center j at capacity level u
$e_{f,p}^F$	GHG generated at center f for producing a unit of tire p
$e_{j,p}^J$	GHG generated at center j for recycling a unit of tire p
$e_{k,p}^K$	GHG generated at center k for retreading a unit of tire p
$e_{w,p}^W$	GHG generated at center w for incineration of a unit of tire p
$rate_{m,p}^F$	Quantity of material m needed to produce one unit of tire p
$\widetilde{dem_{c,p}^C}$	Market demand for new and retread tires p (fuzzy)
$\widetilde{\theta 1}$	Retread rate of EOL new tires
$\widetilde{\theta 2}$	Retread rate of EOL retread-1 tires
$\widetilde{\theta 3}$	Retread rate of EOL retread-2 tires
β	Percentage of tires being recycled for recycling market
ρ_p^0	Unit price of the new tire p
ρ_p^1	Unit price of the retread-1 tire p
ρ_p^2	Unit price of the retread-2 tire p
ρ_p^3	Price of the retread-3 tire p
ρ_p^r	Value of the recycled material for unit tire p sold to recycling market
ρ_p^g	Base price of the new imported tire p at the dock before tariffs
$ir_{p,w}^W$	Value of the recycled material for unit tire p sold to incineration centers
$Triff_{p,g}^G$	Tariff rate imposed on product p purchased from country g
$LBR_{f,u}^F$	Number of employee hired at new manufacturing center $f \in F^b$at capacity u
$LBR_{d,u}^D$	Number of employee hired at new dist. center $d \in D^b$ at capacity u
$LBR_{k,u}^K$	Number of employee hired at new retreading center k at capacity u
$LBR_{i,u}^I$	Number of employee hired at new collection center i at capacity u
$LBR_{j,u}^J$	Number of employee hired at new recycling center j at capacity u

Variables:

$Q_{m,s,f}$	Quantity of raw material m shipped from supplier s to center f
$V_{f,p}$	Total production quantity at the center f
$X_{f,d,p}^{FD}$	Quantity of new tire p shipped from center f to d
$X_{d,c,p}^{DC}$	Quantity of new tire p shipped from center d to c
$Ximp_{g,c,p}^{GC}$	Quantity of imported tire p shipped to customer c
$X1_{d,c,p}^{DC}$	Quantity of retread-1 tire p shipped from center d to c
$X2_{d,c,p}^{DC}$	Quantity of retread-2 tire p shipped from center d to c
$X3_{d,c,p}^{DC}$	Quantity of retread-3 tire p shipped from center d to c
$\Delta_{c,p}$	Quantity of unsatisfied demand for tire p at customer c
$X_{c,i,p}^{CI}$	Quantity of new tire p shipped from center c to i
$Ximp_{c,i,p}^{CI}$	Quantity of imported tire p shipped from center c to i
$X1_{c,i,p}^{CI}$	Quantity of retread-1 tire p shipped from center c to i
$X2_{c,i,p}^{CI}$	Quantity of retread-2 tire p shipped from center c to i
$X3_{c,i,p}^{CI}$	Quantity of retread-3 tire p shipped from center c to i
$X_{i,k,p}^{IK}$	Quantity of new tire p shipped from center i to k
$X1_{i,k,p}^{IK}$	Quantity of retread-1 tire p shipped from center i to k
$X2_{i,k,p}^{IK}$	Quantity of retread-2 tire p shipped from center i to k
$X3_{i,j,p}^{IJ}$	Quantity of retread-3 tire p shipped from center i to j
$Ximp_{i,j,p}^{IJ}$	Quantity of imported tire p shipped from center i to j
$X1_{k,d,p}^{KD}$	Quantity of retread-1 tire p shipped from center k to d
$X2_{k,d,p}^{KD}$	Quantity of retread-2 tire p shipped from center k to d
$X3_{k,d,p}^{KD}$	Quantity of retread-3 tire p shipped from center k to d
$X1_{k,j,p}^{KJ}$	Quantity of retread-1 tire p shipped from center k to j
$X2_{k,j,p}^{KJ}$	Quantity of retread-2 tire p shipped from center k to j
$X3_{k,j,p}^{KJ}$	Quantity of retread-3 tire p shipped from center k to j

$X_{j,p}^{J}$	Quantity of recycled tire p at recycling center j
$X_{j,W,p}^{JW}$	Quantity of tire p shipped from center j to center w
$X_{w,p}^{W}$	Total quantity of tire p incinerated at center w

Binary variables:

$Y_{f,u}^{F}$	Indicating if center f at capacity level u opened at location $f \in F^b$ or not
$Y_{d,u}^{D}$	Indicating if center d at capacity level u opened at location $d \in D^b$or not
$Y_{i,u}^{I}$	Indicating if center i at capacity level u opened or not
$Y_{k,u}^{K}$	Indicating if center k at capacity level u opened or not
$Y_{j,u}^{J}$	Indicating if center j at capacity level u opened or not
Y_{s}^{S}	Indicating if raw material is purchased from supplier s or not

3.2. Problem formulation

In the following, we will introduce four objective functions of the model, Z_1, Z_2, Z_3, Z_4 representing the total profit of the network, the overal cost to the customer, overall environmental impact and the social benefits, respectively.

$$
\begin{aligned}
\max Z_1 = {} & \left[\sum_{d}\sum_{c}\sum_{p}\left(\rho_1^0 X1_{d,c.p}^{DC} + \rho_p^1 X1_{d,c,p}^{DC} + \rho_p^2 X2_{d,c,p}^{DC} + \rho_p^3 X3_{d,c.p}^{DC}\right) + \sum_{j}\sum_{p}\rho_p^r X_{j,p}^{J}\right] \\
& - \left(\left[\sum_{f\in F^b}\sum_{u} fc_{f,u}^{F} . Y_{f,u}^{F} + \sum_{d\in D^b}\sum_{u} fc_{d,u}^{D} . Y_{d,u}^{D} + \sum_{i}\sum_{u} fc_{i,u}^{I} . Y_{i.u}^{I} + \sum_{j}\sum_{u} fc_{j,u}^{J} . Y_{j,u}^{J}\right.\right. \\
& \left. + \sum_{k}\sum_{u} fc_{k,u}^{K} . Y_{k,u}^{K}\right] + \left[\sum_{s} fc_{s}^{S} . Y_{s}^{S} + \sum_{m}\sum_{s}\sum_{f} \widetilde{mc}_{m,s}^{S} . Q_{m,s,f}\right] + \left[\sum_{f}\sum_{p} \widetilde{pc}_{pf}^{F} . V_{f,p}\right] \\
& + \left[\sum_{c}\sum_{i}\sum_{p}\left(Bbc_{p,c} . X_{c,i,p}^{CI} + Bbc1_{p,c} . X1_{c,i,p}^{CI} + Bbc2_{p,c} . X2_{c,i,p}^{CI} + Bbc3_{p,c} . Q3_{c,i,p}^{CI}\right.\right. \\
& \left.\left. + BbcIMP_{p,c} . Ximp_{c,i,p}^{CI}\right)\right] + \left[\sum_{k}\sum_{d}\sum_{p}\left(rtc1_{p,k}^{k} X1_{k,d,p}^{KD} + rtc2_{p,k}^{k} X2_{k,d,p}^{KD} + rtc3_{pk}^{k} X3_{k,d,p}^{KD}\right)\right] \\
& + \left[\sum_{j}\sum_{p} rc_{p,j}^{J} X_{j,p}^{J}\right] + \left[\sum_{w}\sum_{p} ic_{p,w}^{W} X_{w,p}^{W}\right] \\
& + \left[\sum_{m}\sum_{s}\sum_{f} tr_{m,s,f}^{SF} . Q_{m,s,f} + \sum_{f}\sum_{d}\sum_{p} tr_{p,f,d}^{FD} . X_{f,d,p}^{FD}\right. \\
& + \sum_{d}\sum_{c}\sum_{p} tr_{p,d,c}^{DC} . \left(X_{d,c,p}^{DC} + X1_{d,c,p}^{DC} + X2_{d,c,p}^{DC} + X3_{d,c,p}^{DC}\right) \\
& + \sum_{c}\sum_{i}\sum_{p} tr_{p,c,i}^{CI}\left(X_{c,i,p}^{CI} + X1_{c,i,p}^{CI} + X2_{c,i,p}^{CI} + X3_{c,i,p}^{CI}\right) \\
& + \sum_{i}\sum_{k}\sum_{p} tr_{p,i,k}^{IK}\left(X_{i,k,p}^{IK} + X1_{i,k,p}^{IK} + X3_{i,k,p}^{IK}\right) + \sum_{i}\sum_{j}\sum_{p} tr_{p,i,j}^{IJ}\left(X3_{i,j,p}^{IJ} + Ximp_{i,j,p}^{IJ}\right) \\
& + \sum_{k}\sum_{d}\sum_{p} tr_{p,k,d}^{KD}\left(X1_{k,d,p}^{KD} + X2_{k,d,p}^{KD} + X3_{k,d,p}^{KD}\right) \\
& \left.\left. + \sum_{k}\sum_{j}\sum_{p} tr_{p,k,j}^{KJ}\left(X1_{k,j,p}^{KJ} + X2_{k,j,p}^{KJ} + X3_{k,j,p}^{KJ}\right) + \sum_{j}\sum_{w}\sum_{p} tr_{p,j,w}^{JW} . X_{j,W,p}^{JW}\right]\right)
\end{aligned}
\tag{1}
$$

Eq.(1) maximizes the total profit of the supply chain. The components of Eq. (1) includes: The overall cost of opening new centers; Cost of procurement of raw material; Overallmanufacturing cost; Collection cost; Overall retreading cost; Overall recycling cost; Overall energy recovery cost; Total transportation cost; Revenue from sales of new tires; Revenue from sales of retread tires;Revenue from sales of recycled material.

$$\begin{aligned} \mathit{min}\mathrm{Z}_2 = {} & \left[\sum_{d}\sum_{c}\sum_{p}\left(\rho_p^0 X1_{d,c.p}^{D\to C} + \rho_p^1 X1_{d,c,p}^{D\to C} + \rho_p^2 X2_{d,c,p}^{D\to C} + \rho_p^3 X3_{d,c.p}^{D\to C}\right)\right] + \left[\sum_{g}\sum_{c}\sum_{p}(1 + \mathrm{Triff}_{p,g}^{G}).\,\rho_p^{G}.\,\mathrm{Ximp}_{g,c.p}^{GC}\right] \\ & - \Bigg[\sum_{c}\sum_{i}\sum_{p}\Big(\mathrm{Bpc}_{p,c}\,.\,X_{c,i,p}^{CI} + \mathrm{Bbc1}_{p,c}\,.\,X1_{c,i,p}^{CI} + \mathrm{Bbc2}_{p,c}\,.\,X2_{c,i,p}^{CI} + \mathrm{Bbc3}_{p,c}\,.\,X3_{c,i,p}^{CI} \\ & + \mathrm{BbcIMP}_{p,c}\,.\,\mathrm{Ximp}_{c,i,p}^{CI}\Big)\Bigg] \end{aligned} \quad (2)$$

Eq.(2) minimizes the total customer's cost of procuring tires. Fleets can choose between domestic new and retread tires and imported low-cost tires to minimize their overall cost. The components of Eq. (2) includes:

The overall cost of purchasing domestic new and retread tires; Cost of purchasing imported tires; Revenue from selling back EOL tires.

$$\min \mathrm{Z}_3 = \left[\sum_{f}\sum_{p} e_{fp}^{F}\,.\,V_{f,p}\right] + \left[\sum_{k}\sum_{d}\sum_{p} e_{kp}^{K}\left(X1_{k,d,p}^{KD} + X2_{k,d,p}^{KD} + X3_{k,d,p}^{KD}\right)\right] + \left[\sum_{j}\sum_{p} e_{jp}^{J} X_{j,p}^{J}\right] + \left[\sum_{w}\sum_{p} e_{wp}^{W} X_{w,p}^{W}\right] \quad (3)$$

Eq. (3) minimizes the overall environmental impact which is expressed as the amount of greenhouse gases (GHG) generated at production centers, retreading centers, recycling centers, and energy recovery centers.

$$\begin{aligned} \max \mathrm{Z}_4 = {} & \Bigg[\sum_{f\in F^b}\sum_{u} \mathrm{LBR}_{f,u}^{F}\,.\,Y_{f,u}^{F} + \sum_{d\in D^b}\sum_{u} \mathrm{LBR}_{d,u}^{D}\,.\,Y_{d,u}^{D} + \sum_{i}\sum_{u} \mathrm{LBR}_{i,u}^{I}\,.\,Y_{i.u}^{I} + \sum_{j}\sum_{u} \mathrm{LBR}_{j,u}^{J}\,.\,Y_{j,u}^{J} \\ & + \sum_{k}\sum_{u} \mathrm{LBR}_{k,u}^{K}.\,Y_{k,u}^{K}\Bigg] \end{aligned} \quad (4)$$

Eq. (4) maximizes the total number of job opportunities created as a result of opening new facilities in forward logistics and establishing a new reverse logistic network.

Constraints:

$$\sum_{f} Q_{m,s,f} \leq \mathrm{cap}_{m,s}^{S} Y_s^{S}\ ;\ \forall\, m \in M\,, s \in S \quad (5)$$

$$\sum_{p} V_{f,p} \leq \sum_{u} \mathrm{cap}_u^{F}.\, g_{f,u}^{F}\ \ ;\ \forall\, f \in F^a \quad (6)$$

$$\sum_{p} V_{f,p} \leq \sum_{u} \mathrm{cap}_u^{F}.\, Y_{f,u}^{F}\ \ ;\ \forall\, f \in F^b \quad (7)$$

$$\sum_{u} Y_{f,u}^{F} \leq 1;\ \forall\, f \in F^b \quad (8)$$

$$\sum_{p} \mathrm{rate}_{m,p}^{F} V_{f,p} \leq \sum_{s} Q_{m,s,f}\ \ ;\ \forall\, m \in M\,, f \in F \quad (9)$$

$$V_{f,p} = \sum_{d} X_{f,d,p}^{F\to D}\ ;\ \forall\ f \in F\,, p \in P \quad (10)$$

$$\sum_{f}\sum_{p} X_{f,d,p}^{FD} + \sum_{k}\sum_{p}\left(X1_{k,d,p}^{KD} + X2_{k,d,p}^{KD} + X3_{k,d,p}^{KD}\right) \leq \sum_{u} \mathrm{cap}_u^{D}.\, g_{d,u}^{D}\ ;\ \forall\, d \in D^a \quad (11)$$

$$\sum_{f}\sum_{p} X_{f,d,p}^{FD} + \sum_{k}\sum_{p}\left(X1_{k,d,p}^{KD} + X2_{k,d,p}^{KD} + X3_{k,d,p}^{KD}\right) \leq \sum_{u} \mathrm{cap}_d^{D}.\, x_{d,u}^{D}\ ;\ \forall\, d \in D^b \quad (12)$$

$$\sum_{u} Y_{d,u}^{D} \leq 1;\ \forall\, d \in D^b \quad (13)$$

$$\sum_{f} X_{f,d,p}^{FD} = \sum_{c} X_{d,c,p}^{DC};\ \forall\ d \in D\,, p \in P \quad (14)$$

$$\sum_{k} X1_{k,d,p}^{KD} = \sum_{c} X1_{d,c,p}^{DC};\ \forall\ d \in D\,, p \in P \quad (15)$$

$$\sum_{k} X2^{KD}_{k,d,p} = \sum_{c} X2^{DC}_{d,c,p} \,;\ \forall\ d \in D\,, p \in P \tag{16}$$

$$\sum_{k} X3^{KD}_{k,d,p} = \sum_{c} X3^{DC}_{d,c,p} \,;\ \forall\ d \in D\,, p \in P \tag{17}$$

$$\sum_{d} \left(X^{DC}_{d,c,p} + X1^{DC}_{d,c,p,\xi} + X2^{DC}_{d,c,p,\xi} + X3^{DC}_{d,c,p}\right) + \sum_{g} Ximp^{GC}_{g,c,p} = \widetilde{dem}^{C}_{c,p} + \Delta_{c,p};\ \forall\ c \in C\,, p \in P \tag{18}$$

$$\sum_{c}\sum_{p} Ximp^{GC}_{g,c,p} \ \leq\ cap^{G}\ \ \forall\ g \in G \tag{19}$$

$$\sum_{i} X^{CI}_{c,i,p} = \sum_{d} X^{DC}_{d,c,p} \,;\ \forall\ c \in C\ , p \in P \tag{20}$$

$$\sum_{i} X1^{CI}_{c,i,p} = \sum_{d} X1^{DC}_{d,c,p} \,;\ \forall\ c \in C\,, p \in P \tag{21}$$

$$\sum_{i} X2^{CI}_{c,i,p} = \sum_{d} X2^{DC}_{d,c,p} \,;\ \forall\ c \in C\,, p \in P \tag{22}$$

$$\sum_{i} X3^{CI}_{c,i,p} = \sum_{d} X3^{DC}_{d,c,p} \,;\ \forall\ c \in C\,, p \in P \tag{23}$$

$$\sum_{i} Ximp^{CI}_{c,i,p} = \sum_{g} Ximp^{GC}_{g,c,p} \,;\ \forall\ c \in C\,, p \in P \tag{24}$$

$$\sum_{i}\sum_{p} X^{CI}_{c,i,p} + \sum_{i}\sum_{p} X1^{CI}_{c,i,p} + \sum_{i}\sum_{p} X2^{CI}_{c,i,p} + \sum_{i}\sum_{p} X3^{CI}_{c,i,p} + \sum_{i}\sum_{p} Ximp^{CI}_{c,i,p} \leq \sum_{u} cap^{I}_{i}.\,Y^{I}_{i,u} \,;\ \forall\ i \in I \tag{25}$$

$$\sum_{c} X^{CI}_{c,i,p} = \sum_{k} X^{IK}_{i,k,p} \,;\ \forall\ i \in I\,, p \in P \tag{26}$$

$$\sum_{c} X1^{CI}_{c,i,p} = \sum_{k} X1^{IK}_{i,k,p} \,;\ \forall\ i \in I\,, p \in P \tag{27}$$

$$\sum_{c} X2^{CI}_{c,i,p} = \sum_{j} X2^{IJ}_{i,j,p} \,;\ \forall\ i \in I\,, p \in P \tag{28}$$

$$\sum_{c} X3^{CI}_{c,i,p} = \sum_{j} X3^{IJ}_{i,j,p} \,;\ \forall\ i \in I\,, p \in P \tag{29}$$

$$\sum_{c} Ximp^{CI}_{c,i,p} = \sum_{j} Ximp^{IJ}_{i,j,p} \,;\ \forall\ i \in I\,, p \in P \tag{30}$$

$$\sum_{i}\sum_{p}\left(X^{IK}_{i,k,p} + X1^{IK}_{i,k,p} + X2^{IK}_{i,k,p}\right) \leq \sum_{u} cap^{K}_{u}.\,Y^{K}_{k,u} \,;\ \forall\ k \in K \tag{31}$$

$$\sum_{d} X1^{KD}_{k,d,p} = \widetilde{\theta 1} \sum_{i} X^{IK}_{i,k,p} \,;\ \forall\ k \in K\,, p \in P \tag{32}$$

$$\sum_{d} X2^{KD}_{k,d,p} = \widetilde{\theta 2} \sum_{i} X1^{IK}_{i,k,p} \,;\ \forall\ \ k \in K\,, p \in P \tag{33}$$

$$\sum_{d} X3^{KD}_{k,d,p} = \widetilde{\theta 3} \sum_{i} X2^{IK}_{i,k,p} \,;\ \forall\ \ k \in K\,, p \in P \tag{34}$$

$$\sum_{j} X1^{KJ}_{k,j,p} = \sum_{i} X^{IK}_{i,k,p} - \sum_{d} X1^{KD}_{k,d,p} \,;\ \forall\ k \in K \tag{35}$$

$$\sum_{j} X2^{KJ}_{k,j,p} = \sum_{i} X1^{IK}_{i,k,p} - \sum_{d} X2^{KD}_{k,d,p} \,;\ \forall\ k \in K\,, p \in P \tag{36}$$

$$\sum_{j} X3^{KJ}_{k,j,p} = \sum_{i} X3^{IK}_{i,k,p} - \sum_{d} X3^{KD}_{k,d,p} \,;\ \forall\ k \in K\,, p \in P \tag{37}$$

$$\sum_{k}\sum_{p} X1^{KJ}_{k,j,p} + \sum_{k}\sum_{p} X2^{KJ}_{k,j,p} + \sum_{i}\sum_{p} X3^{IJ}_{i,j,p} + \sum_{i}\sum_{p} Ximp^{IJ}_{i,j,p} \leq \sum_{u} cap^{J}_{j}.\,Y^{J}_{j,u} \,;\ \forall\ j \in J \tag{38}$$

$$Q^{J}_{j,p} = \beta\left(\sum_{k} X1^{KJ}_{k,j,p} + \sum_{k} X2^{KJ}_{k,j,p} + \sum_{k} X3^{KJ}_{k,j,p} + \sum_{i} X3^{IJ}_{i,j,p} + \sum_{i} Ximp^{IJ}_{i,j,p}\right);\ \forall\ j \in J\,, p \in P \tag{39}$$

$$Q^{W}_{w,p} = (1-\beta)\left(\sum_{k} X1^{KJ}_{k,j,p} + \sum_{k} X2^{KJ}_{k,j,p} + \sum_{k} X3^{KJ}_{k,j,p} + \sum_{i} X3^{IJ}_{i,j,p} + \sum_{i} Ximp^{IJ}_{i,j,p}\right)\ \ \forall\ w \in W\,, p \in P \tag{40}$$

$$\begin{cases} Y^{(.)}_{(*,*)},\, Q_{m,s,f} \in \{0,1\} \\ \\ V_{f,p}\,, X^{.\rightarrow.}_{(*,*)} \geq 0 \end{cases} \tag{41}$$

Constraint (5) ensures that the total quantity of raw material sent to tire manufacturing centers is less than or equal to the maximum capacity of each supplier for that raw material. Constraint (6) and (7) ensures that the total quantity of tires produced at each manufacturing center is less than or equal to the maximum capacity of each existing and potential manufacturing center. Constraint (8) ensures that only one production facility at capacity level u can be open at location f. Constraint (9) guarantees that the raw material needed at production centers are satisfied. Constraint (10) is an equilibrium constraint indicating the total quantity of tires transferred from each manufacturing center f to distribution center d is equal to the quantity of tires manufactured at that center. Constraints (11) and (12) ensures that the maximum capacity of the existing and potential distribution centers are not violated. Constraint (13) guarantees that only one distribution center at capacity level u can be open at any potential location d. Constraints (14) - (17) are equilibrium constraints to ensure the total quantity of new and retread (retread-1, retread-2 & retread-3) tires transferred out of each distribution center is equal to the total quantity of tires enter that center. Constraint (18) ensure that the market demand for new tires is satisfied. Constraint (19) illustrate the import cap imposed by the government for each country. Constraints (20)-(24) show that all the tires in the market are being returned to collection centers at the end of their use. Constraint (25) controls the maximum capacity of the collection centers. Constraint (26)-(30) ensures equilibrium at collection centers. Constraint (31) indicated that the flow of products into and out of each retreading center do not exceed the capacity of that center. Constraints (32) and (34) calculate the quantity of the tires that are being successfully retreaded at each retreading center. Constraints (35)-(37) calculate the total quantity of new and retread tires that cannot be retreaded at retreading centers and are being transferred to recycling centers. Constraint (38) controls the capacity of the recycling centers. Constraint (39) calculates the total quantity of products transfers to each recycling center. Constraint (40) calculates the total number of tires being incinerated at each energy recovery center. Ultimately, constraint (41) enforces the binary and non-negative constraints on the corresponding decision variables.

The proposed tire CLSC model is a Mixed Integer Linear Programming (MILP) problem under fuzzy uncertainty. The Fuzzy uncertainty is related to the demand, retreading rate, recycling rate, procurement cost, production cost. In the following, we will discuss a method to cope with these uncertainties.

4. The proposed approach

4.1. Possibilistic programming

If some of the data in an optimization problem are imprecise due to insufficient data or unavailability of the information, but their approximate values can be expressed in fuzzy numbers, fuzzy mathematical programming can be used [70]. If fuzzy data in the optimization problem is expressed as Trapezoidal Fuzzy Number (TFN) and the possibility of occurrence of the possibilistic parameters are measured by Pos. and Nec., then possibilistic programming can be used where Pos. is the maximum level of occurrence of parameters and Nec. is the minimum possibility level.

The general form of possibilistic programming can be expressed as follows:

$$\begin{cases} \max Z = E(\tilde{c}x) \\ \quad \text{s.t.} \\ \mathrm{Me}\left(Ax \le \tilde{\mathcal{F}}\right) \ge \mathbb{p} \\ \quad x \in X \end{cases} \tag{42}$$

Where Me(.) is a fuzzy measure, $\tilde{\mathcal{F}} = (f_{(1)}, f_{(2)}, f_{(3)}, f_{(4)})$ and $\tilde{c} = (c_{(1)}, c_{(2)}, c_{(3)}, c_{(4)})$ are the fuzzy parameters in the form of TFN, Figure 2. $\mathbb{p}$ is the minimum confidence level and $E(\tilde{c}x)$ is the fuzzy expected value of the objective function, which can be expressed as:

$$E(\tilde{c}x) = \frac{\left(c_{(1)} + 2c_{(2)} + 2c_{(3)} + c_{(4)}\right)}{6}x \tag{43}$$

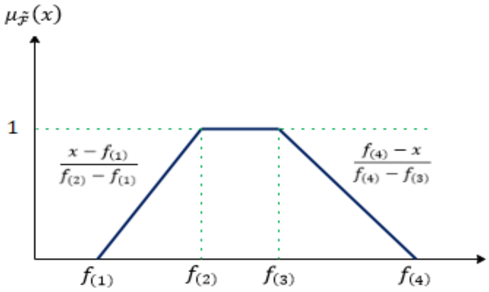

Figure 2: Function of Trapezoidal Fuzzy Numbers

In order to control fuzzy constraints, one of the most widely used fuzzy measures is credibility measure (Cr) which is expressed as the average of the optimistic (Pos) and pessimistic (Nec) measures: [71]

$$\mathrm{Cr}(.) = \frac{1}{2}(\mathrm{Pos}(.) + \mathrm{Nec}(.))$$

$$\begin{cases} \mathrm{Cr}(\mathrm{A}x \geq \tilde{\mathcal{F}}) \geq \mathbb{p} \iff \mathrm{A}x \geq \mathrm{f}_{(3)} + (2\alpha - 1)(\mathrm{f}_{(4)} - \mathrm{f}_{(3)}) & : \mathbb{p} \geq 0.5 \\ \mathrm{Cr}(\mathrm{A}x \leq \tilde{\mathcal{F}}) \geq \mathbb{p} \iff \mathrm{A}x \leq \mathrm{f}_{(2)} - (2\alpha - 1)(\mathrm{f}_{(2)} - \mathrm{f}_{(1)}) & : \mathbb{p} \geq 0.5 \end{cases} \tag{44}$$

In the above-mentioned formulation, it is assumed that the chance constraints should be satisfied with confidence level greater than 0.5. In this approach, DM should determine the minimum confidence level of chance constraints.

4.2. Coping with multi-objective functions

In order to solve multi-objective decision making (MODM) optimization problems, several approaches have been proposed, such as Weighted Sum Method (WSM), Epsilon Constraint (E.C.), Augmented Epsilon Constraint (AEC), Goal Programing (G.P.), Lexicographic (Lex) and so on. The general form of a MODM problem is as follows:

$$\begin{cases} \mathrm{Min}\ (\mathrm{f}_1(\mathrm{x}), \mathrm{f}_2(\mathrm{x}), \ldots, \mathrm{f}_\mathrm{n}(\mathrm{x})) \\ \qquad \mathrm{x} \in \mathrm{X} \end{cases} \tag{45}$$

4.3. Epsilon Constraint

Let's assume the first objective is the main objective, and the remaining objectives will have an upper bound of epsilon and will be presented as constraints of the model. In this case, the E.C. method is being used, and the resulting single objective model can be described as follows:

$$\begin{cases} \qquad \mathrm{Min}\ \ \mathrm{f}_1(\mathrm{x}) \\ \mathrm{f}_\mathrm{i}(\mathrm{x}) \leq \mathrm{e}_\mathrm{i}\ \mathrm{i} = 2,3,\ldots,\mathrm{n} \\ \qquad \mathrm{x} \in \mathrm{X} \end{cases} \tag{46}$$

In the above model, the first objective is considered as the main objective, and the remaining objectives are considered as constraints and are bound by maximum e_i. By changing the e_i different results can be obtained, which may be weakly efficient or not efficient. This issue can be resolved with minor modification, which is known as the AEC method [72]. To better implement the AEC method, the appropriate range of epsilons e_i can be obtained using the Lex method [73]. In the AEC method, the appropriate range of e_i is first determined, and then the Pareto front obtained for different values of e_i .

4.4. Appropriate interval for e_i with Lex method

In order to find the appropriate interval for e_i related to the objective function f_i (i = 2,…, n), the following optimization problem is first being solved:

$$PayOff_{jj} = Min\ f_j(x) j\ = 1,2,\ldots,n$$
$$x \in X$$

where $PayOff_{jj} = f_j(x^{j,*})$ is the optimum value of f_j and $x^{j,*}$ is the vector of decision variables that optimizes f_j.

Then, with the solution that optimizes the objective function f_j, the value of the remaining objective functions is obtained as follows:

$$\mathrm{PayOff}_{\mathrm{ij}} = \mathrm{Min}\ \mathrm{f}_\mathrm{i}(\mathrm{x})$$
$$\mathrm{f}_\mathrm{j}(\mathrm{x}) = \mathrm{PayOff}_{\mathrm{jj}}$$
$$\mathrm{x} \in \mathrm{X}$$
$$\mathrm{j} = 1,2,\ldots,\mathrm{n}\,;\mathrm{j} \neq \mathrm{i}$$

where $PayOff_{jj} = f_i(x^{i,j,*})$is the optimum value of f_i and $x^{i,j,*}$ is the vector of decision variables that optimizes f_i. Using the Lex method, the following payoff matrix is obtained:

$$\mathrm{PayOff} = \left[\mathrm{payOff_{ij}}\right]$$

After calculating the payoff table for f_ii=1,…..n, the followings can be defined:

$$\mathrm{Min}(f_i) = \mathrm{Min_j}\{\mathrm{payOff_{ij}}\} = \mathrm{payOff_{ii}}$$

$$\mathrm{Max}(f_i) = \mathrm{Max_j}\{\mathrm{payOff_{ij}}\}$$

$$\mathrm{R}(f_i) = \mathrm{Max}(f_i) - \mathrm{Min}(f_i)$$

Using the above definition, appropriate rage for each e_i can be obtained using the Lex method:

$$e_i \in [\mathrm{Min}(f_i), \mathrm{Max}(f_i)]$$

The value $\mathrm{R}(f_i)$ is used to normalize the objectives in the AEC objective functions.

4.5. Augmented Epsilon Constraint

The AEC model can be expressed as follows:

$$\begin{cases} \mathrm{Min}\ \ f_1(x) - \sum_{i=2}^{n} \phi_i s_i \\ f_i(x) + s_i = e_i \ i = 2,3,..,n \\ x \in X \\ s_i \geq 0 \end{cases} \tag{47}$$

Where s_i are non-negative variables for the shortage, ϕ_i is a parameter for normalizing the first objective with respect to f_i and $\phi_i = \frac{R(f_1)}{R(f_i)}$.

In the proposed AEC method in this study, first $e_i \in [\mathrm{Min}(f_i), \mathrm{Max}(f_i)]$ is obtained using Lex method, then eq.(45) is solved, which provides an optimum solution.

5. Computational Experiment

To check the validity, practicality, and performance of the model, this model has been applied for the design and optimization of a sample problem. The relevant data presented in Table.1,2,3,4 is collected from literature, field data, interviewing experts in the field, and some organizations involved in this field, including EPA, U.S. Tire Manufacturers Association, Tire Retread & Repair Information Bureau (TRIB), Modern Tire Dealer (MTD) and Institute of Scrap Recycling Industries (ISRI).

We are considering the feasibility of expanding an existing forward logistics network by adding four additional manufacturing facilities, five additional distribution centers, ten collection centers, five retreading centers, and five recycling centers. New potential facilities are selected such that they are within 120 Kilometer of the facilities they are linked to in the network flow and also to provide the maximum coverage to all the customers. The goal is to optimize the number, location, and capacity of the facilities and increase the efficiency and profitability of the network by considering the overall cost to the customer, the environmental impact, and the social responsibilities. We assume all the EOL tires are purchased back when they are replaced with new or retread tires by the customer. The demand rate for truck tires is fuzzy and is tied to the consumption rate of the fleet and logistics companies. Ground transportation is the only mean of transferring the tires and raw material between the facilities. Assuming a 22-foot full truckload on each transfer, the cost of transferring one unit of tire per kilometer is \$0.02 and \$0.002 for one unit of raw material.

Table 1. Network parameters

F^a	2	C	10	W	3
F^b	4	I	10	G	5
D^a	5	J	5	M	5
D^b	5	K	5		
S	5	P	5		

Table 2. Values for fuzzy parameters

Parameters	$c_{(1)}$	$c_{(2)}$	$c_{(3)}$	$c_{(4)}$)
$\widetilde{\theta 1}$	U (0.70- 0.75)	U (0.75-0.80)	U (0.80-0.85)	U (0.85-0.9)
$\widetilde{\theta 2}$	U (0.65-0.70)	U (0.70-0.75)	U (0.75-0.80)	U (0.80-0.85)
$\widetilde{\theta 3}$	U (0.55-0.60)	U (0.60-0.65)	U (0.65-0.70)	U (0.70-0.75)

$\widetilde{pc}_{p,f}^{F}$	U ($100- $110)	U ($110- $120)	U ($120- $130)	U ($130- $140)
$\widetilde{mc}_{m=1,s}^{S}$	U ($9, $9.5)	U ($9.5, $10)	U ($10, $10.5)	U ($10.5, $11)
$\widetilde{mc}_{m=2,s}^{S}$	U ($43, $44)	U ($44, $45)	U ($45, $46)	U ($46, $47)
$\widetilde{mc}_{m=3,s}^{S}$	U ($9, $9.5)	U ($9.5-$10)	U ($10-$10.5)	U ($10.5-$11)
$\widetilde{mc}_{m=4,s}^{S}$	U ($9, $9.5)	U ($9.5-$10)	U ($10-$10.5)	U ($10.5k-$11)
$\widetilde{mc}_{m=5,s}^{S}$	U ($10, $10.5)	U ($10.5, $11)	U ($11, $11.5)	U ($11.5, $12)
$\widetilde{dem}_{c,p}^{C}$	U (90K-93K)	U (93K-96K)	U (96K-100K)	U (100K-104K)

Table3: Fixed opening cost of centers at different capacity levels

	Capacity level (U)		
	Low	Medium	High
$fc_{f,u}^{F}$	U ($3M- $4M)	U ($4M-$6M)	U ($6M- $10M)
fc_{du}^{D}	U ($.2M-$.3M)	U ($.3M-$.5M)	U ($.5M- $.7M)
fc_{iu}^{I}	U ($.2M- $.3M)	U ($.3M- $.4M)	U ($.4M- $.5M)
$fc_{j,u}^{J}$	U ($.3M, $.4M)	U ($.4M, $.5M)	U ($.5M- $.7M)
$fc_{k,u}^{K}$	U ($.8M- $1.5M)	U ($1.5M- $2.5M)	U ($2.5M- $4M)
cap_{u}^{F}	U(200K-400K)	U (400K-600K)	U (600K-1000K)
cap_{u}^{D}	U (100K-200K)	U (200K-300K)	U (300K-400K)
cap_{u}^{I}	U (200K-400K)	U (400K-600K)	U (600K-800K)
cap_{u}^{K}	U (100K-400K)	U (400K-600K)	U (600K-800K)
cap_{u}^{J}	U (100K-400K)	U (400K-600K)	U (600k-800k)
$LBR_{f,u}^{F}$	U (100- 150)	U (200- 300)	U (300- 500)
$LBR_{d,u}^{D}$	U (30- 60)	U (60- 100)	U (100- 150)
$LBR_{k,u}^{K}$	U (30- 50)	U (50- 70)	U (70- 100)
$LBR_{i,u}^{I}$	U (10- 30)	U (30- 50)	U (50- 70)
$LBR_{j,u}^{J}$	U (10- 30)	U (30- 50)	U (50- 70)

Table 4. Other parameters

$rate_{m,p}^{F}$	m1: U (4-6), m2: U (14-17), m3: 4-6), m4: U (9-12), m5: U (10-12)		
fc_{s}^{S}	U ($1000-$1200)	ρ_{p}^{0}	U ($450- $550)
$cc_{p,c}$	U ($10-$20)	ρ_{p}^{1}	U ($200- $300)
$rtc1_{p,k}^{J}$	U ($40-$50)	ρ_{p}^{2}	U ($150- $200)
$rtc2_{p,k}^{J}$	U ($45- $55)	ρ_{p}^{r}	U ($25- $30)
$rtc3_{p,k}^{J}$	U ($55- $60)	ρ_{p}^{g}	U ($150- $170)
$rc_{p,j}^{J}$	U ($5-$10)	cap^{G}	U (300K- 350k)
$ic_{p,w}^{W}$	U ($3-$8)	$Bbc_{p,c}$	U ($50- $60)
e_{f}^{F}	U (9-10)	$Bbc1_{p,c}$	U ($30- $40)
e_{w}^{W}	U (10-12)	$BbcIMP_{p,c}$	U ($5- $10)
e_{k}^{K}	U (6-7)	$Bbc2_{p,c}$	U ($15- $25)
e_{j}^{J}	U (1-2)	$Bbc3_{p,c}$	U ($5- $10)
β	U (0.6-0.7)		

5.1. Computational result and sensitivity analysis

In order to evaluate the performance of the proposed model, we solve the model at two extreme conditions. First, we solved the model assuming there is no tire being imported, and all the demand is fulfilled with domestic production. Then the model is solved assuming the import is allowed, but there are no tariffs imposed on the imported tires. As illustrated in Table 5., the first extreme situation resulted in two new production centers being open at a high capacity level in addition to the existing production centers, five new distribution centers open at medium capacity, ten collection centers open at low capacity , four retreading centers open at medium capacity to cope with the EOL tires that are coming back to be retreaded, three new recycling centers at low capacity and 5 suppliers are being utilized for procurement of the raw material. Also, the domestic production was able to satisfy the demand, so there was no unsatisfied demand at the customer.

Table 6. illustrates the result of the second extreme condition. It can be observed the impact on reduction to the number of the retreading centers, production centers, distribution centers, and the number of the suppliers being utilized. Also, the overall network profit and number of job opportunities drop significantly.

Table 5. Model results considering zero imports

Obj.1(Profit- Million USD)	1063.584
Obj.2 (Customer Cost- Million USD)	1458.71
Obj.3(Total GHG- Kg)	570,325
Obj.4(Number of jobs created)	2050
Production Centers	2 new centers open @High capacity
Distribution Centers	5 new centers open @ Medium capacity
Collection Centers	10 centers open @ Low capacity
Retreading Centers	4 new centers open @ Medium capacity
Recycling Centers	3 new centers open @ Low capacity
Suppliers being utilized	5 suppliers being utilized
$\Delta_{c,p}$ (Shortage)	0
$\mathbb{p}$ (Confidence level of fuzzy constraints)	$\mathbb{p}_1 = 0.5$ /$\mathbb{p}_2$=0.5 /$\mathbb{p}_3 = 0.5$ /$\mathbb{p}_4 = 0.5$

Table 6. Model results considering zero tariffs

Obj.1(Profit- Million USD)	718.251
Obj.2 (Customer Cost- Million USD)	1299.057
Obj.3(Total GHG- Kg)	505,122
Obj.4(Number of jobs created)	497
Production Centers	0 new centers open
Distribution Centers	2 new centers open @ Low capacity
Collection Centers	10 centers open @ Low capacity
Retreading Centers	2 new centers open @ Low capacity
Recycling Centers	3 new centers open @ Low capacity
Suppliers being utilized	2 suppliers being utilized
$\Delta_{c,p}$ (Shortage)	0
$\mathbb{p}$ (Confidence level of fuzzy constraints)	$\mathbb{p}_1 = 0.5$ /$\mathbb{p}_2$=0.5 /$\mathbb{p}_3 = 0.5$ /$\mathbb{p}_4 = 0.5$

Further sensitivity analysis is performed to evaluate the impact of changes to the tariff rate on the model behavior. Fig. 2 illustrates the changes in objective functions with respect to changes to the tariff rate. It can be observed that by increasing tariff rate, the total profit of the domestic supply chain network and the overall cost to the customer increases, which is the result of the sale of more domestic and less imported tires.

Fig. 3 shows the increase in the number of job opportunities with an increase in tariff rate. The increase is a result of more demand for domestic products, which translates to the need for opening new facilities in the network. Fig. 4 indicates that an increase in tariff rate increases the number of tires being retreaded as there is more desire to purchase domestic tires. This has a positive environmental impact by keeping the used tires in the network rather than scrapping them.

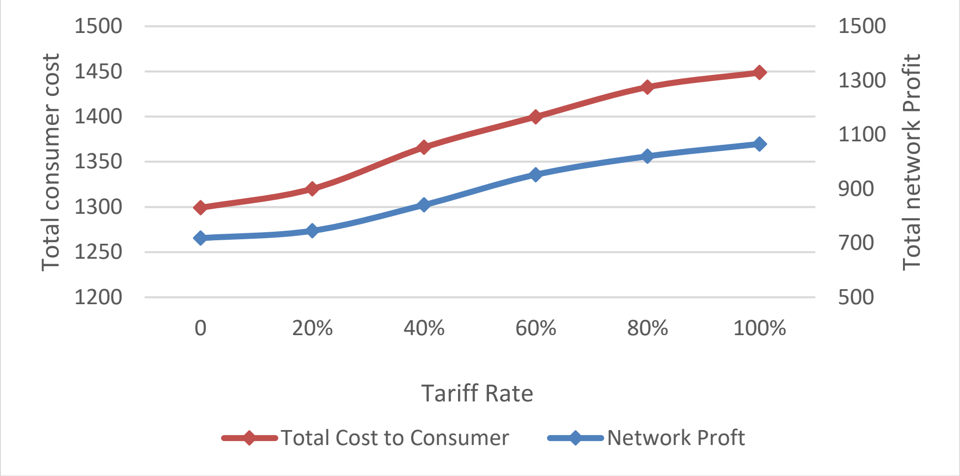

Fig. 2. Value of objective functions at a different tariff rate

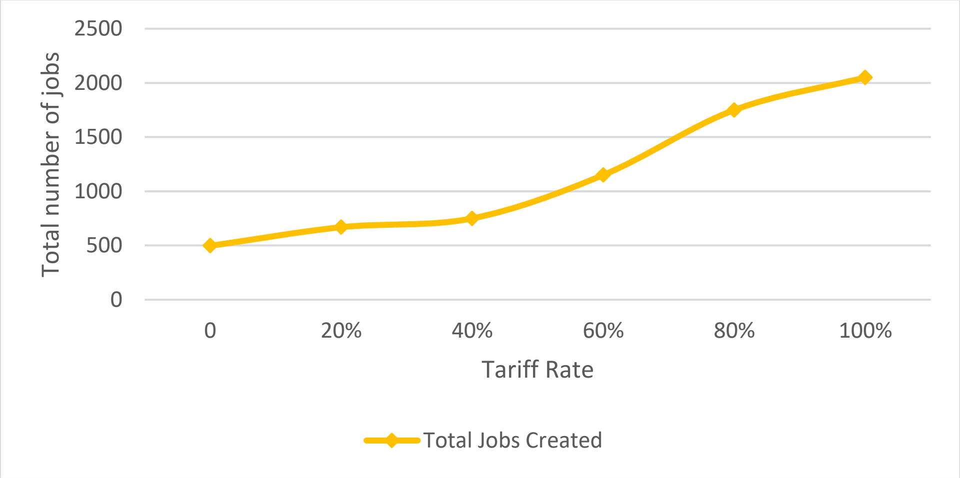

Fig. 3. Total number of jobs created at a different tariff rate

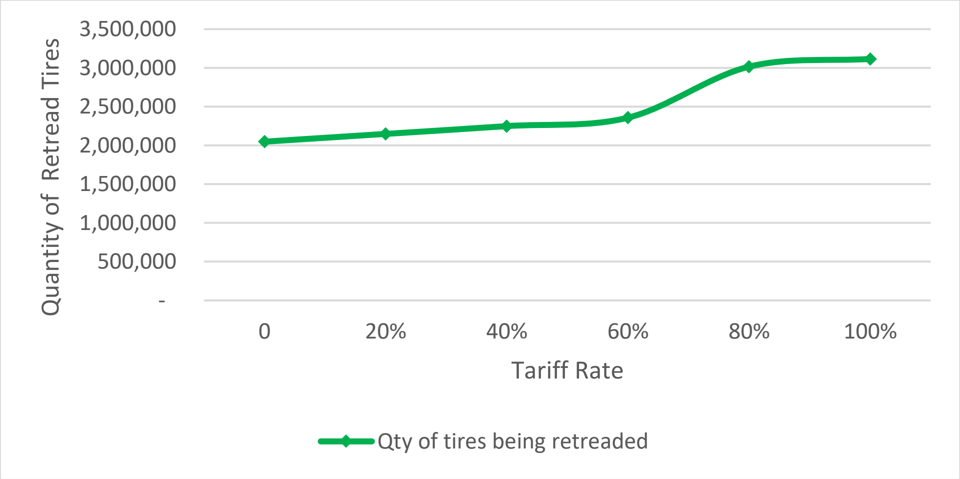

Fig. 4. Total number of tires retreaded at a different tariff rate

A note that worth discussing here is an increase in the overall cost of tire procurement to customers and logistic companies. From customer's perspective, using imported tires seem more favorable to the consumer if the highest consideration is given to the overall cost. However, it is proven that rather than just the price, value is number one on the customer's mind. Every customer has a wide variety of concerns at the point of decision. Factors such as availability of the products, after-sale services, product safety, quality, and durability are some of the important factors that are priced into the premium domestic tires. There is an apparent up-front price gap between the low-cost imported tires and premium domestic tires; however, proper maintenance and tire management programs can extend the life span and the retreadability rate of the premium tire, which can significantly reduce the price gap in the long run. A good quality premium tire casing that is retreaded multiple times can be more economical in the long run than the low-cost, low-quality imported tires.

6. Conclusion

Recovery of EOL tires has been a challenge due to the large volume being produced and the material composition of the tire that makes them difficult to decompose. This indicates the importance of a need for a systemic, sustainable CLSC network for the tire industry. There are many challenges facing the DM in a supply chain network design problem, such as uncertainty in the parameters, government regulations, competition with domestic and international competitors, environmental factors, etc.

In this study, we developed a mixed-integer linear programming model for a CLSC network for tire industry by considering uncertainty with the parameters and taking into account the impact of low-cost import tires and the government tariffs on the network with the aim of optimizing the total profit while minimizing the cost to the customer, minimizing the environmental impact and maximizing the social benefits. We proposed a possibilistic programming method to deal with the uncertainty in the model. To illustrate the performance and practicality of the proposed model, this model was applied to the design and development of a sample CLSC network. The result proved the feasibility of designing a profitable and environmentally friendly CLSC network for the tire industry; however, the results also show that the low-cost import tires pose a significant risk to the profitability of the network. Without government intervention and lack of an appropriate import cap and tariff rate on import tires can result in the elimination of the domestic retreading industry, loss of revenue and market share of the domestic manufacturers, and also greater negative environmental impacts, which is a result of a greater number of tires being scrap. For further study, the impact of utilizing a tire pressure monitoring system and adopting a proper tire maintenance program on the profitability and performance of the network can be considered.

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