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A Resilient Supply Chain Network Design Model with a Novel Fuzzy Programming Method under Uncertainty and Disruptions: A Real Industrial Approach

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Abstract-- *Nowadays, the design of a strategic supply chain network under the incidence of disruption is regarded as one of the important priorities of governments. Supplying sustainable petrochemical products is considered as a strategic goal by managers who require reliable infrastructure design. Crisis conditions such as natural disasters and sanctions have a destructive effect on the raw materials and product flows. On the other hand, the uncertainty of input parameters affects the business environment and intensifies the condition of disruption. In the present research, a new model of resilient supply chain network is introduced in a critical condition, which consists in a combination of reactive and preventive resilient strategies. In order to deal with the parametric uncertainties caused by changes in the business environment and inadequate knowledge, an effective hybrid possibilistic-flexible robust programming method was presented. The proposed model was capable of controlling the adverse effects of uncertainties and risk-aversion level of output decisions. The extended model was analyzed in the national project of polyethylene strategic supply chain network using real data, which included the flexibility of demand, capacity, and lead time components. The results indicated that optimality and feasibility robustness were guaranteed by presenting efficiency solutions.*

Keywords*: Fuzzy programming, Reliability, Resilience, Robustness, Supply chain.*

I. INTRODUCTION

Supply chain networks are faced with uncontrollable incidents and disruptions, causing quantitative or qualitative deviations from normal conditions (Blackhurst et al., 2011). When countries are engaged in disruptions due to sudden and unanticipated events such as economic crises, sanctions, natural disasters, and terrorist operations, their supply chains enter critical and urgent situations, leading to increase in disruptions in the business environment. These disruptions have a destructive and negative effect on performance, cost structure, profitability, income, assets, and inventories (Carvalho et al., 2012a). Hence, it is necessary to improve the compatibility of the supply chain to manage the network against unpredictable events, and enhance the system responsiveness to disruptions and its retrieval. The resiliency approach has been developed as the interface between the three main components of resistance, compatibility, and flexibility (Ivanov and Sokolov, 2013). The resiliency function in dealing with the disruption is accompanied by major reactive and preventive approaches. In the reactive approach, managers design and implement a response path after the incidence of the crisis caused by disturbances, and wait for system retrieval and optimal response. Such behavior is defined within the framework of corrective or reactive strategies, which impose financial burdens and political and social threats on governments (Tomlin, 2006). However, others strategies have been developed as preventive strategies, which identify potential risks and plan the system to respond to disruptions in an optimal state (Sodhi et al., 2011).

Based on the above discussion, the concept of supply chain resilience has been developed as an efficient and multidimensional approach based on the principles of matching and retrieval (Ehrenhuber et al., 2015). This approach covers a set of preventive and reactive strategies, which provide a robust level of flexibility and the ability to adapt to the positive and negative impacts of the environment. Furthermore, this approach improves the adaptation capability of the supply chain to prepare for unexpected incidents and respond to disorders by identifying potential sources of risk (Manuj

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and Mentzer, 2008; Lee, 2014). In this regard, a limited number of studies have been conducted to improve system resiliency. (Christopher and Peck 2004) proposed some principles for designing a resilient supply chain network, including the implementation of supply chain strategies with multiple choices, reviewing the balance of efficiency and redundancy, developing cooperation at the level of supply chain network to reduce risk, developing observability at upstream and downstream supply chain levels, and improving the supply chain speed with focus on principal indicators such as lead time. Tang (2006) introduced resilient strategies with preventive and reactive approaches to dealing with supply chain disruptions, which enhanced the compatibility and flexibility of the supply chain. The above-mentioned strategies included combining production and outsourcing, creating strategic inventory, integrating and expanding supplier network, reducing latency, deferring demand, dynamic pricing, and flexibility of transportation. (Iakovou et al. 2007) suggested other resilient approaches, which covered flexible sourcing, demand-driven management, strategic emergency inventory, supply chain observability, and process and knowledge support. (Ponomarov & Holcomb 2009) emphasized some strategies such as the integration, cohesion, and the communication between supply chain logistics capabilities, which were based on a reactive approach to dealing with disruptions. Further, they analyzed the effect of the above strategies on supply chain retrieval from disruption. (Jüttner & Maklan 2011) considered the improvement of supply chain characteristics, such as flexibility, speed, observability, and collaboration in enhancing the resiliency of the system. (Carvalho et al. 2012b) conducted a review based on primary indicators such as service level, latency, and cost as well as supply chain characteristics and its performance measures with resiliency, agility, and robust approaches (green supply chain). Further, they emphasized the direct and indirect communications of the above three elements for each of the mentioned approaches. (Helm 2015) proposed a new multilayered approach as a comprehensive strategy including system planning, risk management, flexible and compatible responses for enhancing system resiliency, and risk management.

In the review of some fundamental qualitative studies outlining supply chain resilience strategies, we concluded that limited operational models were developed which presented new operational practices with a focus on the explained resilience strategies. (Ishfaq 2012) presented a mathematical programming model based on the transport flexibility strategy, which sought traffic routes with optimal efficiency and used the alternate route when a disruption occurred in one of them. Various scenarios were considered for transportation. (Klibi & Martel 2012) examined modeling approaches for uncertain location-transport issues to improve the supply chain resilienc, and developed their models based on multiple sourcing and routing strategies. (Sawik 2013) made the portfolio of supply chain network resilient by combining the resiliency strategies of supply emergency inventory and multiple sourcing (selection of suppliers and assigning an order to them). For this purpose, risk-insensitive and risk-sensitive mathematical models were designed and evaluated. (Kristianto et al. 2013) proposed a fuzzy scheduling model focusing on inventory allocation and transport routing strategies. Also, the principal indicators such as lead time and the capacity of facilities were considered by using the shortest fuzzy path method. (Mari et al. 2014) examined an idealized planning model with a critical cost criterion for expected disruptions (the cost of non-satisfaction of demand after the incidence of disturbances) and aimed to create an equilibrium level of environmental sustainability of the supply chain network and to increase the flexibility of the system. (Hasani & Khosrojerdi 2016) considered six strategies, including facilities dispersion, production of semi-fabricated products, multiple sourcing, additional inventory, strengthening of facilities, and the chart of primary and secondary components in the design of a global supply chain network. (Fattahi et al. 2017) proposed a mathematical model emphasizing a combination of retrieval speed (lead time) and the assignment of orders strategies.

On the other hand, the expected values of the objective functions can be achieved by the mathematical optimization problems (Hamidieh & Fazli, 2017). However, the values of the objective functions and the optimal variables are very different from the expected values after the incidence of disruption and the realization of non-deterministic parameters of the problem along with the constant changes in the business environment (Sherafati & Bashiri, 2016). Therefore, a growing acceleration starts with the development of the robust approach against non-deterministic parameters in the optimization problems (Pishvaee et al., 2012). The above optimization approach is based on the robustness of the model and the response. The robustness of the response means that the response remains feasible for all scenarios of the input parameters of the model. However, the robustness of the optimization means that the value of the objective function of the response or solution remains close to or has the lowest deviation from the optimal values for all non-deterministic input parameters. In this regard, a large body of research was conducted on the robustness of the response (Zhang & Zhang, 2014); (Govindan & Fattahi, 2017), and some researchers developed optimization issues based on the model robustness (Ramezani et al., 2013). In recent years, a new series of robust approaches have been developed with the application of the robust logic in a possibilistic programming environment, called robust-possibilistic programming. To improve the reliability of the network, the simultaneous implementation of both answer and model robustness is considered in the face of uncertainty. Hence, the robust-possibilistic programming is developed based on the simultaneous application of the feasibility and optimality robustness (Pishvaee et al., 2012).

Based on the above review, few studies have been conducted with the organizing efforts explained in the research method of this study. (Pan & Nagi 2010) proposed a robust stochastic programming approach regarding the robustness of the model and response to deal with demand uncertainty in agile supply chain network. (Pishvaee et al. 2012) developed robust programming in the form of possibilistic programming and considered the scope of possible changes in the model. (Baghalian et al. 2013) suggested a robust stochastic mathematical combination for dealing with supply and demand uncertainties. Instead of using regular intervals defined by flow variables, they defined potential paths between facilities, which covered different types of uncertainty, simultaneously. (Niknamfar et al. 2014) proposed a three-stage supply chain network with the purpose of production-distribution planning, which was related to a robust scenario-driven optimization approach with non-deterministic parameters of production and distribution. (Mohammaddust et al. 2017) considered the demand and supply uncertainty risks to realize an agile and responsive supply chain network. Further, the uncertainty of market demand was considered with the probability distribution function, while the uncertainty of the supply due to disruptions was investigated based on different scenarios. (Salehi Sadghiani et al. 2015) designed the retail supply chain network with multi-state transportation facilities, which covered the uncertainties of disruptive and operational risks and, accordingly, implemented a scenario-based robust stochastic optimization approach. (Hasani & Khosrojerdi 2016) designed the resilient global supply chain network by using a case study of medical devices and provided a non-deterministic budget-based robust optimization approach to address the uncertainty of demand and procurement costs caused by various types of disruptions. (Jabbarzadeh et al. 2017) suggested a resilient supply chain network to deal with the uncertainty of supply (capacity) and demand as well as sudden strategic disruptions, which managed the conservative levels of solutions through using a robust stochastic approach. (Farrokh et al. 2017) developed the closed-loop supply chain network regarding parametric uncertainty and provided a flexible framework by using the robust-possibilistic programming approach through emphasizing both the optimality and feasibility robustness. (Hamidieh et al. 2017) represented a closed-loop supply chain network of educational electronics equipment, which covered the parametric uncertainty of cost, demand, and capacity by using a robust-possibilistic programming approach. Based on the studies above, increasing the compatibility and flexibility of the supply chain has not been accompanied by combined uncertainties. Table I presents the transparency of the present research innovations based on the conducted studies to organize the explored issues based on a robust optimization approach, by using both the optimality and feasibility robustness.

TABLE I. Literature review of resilient supply chain network based on feasibility and optimality robustness

References	Research Goals			Programming Approach			Uncertainty		Planning Horizon		Modeling Approach
	Responsiveness	Reliability	Resilience	Possibilistic	Stochastic	Flexible	Parameter	Disruption	Multi-period	Single-period	
Pan & Nagi (2010)					*		*		*		Stochastic-Robust
Pishvaee et al. (2012)	*			*			*			*	Possibilistic-Robust
Baghalian et al. (2013)	*				*		*			*	Stochastic-Robust
Niknamfar et al. (2015)					*		*		*		Stochastic-Robust
Salehi Sadghiani et al. (2015)			*		*		*	*		*	Possibilistic-Robust
Mohammaddust et al. (2015)	*				*		*	*		*	Stochastic-Robust
Hasani & Khosrojerdi (2016)			*				*	*	*		Robust
Pishvaee & fazli (2016)				*		*	*	*		*	Possibilistic-Robust
Jabbarzadeh et al. (2016)			*				*			*	Robust
Hamidieh et al. (2017)	*			*			*			*	Possibilistic-Robust
Farrokh et al. (2017)				*			*			*	Possibilistic-Robust
Fazli & Hamidieh (2017)		*			*		*	*		*	Stochastic-Robust
This research	*	*	*	*		*	*	*	*		Possibilistic-Robust

The present study aims to investigate the design of a resilient supply chain network for the final strategic products of the petrochemical industry, which has been faced with sanction disruptions and severe changes of the competitive market in recent years, by using a new step-by-step approach. Polyethylene products required by the provinces of the country are regarded among the strategic ones in the petrochemical industry, which are mainly used in the industries related to water and gas branches and kitchen utensils. On the other hand, upstream policies of the country vary based on the political and social conditions and the market. Further, the demand for polyethylene products is different at different time intervals. Sanction disruptions and the non-precision of other business parameters impose increasing uncertainties on the system, causing an imbalance between demand and supply and affecting optimal operations of the product in line with the needs of provinces of the country. In addition, the principle of securing the country's strategic infrastructure has been emphasized as one of the components of national security in the vision document of the Islamic Republic of Iran in the horizon of 2025. In this regard, the development of the infrastructure, such as the pipe industry and branching, has highly been prioritized, which requires special attention to the factors shaping the main framework of the present research as follows:

- The limitation of the capacity of domestic suppliers to supply raw materials for petrochemical industries;
- The lack of precise estimation of the storage capacity of raw materials in provincial strategic warehouses to meet the needs of petrochemical industries;
- The capacity management of the key network facilities during immediate disruptions;
- The control of product inventory based on the needs of provinces at different time periods; and
- The necessity of improving the storage capabilities in the field of strategic products.

Thus, the strategic importance of this research has led to a new approach in the design of a supply chain network in the national industry regarding the sudden and predictable disruptions. Further, uncertainties due to inadequate decision makers' knowledge, disruptions, and a dynamic business environment are covered in a flexible model. Furthermore, a new combination of flexible-credit-limiting mathematical programming with a robust approach is developed to deal with different types of parametric uncertainty in the present study.
The contributions of the present research are as follows:

- Using preventive and reactive strategies of the resiliency, simultaneously, at the upstream, operational, and downstream levels of the supply chain;
- Applying material and product storage strategies, simultaneously, in order to dynamically manage warehouse storage and provincial pole centers in different time periods;
- The implementation of multiple sourcing strategies in inventory replenishment periods; and
- The flexibility of the capacity of the facilities and network flow against severity of the possible disruption;
- The coverage of a variety of uncertainties due to inadequate knowledge and experience of decision-makers and the conditions of business dynamics; and
- The implementation of flexible-robust optimization method by covering the feasibility and optimality robustness.

The present study is a kind of operational research in which a new optimization method has been developed to deal with uncertainty while explaining the resilience strategies in sanctions conditions. Further, it presents one of the effective approaches in the resilient economy, which contributes to the development of applied knowledge to cope with disruptions and uncertainty.

The remainder of this paper is as follows. Comprehensive literature review and contributions of the proposed model are rendered in the Introduction. Problem definition and model formulation inspired by the polyethylene strategic supply chain network are presented in the Statement of the Problem (Section II). The possibilistic-robust programming approach is presented along with model formulation and its comprehensive description in the next section. The reviewed real case and comprehensive analysis of the outputs of the proposed model are presented in Section IV. Finally, future research guidelines, the conclusion of discussed issues on the proposed model, and some managerial proposals are presented in Section V.

II. STATEMENT OF THE PROBLEM

The proposed model is based on a real study of petrochemical-related industries in Iran. The products of the petrochemical industry are produced in three main categories: the main products such as ethylene, propylene, gasoline, and the like are regarded as the main materials of intermediate petrochemical products. The mid-range products can be PVC, melamine, etc., and the third group is the ultimate petrochemical products used in various industries such as rubber and synthetic fibers. In this regard, the growing trend of the plastic materials application, especially the use of polyethylene in the industry, is due to the properties and characteristics of these materials and their applications, which has led to significant advances in the production and usage rates in various industries in a short time period. As shown in Fig (1), effective resiliency strategies are designed based on the strategy development process, which are applied to the targeted levels of the supply chain network. These strategies include the sourcing strategy, the supply-outsourcing combination, confidence buffer, flexible capacity levels, uncertainty coverage, excess strategic inventory, and lead time.

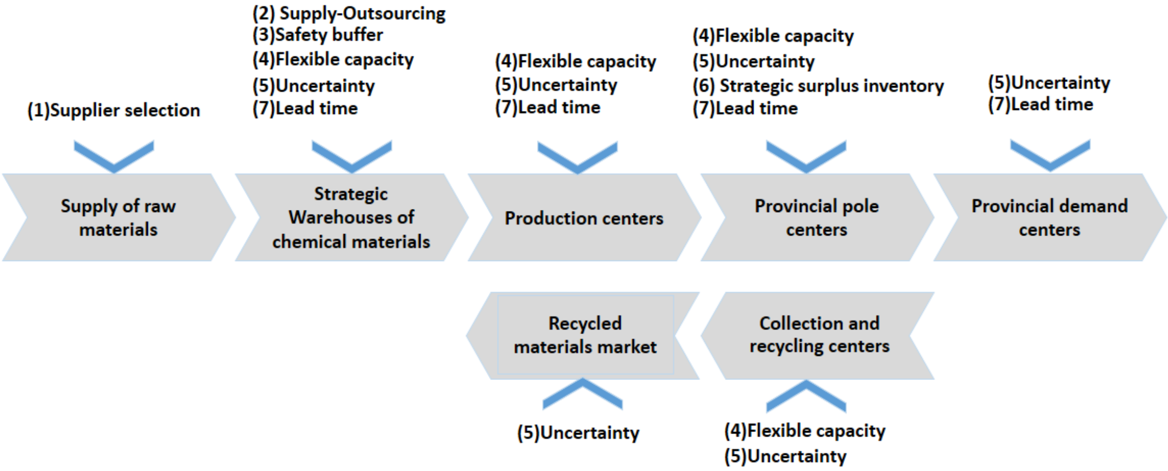

Fig 1. Application of preventive and reactive resilience strategies at different levels of the supply chain network

The conceptual combination of the resiliency indicated that the strategies used at the upstream, operational, and downstream levels of the supply chain network included the dimensions of both prevention and response and covered the sudden and predicted uncertainties of the market demand and facilities capacity.

A. Problem definition

The main framework of the research is the closed-loop multistage supply chain network, which includes the main suppliers, strategic warehouses of raw materials, manufacturing centers, provincial pole centers (distribution), recycling centers, provincial market, and recycled materials market. The network starts with the supply of raw materials from the suppliers' side and is organized in strategic storage warehouses of raw materials. The way of storing and supplying raw materials to factories is regarded as the intersection of several effective strategies for supply chain resiliency. Based on the distribution policies, the production centers receive raw materials and send them to the provincial poles centers after manufacturing the defined products. The way of choosing and the position of pole centers are based on some features such as per capita manufacturing of products (production pole), available hardware resources, and human resources. In pole centers, the demand for the provincial market is provided in line with the product storage and distribution strategies. Returned products are organized in the collection and recycling centers and used in each of the reusable items and commercial returns. Fig (2) represents the conceptual framework of the research.

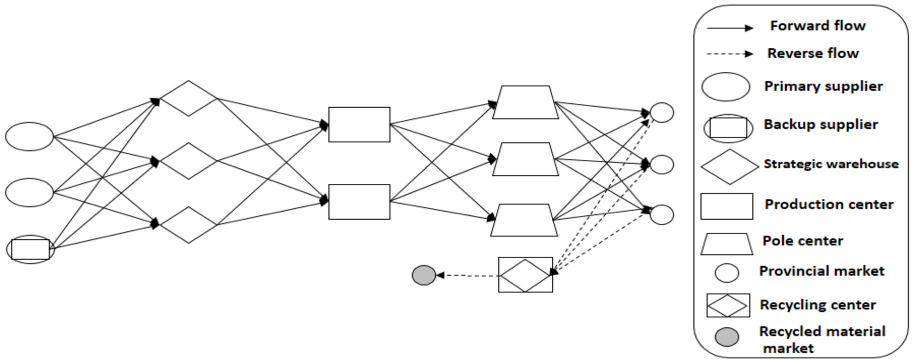

Fig 2. Conceptual model of supply chain network

The present study aims to design a resilient multi-stage, multi-period, multi-product supply chain network with disruptions and uncertainty. The intended disruptions in the present study are of a sudden and potential kind. At the same time, the system uncertainties support the complex and varying market conditions and the lack of experimental data; this study aims to make the system resilient when there are various types of sanction disruptions. The model parameters include processing, operation, maintenance, transportation, and non-deterministic packaging costs. As shown in Figs (2 & 4), the developed strategies are applied at the levels of the supply chain. Fig (3) illustrates the proposed strategic supply chain network.

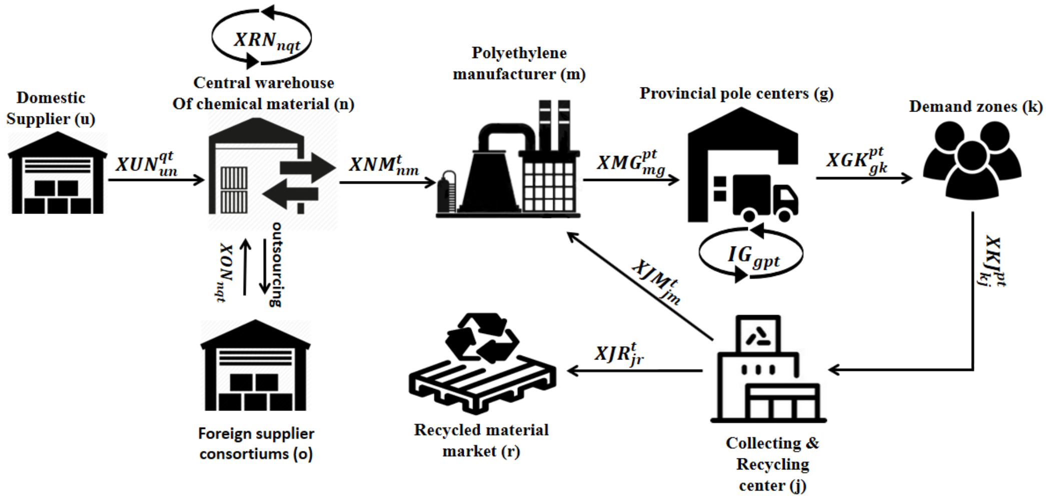

Fig 3. Supply chain network of polyethylene national industries

At the upstream level of the supply chain, we consider the strategy of selecting a supplier with cost reduction approach and then, we pursue the strategy of reducing delay time at all levels of the supply chain. Then, the expected latency of demand centers is controlled, by which an increase occurs in the system responsiveness. Then, the strategy of allocating different levels of capacity is considered for the key facilities of the network in order to increase the flexibility of the system to cover the input and output flows of facilities. There are two strategic storage centers for raw materials and the final product in the network, and different storage resiliency strategies are used at the two centers. In the strategic warehouses of raw material, the confidence buffers strategy and the combination of production-outsourcing are used. The confidence buffer resources are organized in such a way that if the amount of raw material required by the production centers is higher than the confidence buffer of distribution centers due to sanction disruptions, the amount of raw material shortage is outsourced to other suppliers and the cost of outsourcing is calculated. In addition, the maintenance cost is imposed on the system if some amount of confidence buffer remains at the end of the period. On the other hand, the confidence buffer amount consumed during the previous period is supplied from domestic suppliers at the beginning of each period. This strategy makes the outsourcing operations have a rigorous control in the strategic warehouses in the country. Further, the implementation of the above strategy in the system will result in outsourcing operations, which should be passed after experiencing immediate critical conditions, and the manufacturing centers in Iran will remain active. The strategic surplus inventory is another strategy used at the second storage center (provincial pole center), which performs allocation operations in accordance with the needs of the country's provinces at different time periods. Since the demand for various types of polyethylene products is increasing in the country, the production of different types of products in some production centers is more than the demand of regional poles; thus, the production surplus is transferred to other provincial pole centers. The level of strategic inventory is defined in provincial pole centers, which does not permit the amount of inventory of polyethylene products to be lower than the level of strategic inventory at the provincial pole centers at the end of the time period. Hence, the defined level of strategic inventory responds to the demand for the polyethylene products in provincial pole centers and exports its surplus.

The expected lead time of the national and international markets is another strategy, which is implemented at the operational and downstream levels of the supply chain and covers the expected latency of provincial pole centers in demand delivery according to different time intervals. Regarding the expected latency parameters of the operational and downstream facilities of the network strategy, this strategy provides the coverage of the network uncertainty using fuzzy programming, including non-deterministic parameters due to lack of recognition, empirical sources, and the dynamic business environment. Additionally, the flexible capacity level strategy is considered at the operational level of the supply chain network for production and distribution facilities.

B. Problem assumptions

Based on the above-mentioned issues, the following assumptions are suggested:

- All needs of the provinces are met and the shortage of polyethylene products is not allowed in different time periods;
- Periods are set seasonally;
- The confidence buffer resources are maintained in strategic warehouses and are resistant to disruptions;
- The numbers and the locations of foreign suppliers, strategic warehouses of raw materials, manufacturing centers, and provincial pole centers are specified;
- Manufacturing centers, strategic warehouses of raw materials, and provincial pole centers are multi-capacity;
- Strategic warehouses of raw materials include confidence buffer resources and allocate a level of confidence buffer capacity to each strategic warehouse; and
- The proposed resiliency model is multi-product and multi-period.

C. Optimization model

Indices

O	Potential location index of foreign supplier consortiums (backup)
U	Potential location index of the domestic supplier (polyethylene production refinery)
M	Potential location index of production center (polyethylene manufacturer)
N	Potential location index of the central warehouse of chemical material
G	Potential location index of provincial pole center
K	Index of demand zones
R	Index of recycled materials market
J	Potential location index of collecting and recycling centers
T	Index of periods
Q	Index of material type
A	Index of the capacity level of the central warehouse of chemical material
B	Index of the capacity level of the production center (polyethylene manufacturer)

C	Index of the capacity level of provincial pole centers
E	Index of the capacity level of collecting and recycling centers
I	Index of the capacity level of confidence buffer
P	Index of product (a group of polyethylene products)

Parameters

FM_{mb}	The fixed cost of creating and implementing the polyethylene production centers *m* with capacity level *b*
FG_{gc}	The fixed cost of creating and implementing the provincial pole center *g* with capacity level *c*
FN_{na}	The fixed cost of creating and implementing the central warehouse of chemical material *n* with the capacity level *a*
FJ_{je}	The fixed cost of creating and implementing of the collecting and recycling center *j* with capacity level *e*
FSN_{ni}	Creating cost of confidence buffer with capacity level *i* in the central warehouse of chemical material *n*
FU_u	The exploiting and selecting cost of domestic supplier *u* (polyethylene production refinery)
CU_{uqt}	The purchasing price of the polyethylene material *q* from domestic supplier *u* in period *t*
CPN_{nqt}	The supplying cost of each unit of outsourced polyethylene material *q* in the central warehouse of chemical material *n* in period *t*
CN_{nqt}	Maintenance cost of polyethylene material *q* in the central warehouse of chemical material *n* in period *t*
CM_{mpt}	Production cost of each unit of polyethylene product *p* in the polyethylene manufacturer *m* in period *t*
$CJ1_{jt}$	Operation cost of each pallet of polyethylene product in the collecting and recycling center *j* in period *t*
$CJ2_{jqt}$	Operation cost of each unit of polyethylene material *q* in the collecting and recycling center *j* in period *t*
TMG_{mg}^{p}	Transportation cost of polyethylene product *p* from polyethylene manufacturer *m* to provincial pole center *g*
θH_p	Maximum percentage of processed polymer material to produce product *p*
θL_p	Minimum percentage of processed polymer material to produce product *p*
CG_{gp}	Maintenance cost of polyethylene product *p* in the provincial pole center *g*
TGK_{gk}^{p}	Transportation cost of polyethylene product *p* from pole center *g* to provincial market *k*
CK_{kp}	Operation cost of provincial market *k* for product *p*
TKJ_{kj}^{p}	Transportation cost of returned product *p* from provincial center *k* to recycling center *j*
TNM_{nm}	Transportation cost of chemical material from central warehouse *n* to polyethylene manufacturer *m*
TUN_{un}	Transportation cost of chemical material from polyethylene industry *u* to central warehouse of chemical material *n*
TJM_{jm}	Transportation cost of recycled polyethylene material from recycling center *j* to polyethylene manufacturer *m*
TJR_{jr}	Transportation cost of recycled polymer material *j* to recycled material market *r*
DEK_{kpt}	Demand of provincial market *k* for product *p* in period *t*
DER_{rt}	Demand for recycled polymer material *r* in period *t*
$CAPM_{mb}$	Maximum capacity of polyethylene manufacturer *m* with capacity level *b*
$CAPG_{gc}$	Maximum capacity of provincial pole center *g* with capacity level *c*
$CAPN_{na}$	Maximum capacity of the central warehouse of chemical material *n* with capacity level *a*
$CAPU_{uqt}$	Maximum capacity of domestic supplier *u* with type *q* in period *t*
$CAPJ_{je}$	Maximum capacity of recycling center *j* with capacity level *e*

RK	Percentage of returned products from provincial demand center
POR_{pq}	Percentage of recycled polyethylene *q* from polyethylene product *p*
DTN_{nmt}	Maximum acceptable delay time to supply polyethylene from central warehouse of chemical material *n* to the polyethylene manufacturer *m* in period *t*
DTM_{mgt}	Maximum acceptable delay time to produce polyethylene products from polyethylene manufacturer *m* for provincial pole center *g* in period *t*
DTG_{gkt}	Maximum acceptable delay time to distribute polyethylene products from provincial pole center *g* to provincial demand centers *k* in period *t*
DTK_{kt}	Maximum acceptable delay time to satisfy provincial demand centers *k* in period *t*
$ב_p$	The production rate of polyethylene products p due to reactive effect on polymer-based materials
POQ_q	Quality percentage of polyethylene material *q*
DN_{nt}	Capacity percentage of the central warehouse of chemical material *n* in period *t*
DM_{mt}	Disrupted capacity percentage of polyethylene manufacturer *m* in period *t*
DG_{gt}	Disrupted capacity percentage of provincial pole center *g* in period *t*
DJ_{jt}	Disrupted capacity percentage of recycling center *j* in period *t*
CSN_{nqi}	Amount of confidence buffer of chemical material *q* in the central warehouse *n* with capacity level *i*
SIG_g	Strategic inventory level of provincial pole center *g*

Variables

XNM_{nm}^{qt}	The quantity of shipped polyethylene material *q* from central warehouse *n* to polyethylene manufacturer *m* in period *t*
XUN_{un}^{qt}	The quantity of shipped polyethylene material *q* from domestic supplier *u* to central warehouse *n* in period *t*
XMG_{mg}^{pt}	The quantity of shipped product *p* from polyethylene manufacturer *m* to provincial pole center *g* in period *t*
XGK_{gk}^{pt}	The quantity of shipped product *p* from provincial pole center *g* to provincial market *k* in period *t*
XKJ_{kj}^{pt}	The quantity of shipped product *p* from demand center *k* to recycling center *j* in period *t*
XJM_{jm}^{qt}	The quantity of recycled polyethylene material *q* shipped from recycling center *j* to polyethylene manufacturer *m* in period *t*
XJR_{jr}^{t}	The quantity of recycled polymer material from recycling center *j* to recycled material market *r* in period *t*
XCN_{nqt}	Auxiliary variable of the amount of lost polyethylene material *q* in the central warehouse *n* in period *t* under disruption
XON_{nqt}	The quantity of polyethylene material *q* provided through outsourcing in the central warehouse *n* in period *t*
XRN_{nqt}	The quantity of the remaining confidence buffer (polyethylene material) *q* in the central warehouse *n* in period *t*
XU_{mt}^{qp}	The quantity polyethylene material *q* to produce polyethylene product *p* in the polyethylene manufacturer *m* in period *t*
XP_{mp}^{t}	The quantity of produced polyethylene product *p* in the polyethylene manufacturer *m* in period *t*
IG_{gpt}	The quantity of product inventory *p* in the provincial pole center *g* in period *t*
XRU_u	Binary variable; equals *1* if domestic supplier *u* is opened, *0* otherwise
XN_{na}	Binary variable; equals *1* if the central warehouse of chemical material *n* with the capacity level *a* is opened, *0* otherwise
XM_{mb}	Binary variable; equals *1* if polyethylene manufacturer *m* with capacity level *b* is opened, *0* otherwise
XG_{gc}	Binary variable; equals *1* if provincial pole center *g* with capacity level *c* is opened, *0* otherwise

XJ_{je}	Binary variable; equals *1* if recycling center *j* with capacity level *e* is opened, *0* otherwise
XSN_{nqi}	Binary variable; equals *1* if the confidence buffer of polyethylene material *q* with capacity level *i* is assigned to central warehouse *n*, *0* otherwise
XTM_{nm}^{qt}	Binary variable; equals *1* if polyethylene material *q* is shipped from central warehouse *n* to polyethylene manufacturer *m* in period *t*, *0* otherwise
XTG_{mg}^{pt}	Binary variable; equals *1* if polyethylene product *p* is shipped from polyethylene manufacturer *m* to provincial pole center *g* in period *t*, *0* otherwise
XTK_{gk}^{pt}	Binary variable; equals *1* if polyethylene product *p* is shipped from provincial pole center *g* to provincial demand market *k* in period *t*, *0* otherwise

$$\begin{aligned} Min\ Z_1 = & \sum_u FU_u\, XRU_u + \sum_n \sum_a FN_{na}\, XN_{na} + \sum_n \sum_q \sum_i FSN_{ni}\, XSN_{nqi} + \sum_m \sum_b FM_{mb}\, XM_{mb} \\ & + \sum_g \sum_c FG_{gc}\, XG_{gc} + \sum_g \sum_p \sum_t CG_{gp}\, IG_{gpt} + \sum_j \sum_e FJ_{je}\, XJ_{je} + \sum_e \sum_n \sum_q \sum_t (CU_{uqt} + TUN_{un})\, XUN_{un}^{qt} \\ & + \sum_n \sum_q \sum_t CPN_{nqt}\, XON_{nqt} + \sum_n \sum_q \sum_t CN_{nqt}\, XRN_{nqt} + \sum_n \sum_m \sum_q \sum_t TNM_{nm}\, XNM_{nm}^{qt} \\ & + \sum_m \sum_g \sum_p \sum_t (CM_{mpt} + TMG_{mg}^{p})\, XMG_{mg}^{pt} + \sum_k \sum_j \sum_p \sum_t (TKJ_{kj}^{p} + CJ1_{jt})\, XKJ_{kj}^{pt} \\ & + \sum_j \sum_m \sum_q \sum_t (CJ2_{jqt} + TJM_{jm}) XJM_{jm}^{qt} + \sum_g \sum_k \sum_p \sum_t TGK_{gk}^{p}\, XGK_{gk}^{pt} + \sum_j \sum_r \sum_t XJR_{jr}^{t} TJR_{jr} \end{aligned} \tag{1}$$

s.t.

$$\sum_n XUN_{un}^{qt} \le CAPU_{uqt} XRU_u \qquad \forall\ u, q, t \tag{2}$$

$$XCN_{nqt} - \sum_i CSN_{nqi}\, XSN_{nqi} = XON_{nqt} - XRN_{nqt} \qquad \forall n, q, t \tag{3}$$

$$\sum_m XNM_{nm}^{qt} + \sum_i CSN_{nqi}\, XSN_{nqi} = \sum_e XEN_{en}^{qt} \qquad \forall n, q, t = 1 \tag{4}$$

$$\sum_m XNM_{nm}^{qt} + XCN_{nqt-1} - XON_{nqt-1} = \sum_e XEN_{en}^{qt} \qquad \forall n, q, t > 1 \tag{5}$$

$$\sum_m XNM_{nm}^{qt} DN_{nt} \le XCN_{nqt} \qquad \forall n, q, t \tag{6}$$

$$\sum_n XNM_{nm}^{qt} + \sum_j XJM_{jm}^{qt} = \sum_p XU_{mt}^{qp} \qquad \forall\ m, q, t \tag{7}$$

$$\sum_q POQ_q\, XU_{mt}^{qp} \le \theta H_p \sum_q XU_{mt}^{qp} \qquad \forall m, t, p \tag{8}$$

$$\sum_q POQ_q\, XU_{mt}^{qp} \ge \theta L_p \sum_q XU_{mt}^{qp} \qquad \forall m, t, p \tag{9}$$

$$\beth_p \sum_q XU_{mt}^{qp} = XP_{mp}^{t} \qquad \forall m,t,p \qquad (10)$$

$$\sum_g XMG_{mg}^{pt} = XP_{mp}^{t} \qquad \forall m,t,p \qquad (11)$$

$$\sum_m XMG_{mg}^{pt} + IG_{g,p,t-1} = IG_{gpt} + \sum_k XGK_{gk}^{pt} + \sum_v XGV_{gv}^{pt} \qquad \forall g,p,t > 1 \qquad (12)$$

$$\sum_p \sum_t IG_{gpt} \geq SIG_g \qquad \forall g \qquad (13)$$

$$\sum_g XGK_{gk}^{pt} \geq DEK_{kpt} \qquad \forall k,p,t \qquad (14)$$

$$\sum_j XKJ_{kj}^{pt} = RK.DEK_{kpt} \qquad \forall\ k,p,t \qquad (15)$$

$$\sum_k \sum_p \mathrm{POR}_{pq}\, XKJ_{kj}^{pt} = \sum_m XJM_{jm}^{qt} \qquad \forall q,t,j \qquad (16)$$

$$\sum_k \sum_p \sum_q (1 - \mathrm{POR}_{pq})\, XKJ_{kj}^{pt} = \sum_r XJR_{jr}^{t} \qquad \forall\ t,j \qquad (17)$$

$$\sum_j XJR_{jr}^{t} \geq DER_{rt} \qquad \forall\ r,t \qquad (18)$$

$$\sum_p IG_{gpt} \leq \sum_c CAPG_{gc} XG_{gc} (1 - DG_{gt}) \qquad \forall g,t \qquad (19)$$

$$\sum_g \sum_p XMG_{mg}^{pt} \leq \sum_b CAPM_{mb}\, XM_{mb} (1 - DM_{mt}) \qquad \forall m,t \qquad (20)$$

$$\sum_m \sum_q XNM_{nm}^{qt} + \sum_i CSN_{ni} XSN_{ni} \leq \sum_a CAPN_{na}\, XN_{na} (1 - DN_{nt}) \qquad \forall n,t \qquad (21)$$

$$\sum_m XJM_{jm}^{t} + \sum_r XJR_{jr}^{t} \leq \sum_e CAPJ_{je}\, XJ_{je} (1 - DJ_{jt}) \qquad \forall j,t \qquad (22)$$

$$DTN_{nmt} XTM_{nm}^{qt} + DTM_{mgt} XTG_{mg}^{pt} + DTG_{gkt} XTK_{gk}^{pt} \leq DTK_{kt} \qquad \forall\ k,n,m,g,q,p,t \qquad (23)$$

$$XNM_{nm}^{qt} \leq M.XTM_{nm}^{qt} \qquad \forall\ n,m,q,t \qquad (24)$$

$$XMG_{mg}^{pt} \leq M.XTG_{mg}^{pt} \qquad \forall\ m,g,p,t \qquad (25)$$

$$XGK_{gk}^{pt} \leq M.XTK_{gk}^{pt} \qquad \forall\ g,k,p,t \qquad (26)$$

$$\sum_b XM_{mb} \leq 1 \qquad \forall\ m \qquad (27)$$

$$\sum_{a} XN_{na} \leq 1 \qquad \forall\, n \qquad (28)$$

$$\sum_{c} XG_{gc} \leq 1 \qquad \forall\, g \qquad (29)$$

$$\sum_{e} XJ_{je} \leq 1 \qquad \forall\, j \qquad (30)$$

$$\sum_{u} XRU_{u} \leq 1 \qquad (31)$$

$$\sum_{a} XN_{na} = \sum_{i} XSN_{ni} \qquad \forall\, n \qquad (32)$$

$$XM_{mb}, XN_{na}, XRU_{u}, XSN_{ni}, XG_{gc}, XJ_{je}, XTM_{nm}^{qt}, XTG_{mg}^{pt}, XTK_{gk}^{pt} \in \{0,1\} \qquad (33)$$

$$XNM_{nm}^{qt},\ XEN_{en}^{qt},\ XMG_{mg}^{pt}, XGK_{gk}^{pt}, XGV_{gv}^{pt}, XCN_{nt}, XJM_{jm}^{t} \qquad (34)$$

$$, XON_{nt}, XRN_{nt}, XU_{mt}^{qp}, IG_{gpt}, XKJ_{kj}^{t}, XJR_{jr}^{t} \geq 0$$

In the above math combination, relation (1) minimizes a varied range of network costs. These costs include those of supplier selection, setting up strategic storage facilities and creating their confidence buffers, setting up production centers, setting up a provincial pole and maintaining its strategic inventory, setting up collection and recycling centers, purchasing and shipping of polyethylene materials, outsourcing and maintenance of confidence buffer, polyethylene materials delivery to polyethylene production plants, production and transportation to provincial pole centers, collection, primary recycling and transportation to recycling centers, separation, and secondary recycling and sending to production centers. The last two items involve transportation costs to provincial demand centers and the market for recycled materials. Relation (2) regulates the output flow of suppliers in proportion to their capacity. Relation (3) ensures that in the event of disturbances such as sanctions when the central raw materials warehouses are facing a shortage, a portion of products would be provided through outsourcing to foreign suppliers. It should be noted that at the end of each period, we will have the remaining confidence buffer with a certain amount. In fact, the lack of chemicals occurs when the amount of raw material lost due to disturbances is greater than the confidence buffer. Equation (4) balances the material flow in the central stock of raw materials in the first period. Equation (5) balances the material flow after the first period. In the event of an impairment, if the amount of raw material lost is greater than the confidence buffer level, the customers' demand and capacity levels of the confidence buffer are supplied by the main suppliers of polyethylene materials. Otherwise, the capacity levels of confidence reserves are merely completed. Constraint (6) explains the amount of raw material destroyed in each strategic warehouse of chemicals while the disturbances occur. In relations (7-9), a combined variable is defined, which adjusts the polythene materials with maximum and minimum processing levels proportionate to the production of a variety of products so that the desired target combination will be lower than the maximum level of product in constraint (8) and more than the minimum level of the product in constraint (9). Relation (10) determines the amount of products manufacturing according to the combined variable and the product processing rate. Equation (11) balances the product manufacturing flow and output from production centers. Relations (12-13) explain the strategy of "strategic inventory" at provincial pole centers. In fact, the amount of "strategic inventory" is defined in line with governmental policies and the necessity to meet demands from the provinces in each period, which is continually being used and re-filled proportional to the input and output flows of the provincial pole centers. Relation (14) ensures that the demands of the provincial centers are fully satisfied. Relation (15) explains the amount of returned products from provincial demand centers. Relations (16-17) balance the number of recycled materials and output stream from collection and recycling centers. Relation (18) ensures the supply of market demand for recycling materials. Relations (19-22) improve the system reliability. In critical situations leading to interruptions in the main facilities of the network, they guarantee the flow allocation merely as large as their remaining capacity. Therefore, the flow of raw materials and products in the supply chain network is not interrupted. In this regard, the target facilities, the central warehouse of chemicals, manufacturing centers, provincial pole centers, and centers for collecting and recycling vulnerable facilities are considered. Constraint (23) ensures that the provincial center's demands are met at the acceptable maximum lead time and within the framework of different time periods. Constraints (24-26) determine the route of movement of products required by provincial centers and satisfy the customers' demand for compliance with the acceptable lead time of each path. The value of the parameter M is determined based on the maximum demand of the provincial market. Constraints (27-31) lead to allocating a level of capacity to domestic raw materials warehouses, manufacturer centers, provincial pole centers, and recycling centers at maximum. Constraint (32) causes the allocation of only a capacity level of the confidence buffer to each strategic storehouse of opened chemicals. Constraints (33-34) also explain the binary and non-negative variables.

III. POSSIBILISTIC-ROBUST PROGRAMMING APPROACH

In the industrial environment, several non-deterministic parameters are involved in the decision-making process. These non-deterministic or probabilistic parameters are divided into two general categories. The first category is related to the variations of the expected values of target and constraint parameters, which are caused by the changing conditions of the business market. The second category is related to inadequate knowledge of the parameters. The disruptions caused by sanctions are one of the most important factors in its emergence. Therefore, to deal with the uncertainty in decision making about the atmosphere and quick, timely response to customers' demand, two efficient approaches are suggested. The flexible approach is suggested to address the first category of uncertainties, and the credibility constrained programming approach is proposed to face the second category; it is a new mathematical combination. In this regard, the basic flexible model of the design of the supply chain network is introduced (Pishvaee and Fazli, 2016).

$$
\begin{aligned}
& Min\ Z = (\widetilde{Fc})y + (\widetilde{Pc} + \widetilde{Tc})x \\
& s.t. \quad Ax \geq \widetilde{DE} - \tilde{\rho}(1-\eta) \\
& Bx = 0 \\
& Hx \leq (\widetilde{Cap})y + [\tilde{\tau}(1-\Pi)]y \\
& Tx \leq 1 \\
& L.XT \leq \widetilde{\mathrm{DT}} + \widetilde{\Theta}(1-\Omega) \\
& y \in \{0,1\}, \ \ x \geq 0
\end{aligned}
\tag{35}
$$

In the above flexible model, $\widetilde{Fc}$, $\widetilde{Pc}$, $\widetilde{Tc}$, $\widetilde{DE}$, $\widetilde{Cap}$, and $\widetilde{DT}$ represent the fixed opening cost of facilities, processing cost, transportation cost, customer demand, facilities capacity, and acceptable lead time. $A, B, H, L,$ and T indicate the technical coefficients of the model. $\eta, \Pi,$ and Ω define satisfaction levels of flexible constraints and the fuzzy numbers $\tilde{\rho}, \tilde{\tau},$ and $\widetilde{\Theta}$ are violations of soft constraints. Also, the binary variable XT explains the flow between facilities in each period (Peidro et al., 2009). The prominent points of the triangular fuzzy numbers are as follows:

$$\tilde{\rho} = \rho_{(1)} + \rho_{(2)} + \rho_{(3)}, \ \tilde{\tau} = \tau_{(1)} + \tau_{(2)} + \tau_{(3)} \ and \ \widetilde{\Theta} = \Theta_{(1)} + \Theta_{(2)} + \Theta_{(3)}$$

In this case, by using the fuzzy ranking method and the equations $\left(\rho_{(2)} + \frac{\xi_\rho - \xi_\rho'}{3}\right), \left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon_\tau'}{3}\right),$ and $\left(\Theta_{(2)} + \frac{\chi_\Theta - \chi_\Theta'}{3}\right)$, an equivalent definitive model of the above mathematical combination is presented (Zhang et al., 2012). Also, $\upsilon_\tau, \upsilon_\tau'$; ξ_ρ, ξ_ρ'; and $\chi_\Theta, \chi_\Theta'$ are the marginal distances of the triangular fuzzy numbers $\tilde{\rho}, \tilde{\tau},$ and $\widetilde{\Theta}$, which are defined, for example, as relations $\left(\xi_\rho = \rho_3 - \rho_2\right)$ and $\left(\xi_\rho' = \rho_2 - \rho_1\right)$ (Yager, 1981).

$$Min\ Z = (\widetilde{FC})y + (\widetilde{CC})x$$

$$s.t. \quad Ax \geq \widetilde{DE} - \left(\rho_{(2)} + \frac{\xi_\rho - \xi_\rho'}{3}\right)(1-\eta)$$

$$Bx = 0 \tag{36}$$

$$Hx \leq (\widetilde{Cap})y + [\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon_\tau'}{3}\right)(1-\Pi)]y$$

$$Tx \leq 1$$

$$L.XT \leq \widetilde{DT} + \left(\Theta_{(2)} + \frac{\chi_\Theta - \chi_\Theta'}{3}\right)(1-\Omega)$$

$$y \in \{0,1\}, \ \ x \geq 0$$

The expressions $\left(\rho_{(2)} + \frac{\xi_\rho - \xi_\rho'}{3}\right)(1-\eta)$, $\left[\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon_\tau'}{3}\right)(1-\Pi)\right]y$, and $\left(\Theta_{(2)} + \frac{\chi_\Theta - \chi_\Theta'}{3}\right)(1-\Omega)$ determine the possible violation values of the soft constraints of the problem. In the above model, the minimum satisfaction levels of flexible constraints (η≥0 and Π, Ω≤1) are determined by the decision makers. Then, the credibility constrained programming is used to control the soft constraints of the model. In fact, an efficient approach is proposed that supports all types of triangular and trapezoidal fuzzy spaces and provides the possibility of satisfying the chance constraints of the problem at optimum confidence levels (Zhang et al., 2012). On the other hand, the credibility criterion used determines the credit value of the fuzzy event and specifies the occurrence of a fuzzy parameter with strong fuzzy mathematical concepts.

We now consider the fuzzy number $\tilde{\zeta} = (\zeta_1, \zeta_2, \zeta_3)$ of the membership function $\mu_{\tilde{\zeta}(x)}$ and the real number r. In this case, the criterion of fuzzy parameter validity is defined as the average of the criteria of possibility and requirement:

$$Cr\{\tilde{\zeta} \geq r\} = \frac{1}{2}(\underbrace{sup\ \mu_{\tilde{\zeta}(x)}}_{Pos\{\tilde{\zeta}\geq r\}} + \underbrace{1 - sup\ \mu_{\tilde{\zeta}(x)}}_{Nec\{\tilde{\zeta}\geq r\}}) \tag{37}$$

In this case, the criteria for the possibility and the requirement of the fuzzy parameter ζ are defined in the form of relations (38) and (39).

$$Pos\{\tilde{\zeta} \geq r\} = \begin{cases} 1 & r \leq \zeta_{(2)} \\ \frac{r-\zeta_{(3)}}{\zeta_{(2)}-\zeta_{(3)}} & \zeta_{(2)} \leq r \leq \zeta_{(3)} \\ 0 & r \geq \zeta_{(3)} \end{cases} \tag{38}$$

$$Nec\{\tilde{\zeta} \geq r\} = \begin{cases} 1 & r \leq \zeta_{(1)} \\ \frac{r-\zeta_{(2)}}{\zeta_{(1)}-\zeta_{(2)}} & \zeta_{(1)} \leq r \leq \zeta_{(2)} \\ 0 & r \geq \zeta_{(2)} \end{cases} \tag{39}$$

Also, the degrees of credibility of ζ ≥ r and ζ ≤ r are defined as relations (40) and (41).

$$Cr\{\tilde{\zeta} \geq r\} = \begin{cases} 1 & r \leq \zeta_{(1)} \\ \frac{2\zeta_{(2)}-\zeta_{(1)}-r}{2(\tau_{(2)}-\zeta_{(1)})} & \zeta_{(1)} \leq r \leq \zeta_{(2)} \\ \frac{r-\zeta_{(3)}}{2(\zeta_{(2)}-\zeta_{(3)})} & \zeta_{(2)} \leq r \leq \zeta_{(3)} \\ 0 & r \geq \zeta_{(3)} \end{cases} \quad (40)$$

$$Cr\{\widetilde{\zeta} \leq r\} = \begin{cases} 0 & r \leq \zeta_{(1)} \\ \frac{r-\zeta_{(1)}}{2(\zeta_{(2)}-\zeta_{(1)})} & \zeta_{(1)} \leq r \leq \zeta_{(2)} \\ \frac{2\zeta_{(2)}-\zeta_{(3)}-r}{2(\zeta_{(2)}-\zeta_{(3)})} & \zeta_{(2)} \leq r \leq \zeta_{(3)} \\ 1 & r \geq \zeta_{(3)} \end{cases} \quad (41)$$

Now, we assume that $\zeta_i = (\zeta_i^1, \zeta_i^2, \zeta_i^3)$ and $\acute{\zeta}_j = (\acute{\zeta}_j^1, \acute{\zeta}_j^2, \acute{\zeta}_j^3)$ are corresponding triangular fuzzy variables, which are defined by the levels of credibility of $k_i, \acute{k}_j > 0$ and the value of $\beta \epsilon [0.5,1]$. Therefore, the following fuzzy relations are established (Liu & Liu, 2002; Zhang & Huang, 2010):

$$Cr\left\{\sum_i k_i\,\tilde{\zeta}_i \leq r\right\} \geq \beta \Leftrightarrow (2\beta-1)\sum_i k_i\,\zeta_i^3 + 2(1-\beta)\sum_i k_i\,\zeta_i^2 \leq r \quad (42)$$

$$Cr\left\{\sum_j \acute{k}_j\,\tilde{\acute{\zeta}}_j \geq r\right\} \geq \beta \Leftrightarrow (2\beta-1)\sum_j \acute{k}_j\,\acute{\zeta}_j^1 + 2(1-\beta)\sum_j \acute{k}_j\,\acute{\zeta}_j^2 \geq r \quad (43)$$

$$Cr\left\{\sum_i k_i\,\tilde{\zeta}_i - \sum_j \acute{k}_j\,\tilde{\acute{\zeta}}_j \leq r\right\} \geq \beta \Leftrightarrow (2\beta-1)\sum_i k_i\,\zeta_i^3 + 2(1-\beta)\sum_i k_i\,\zeta_i^2$$
$$-\left[(2\beta-1)\sum_j \acute{k}_j\,\acute{\zeta}_j^1 + 2(1-\beta)\sum_j \acute{k}_j\,\acute{\zeta}_j^2\right] \leq r \quad (44)$$

Definition: If $Cr\{\sum_i k_i\,\tilde{\zeta}_i \leq r\} = 1/2$ and $Cr\{\sum_i k_i\,\tilde{\zeta}_i \geq r\} = 1/2$ are established, then, the degree of validity or credibility of 0.5 is set and there would be an equivalent equation between $\sum_i k_i\,\tilde{\zeta}_i$ and r, which can be defined as the relation $\sum_i k_i\,\tilde{\zeta}_i \approx r$. Based on the above definition and relations (40) and (41), the following relation is established:

$$\sum_i k_i\,\tilde{\zeta}_i \approx r \Leftrightarrow \sum_i k_i\,\zeta_i^2 = r \quad (45)$$

Also, the expected value of $\sum_i k_i\,\tilde{\zeta}_i$ is obtained from the following equation based on the criterion of credibility (Hatefi et al., 2014).

$$E\left[\sum_i k_i\,\tilde{\zeta}_i\right] = \sum_i k_i E[\tilde{\zeta}_i] = \sum_i k_i\left(\frac{\zeta_i^1 + 2\zeta_i^2 + \zeta_i^3}{4}\right) \quad (46)$$

In this case, the definitive model of the possibilistic-flexible programming of the problem is presented as follows.

$$\begin{aligned} & Min\ Z = \left(\frac{FC^1 + 2FC^2 + FC^3}{4}\right)y + \left(\frac{CC^1 + 2CC^2 + CC^3}{4}\right)x \\ & s.t. \quad Ax \geq [(2\sigma-1)DE^3 + (2-2\sigma)DE^2] - \left(\rho_{(2)} + \frac{\xi_\rho - \xi_\rho'}{3}\right)(1-\eta) \\ & Bx = 0 \\ & Hx \leq [(2\varsigma-1)Cap^1 + (2-2\varsigma)Cap^2]y + \left[\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon_\tau'}{3}\right)(1-\Pi)\right]y \\ & Tx \leq 1 \end{aligned} \quad (47)$$

$$L.XT \leq [(2\varrho - 1)DT^3 + (2 - 2\varrho)DT^2] + \left(\Theta_{(2)} + \frac{\chi_\Theta - \chi'_\Theta}{3}\right)(1 - \Omega)$$

$$y, XT \in \{0,1\}, \;\; x \geq 0$$

In the above deterministic fuzzy programming model, ς, σ, and ρ are the confidence levels of the constraints encompassing the non-deterministic parameters of demand, capacity, and acceptable lead time ($\sigma, \varrho \geq 0.5, \varsigma \leq 1$) and η, Π, and Ω are the satisfaction levels of the problem's flexible constraints. It is worth noting that the levels of confidence and satisfaction levels of the flexible constraints of the problem are determined by the decision maker. However, the above flexible possibilistic programming model faces the following challenges:

- There is no guarantee that the optimum values of confidence levels and satisfaction levels of soft constraints of the problem will be determined.
- By increasing the number of flexible constraints of the problem, the number of tests to determine the levels of confidence and satisfaction of the constraints increases.
- The model is not sensitive to possible deviations from flexible constraints and unexplained answers, which increases the network costs.
- This model is not sensitive to the objective function deviations from expected values. It therefore creates great risk for the decision maker.

To meet the challenges mentioned above, the new robust fuzzy mathematical programming model is provided. It should be noted that in this article, the new combination of the flexible credibility constrained mathematical programming is presented to control a variety of uncertainties according to which the flexible-probabilistic model is defined.

$$Min\, Z = \left(\frac{FC^1 + 2FC^2 + FC^3}{4}\right)y + \left(\frac{CC^1 + 2CC^2 + CC^3}{4}\right)x$$

$$+\partial\left[(FC^3 y + CC^3 x) - \left[\left(\frac{FC^1 + 2FC^2 + FC^3}{4}\right)y + \left(\frac{CC^1 + 2CC^2 + CC^3}{4}\right)x\right]\right]$$

$$+\varphi[DE^2 - [(2\sigma - 1)DE^3 + (2 - 2\sigma)DE^2]] + \phi[[(2\varsigma - 1)Cap^1 + (2 - 2\varsigma)Cap^2] - Cap^1]y$$

$$+\Phi[DT^2 - [(2\varrho - 1)DT^3 + (2 - 2\varrho)DT^2]]$$

$$+\Gamma\left[\left(\Theta_{(2)} + \frac{\chi_\Theta - \chi'_\Theta}{3}\right)(1 - \Omega)\right] + \theta\left[\left(\rho_{(2)} + \frac{\xi_\rho - \xi'_\rho}{3}\right)(1 - \eta)\right] + \omega\left[\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon'_\tau}{3}\right)(1 - \Pi)\right]$$

$$s.t. \quad Ax \geq [(2\sigma - 1)DE^3 + (2 - 2\sigma)DE^2] - \left(\rho_{(2)} + \frac{\xi_\rho - \xi'_\rho}{3}\right)(1 - \eta)$$

$$Bx = 0 \qquad (48)$$

$$Hx \leq [(2\varsigma - 1)Cap^1 + (2 - 2\varsigma)Cap^2]y + [\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon'_\tau}{3}\right)(1 - \Pi)]y$$

$$Tx \leq 1$$

$$L.XT \leq [(2\varrho - 1)DT^3 + (2 - 2\varrho)DT^2] + \left(\Theta_{(2)} + \frac{\chi_\Theta - \chi'_\Theta}{3}\right)(1 - \Omega)$$

$$y, XT \in \{0,1\} \quad , \quad x \geq 0 \quad , \quad 0 \leq \eta, \Pi, \Omega \leq 1 \quad , \quad 0.5 < \varrho, \sigma, \varsigma \geq 1$$

In model 38, the first and second sections of the objective function represent the expected values of the non-deterministic network parameters. The third part is defined as the probabilistic variability of the objective function. The coefficient of possibilistic variability, ∂, adjusts the robustness degree of the system's optimality. The control of the costs of fines caused by violations of the problem soft constraints is performed in the fourth, fifth, and sixth phrases. The parameters ϕ , φ, and Φ set the soft constraints of the problem (demand, capacity, and acceptable lead time). The robustness of the problem is attained by the above phrases. The sixth and seventh phrases of the robustness model control the answers associated with the flexibility of the soft constraints. Also, the parameters σ, ς, η, Π, Ω, and ϱ optimize the level of confidence of the soft constraints of the problem. As can be seen, a nonlinear combination has occurred in the objective function of the above model. Therefore, using the equations $\vartheta = \varsigma y$, $\epsilon = \Pi y$, we transform the above model into a linear mathematical combination. The linear flexible-possibilistic robust programming combination is presented in model 49.

$$
\begin{aligned}
& Min\ Z = \left(\frac{FC^1 + 2FC^2 + FC^3}{4}\right) y + \left(\frac{CC^1 + 2CC^2 + CC^3}{4}\right) x \\
& +\partial \left[(FC^3 y + CC^3 x) - \left[\left(\frac{FC^1 + 2FC^2 + FC^3}{4}\right) y + \left(\frac{CC^1 + 2CC^2 + CC^3}{4}\right) x \right] \right] \\
& +\varphi\left[DE^2 - [(2\sigma - 1)DE^3 + (2 - 2\sigma)DE^2]\right] + \phi\left[[(2\vartheta - y)Cap^1 + (2y - 2\vartheta)Cap^2] - Cap^1 y\right] \\
& +\Phi\left[DT^2 - [(2\varrho - 1)DT^3 + (2 - 2\varrho)DT^2]\right] \\
& +\Gamma\left[\left(\Theta_{(2)} + \frac{\chi_\Theta - \chi'_\Theta}{3}\right)(1 - \Omega)\right] + \theta\left[\left(\rho_{(2)} + \frac{\xi_\rho - \xi'_\rho}{3}\right)(1 - \eta)\right] + \omega\left[\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon'_\tau}{3}\right)(y - \epsilon)\right] \\
& s.t. \quad Ax \geq [(2\sigma - 1)DE^3 + (2 - 2\sigma)DE^2] - \left(\rho_{(2)} + \frac{\xi_\rho - \xi'_\rho}{3}\right)(1 - \eta) \\
& Hx \leq [(2\vartheta - 1)Cap^1 + (2y - 2\vartheta)Cap^2] + [\left(\tau_{(2)} + \frac{\upsilon_\tau - \upsilon'_\tau}{3}\right)(y - \epsilon)] \\
& L.XT \leq [(2\varrho - 1)DT^3 + (2 - 2\varrho)DT^2] + \left(\Theta_{(2)} + \frac{\chi_\Theta - \chi'_\Theta}{3}\right)(1 - \Omega) \\
& \vartheta \geq M(y - 1) + \varsigma \qquad (49) \\
& \vartheta \leq \varsigma \\
& \vartheta \leq My \\
& \epsilon \leq My \\
& \epsilon \geq M(y - 1) + \Pi \\
& \epsilon \leq \Pi \\
& Bx = 0 \\
& T.x \leq 1 \\
& y, XT \in \{0,1\} \quad , \quad x, \vartheta, \epsilon \geq 0 \quad , \quad 0 \leq \eta, \Pi, \Omega \leq 1 \quad , \quad 0.5 < \varrho, \sigma, \varsigma \geq 1.
\end{aligned}
$$

In the above model, M is a very large number and the constraints added to the problem guarantee that if the problem binary variable is zero, the new variable will be zero as well, and if the problem binary variable is equal to 1, then, the new variable will be ς. In the above-developed model, we have several critical features as follows:

- Simultaneous attention to flexible mathematical programming and a variety of parametric uncertainties;
- Controlling and optimizing the conservatism level of the problem soft constraints regarding the number of fines created in critical situations; and
- Defining an independent level of satisfaction for the objective function and constraints.

IV. IMPLEMENTATION OF THE MODEL AND EVALUATION

The data and structure of the model were constructed based on documented feasibility studies of the production of final petrochemical products (polyethylene) and according to documentation and experiences of supply chain operational executives. The probabilistic distribution of the problem parameters was determined based on the prominent values of the triangular fuzzy numbers. The dimensions of the problem are presented in Table II.

TABLE II. Dimensions of supply chain national network of polyethylene products

Facilities	**Scale**
Polythene national industries	**10**
Demand zone	**31**
Foreign suppliers	**4**
Strategic warehouse of chemical material	**3**
Confidence buffer level of warehouse	**3**
Capacity levels of facility	**3**
Manufacturers of polythene products	**4**
Collecting and recycling center	**2**
Recycled material market	**3**

In this section, we analyze the sensitivity of the problem resilience model and the solution approach based on the strategies used in the model. Two coherent strategies, including a “confidence buffer” in the strategic warehouses of raw materials and “strategic inventory,” were used in the provincial pole centers. In this regard, the effect of increasing the costs of outsourcing the supply of raw materials from foreign suppliers on the confidence buffer of strategic warehouses is of great importance. We examined this effect with regard to the confidence levels of the probabilistic approach (credibility constrained).

TABLE III. Effect of outsourcing costs on confidence buffers

Increasing the Cost of Outsourcing			**25%**			**50%**			**70%**			**90%**		
Confidence Level			**0.55**	**0.7**	**0.95**	**0.55**	**0.7**	**0.95**	**0.55**	**0.7**	**0.95**	**0.55**	**0.7**	**0.95**
Strategic Warehouse of Chemical Material (W) **CL (Capacity Level)**	W1	CL1	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(2)	(2)		
		CL2											(2)	(2)
		CL3												
	W2	CL1												
		CL2		(1)	(1)	(1)	(1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
		CL3												
	W3	CL1	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(2)	(2)		
		CL2											(2)	(2)
		CL3												

According to Table III, by increasing the costs of outsourcing (procurement of raw materials from foreign suppliers), the level of strategic warehouses capacity and the level of confidence buffer are affected. In this regard, with 25% increase in costs and at all levels of confidence of the possibilistic approach, the first level of the confidence buffer is allocated to the warehouses. With increase in costs by 50% and at a possibilistic confidence level of 0.95, the confidence buffer of the second warehouse is upgraded to level 2. Eventually, by increasing the costs to 90%, the capacity level and the confidence buffer of strategic warehouses are changed to the second level. The above results suggest that increase in outsourcing costs leads to increase in the level of confidence buffer of strategic warehouses. In other words, more confidence buffer is considered for the system. Therefore, the model has a desirable function.

On the other hand, the final product of the supply chain network includes polyethylene products. The cost of producing the above products covers a part of the total costs. With increase in production costs as a result of the processing, the total costs will also increase. The maintenance costs have lower impact than production costs on total costs in two strategic depots. As shown in Fig (4), the doubling of maintenance costs in strategic depots will increase the total network cost by 8.7%. However, the doubling of production costs increases the value of the objective function by 24%. Thus, increased maintenance costs have little effect on increasing the objective function. Hence, the strategic inventory strategy increases the network efficiency and improves the network reliability level.

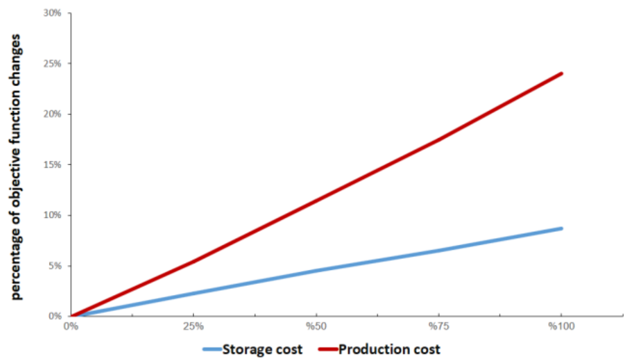

Fig 4. Changes of the objective function with increase in production and storage costs of products

Other important parameters of the model are the purchase price of polyethylene materials and the shipping or transportation costs. A survey of the above parameters in the model suggests that purchasing of polyethylene materials imposes the highest financial burden on the supply chain. By increased purchase of polyethylene, the value of the objective function increases by 56% Fig (5).

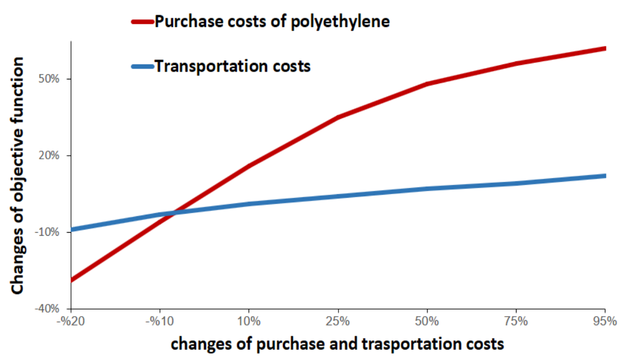

Fig 5. Changes of the objective function with increase in transportation and purchase costs

As shown in Fig (6), increased capacity levels of strategic depots of chemicals have the greatest effect on the objective function. In fact, increased capacity of the strategic warehouses increases the flow of material in the network and has an incremental effect on the value of the objective function. In addition, improving the capacity level of production centers has a considerable ascending effect on the value of the objective function. As seen, 75% improvement of the capacity of production centers increases the value of the objective by 17%, which is considered as a significant increasing trend. Meanwhile, promoting the capacity of the provincial pole centers creates the slightest increase in the objective function.

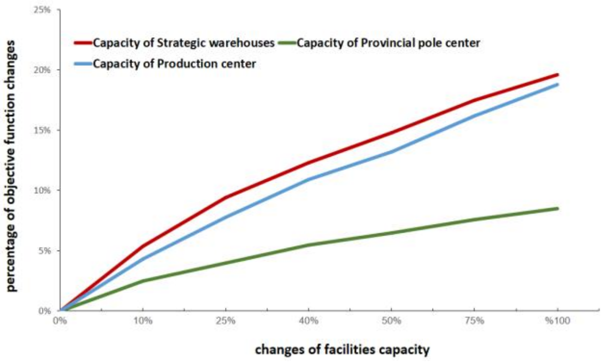

Fig 6. Changes of the objective function with increase in the capacity level of strategic warehouse, provincial pole center, and production centers

In this section, we evaluate the performance of flexible-possibilistic and flexible-possibilistic robust programming models. Initially, the new flexible-possibilistic programming model was investigated under various confidence levels ($\sigma = \varrho = \varsigma$ = 0.55, 0.65, 0.75, 0.85, 0.95). With increase in confidence levels, the flexible-possibilistic programming model acts through a risk avoidance approach and increases the network costs. The reason for this phenomenon is the need for more resources, such as purchasing polyethylene materials, higher capacity levels of facilities, and increased transportation system capacity to meet the needs of customers at higher levels of confidence. Figs (7 and 8) show the variations of the problem objective function under various levels of confidence. As can be seen, with increasing confidence level, the total cost and shipping costs of the network will increase.

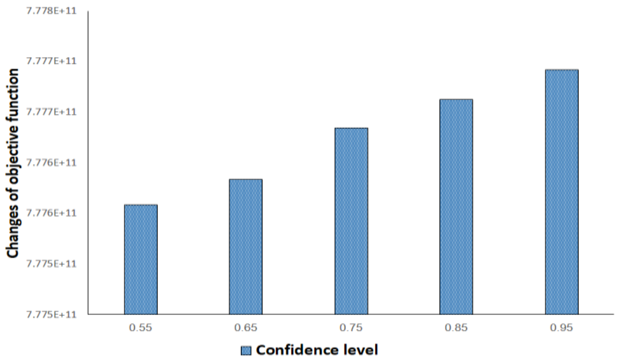

Fig 7. Changes of the objective function with increase in the confidence level in the possibilistic approach

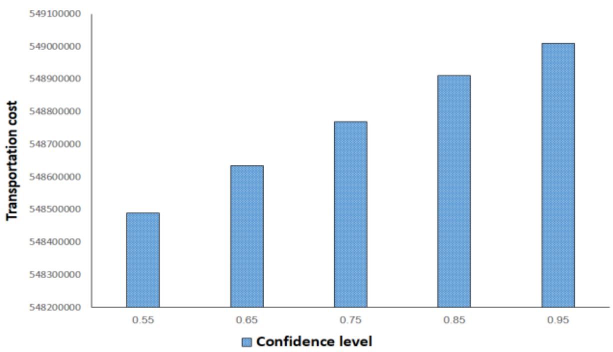

Fig 8. Changes of transportation cost with increase in the confidence level in the possibilistic approach

In the proposed flexible possibilistic-robust models, the soft constraints and the objective function of the problem are flexible. The parameters of the probable violation of the objective function and the constraints are also defined. The maximum probable violation of the objective function is considered to be 68% greater than the ideal value of the objective function. In addition, the maximum allowed flexibility of the flexible constraints of the problem at the right side of the constraints is defined as 35%. In this case, changes in the objective function are examined in the flexible possibilistic-robust model. Moreover, the proposed model is solved for feasibility and optimality robustness coefficients. Fig (9) shows the results of the calculation of the mean cost and the probability variability of the objective function. As shown, by increasing the risk-taking index in the objective function, the mean cost increases and, contrarily, the variability rate decreases. By determining the optimal value of this indicator based on the choices of the decision makers, the optimality robustness is controlled.

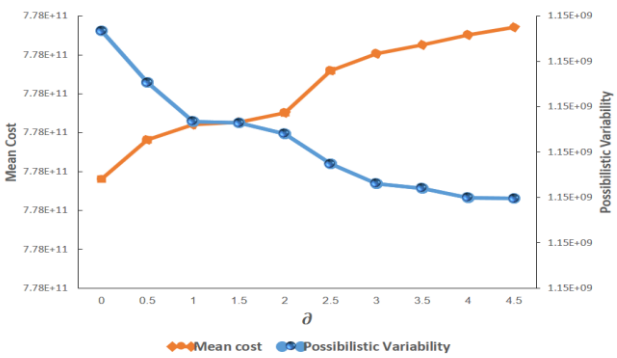

Fig 9. The variations of the average cost probability and possibilistic variability for the values of ∂

In Fig (10), the feasible robustness is explained. With increased φ, the cost of demand non-satisfaction decreases and tends to zero, eventually. The capacity constraint with the parameter θ also follows a function similar to the demand constraint. Finally, with increasing ϕ and θ, the feasible robustness of the model will increase.

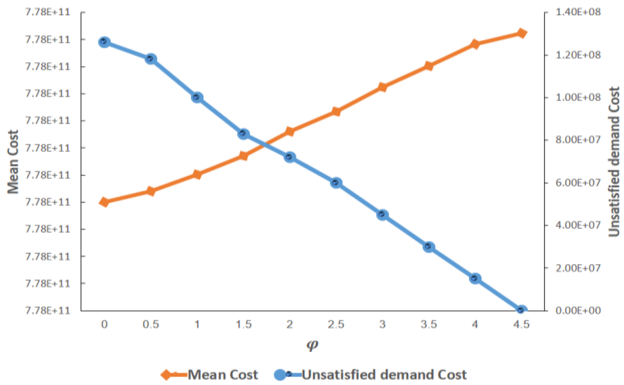

Fig 10. The variations of the average cost probability and unsatisfied demand for the values of φ

The behavior of the model against the fines for violations of the flexible constraints of the market demand, facilities capacity, and acceptable lead time in a national project is of great importance. Fig (11) shows the performance of the possibilistic-flexible programming models (PFPM) and robust-possibilistic flexible programming models (RPFM) under the fines for violations of the problem soft constraints. In this analysis, the RPFM model has a more favorable performance than the PFPM model. In addition, the RPFM model has shown a more independent performance against increased fines, which proves the superiority of the model above. In fact, the RPFM model has succeeded in optimizing the confidence levels of the flexible constraints of the problem and it creates a logical balance between the model robustness and the answer.

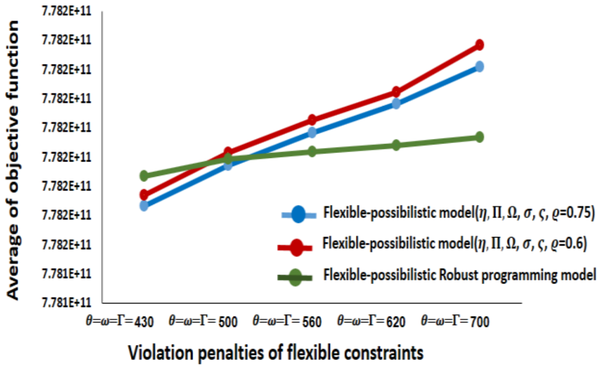

Fig 11. The variations of the average objective function with violation penalties of flexible constraints

Another analysis for demonstrating the optimal performance of the RPFM model is the evaluation of the optimality robustness of the proposed flexible robust-possibilistic models. The results of this model are examined and compared with the results of the flexible-possibilistic model. Since the flexible possibilistic programming model cannot identify the minimum confidence levels of model satisfaction, the above model is solved at three levels of confidence (0.6, 0.8, and 0.95). Also, reduced feasibility variability can reduce the variability of the objective function.

TABLE IV. The performance of PFPM & RPFM models under different realizations

Realization No.	Flexible-possibilistic Programming Model			Flexible Possibilistic-robust Programming Model		
	0.6	0.8	0.95	0.6	2.5	4
1	778273840654	778374641571	778413947159	77^273840654	778437973465	**778442616329**
2	778156630768	778212302447	778217873840	778265427351	778358162451	**778362225180**
3	778326127520	778256217430	778329255127	778133122135	778292048615	**778298182423**
4	778372328226	778378401342	778363571662	778119394593	778424421527	**778426382595**
5	778178828199	778200315527	778228319440	778263162184	778463273310	**778470257819**
Mean Cost	7.78262E+11	7.78284E+11	7.78311E+11	7.78211E+11	7.78395E+11	**7.784E+11**
Standard Deviation	92795572.66	86663578.67	85444246.59	77602657.26	69515156.33	**69357925.69**

As shown in Table IV, the proposed robust-possibilistic programming model with $\partial = 4$ has the minimum standard deviation and an acceptable mean. It should be noted that the optimality robustness of the answer is not guaranteed by considering the mean of non-deterministic parameters in the objective function, while the proposed approach controls the robustness of the solution according to priorities of the decision makers. On the other hand, the industry decision makers insist on minimizing the mean costs in a long-term horizon and controlling the fuzzy costs variability to reduce the short-term risks. In the proposed robust-possibilistic model, we have achieved a low average cost and a proper standard deviation. In this model, two factors contribute to the robustness of the provided solution. The first one is the optimality robustness coefficient, which is also reflected in the results, and with its increase, the performance of the robust model improves. The other factor is the fine on the violation of constraints. Usually, the greater the amount of this fine, the more robust the solution provided would be.

V. CONCLUSION

Sustainable production of petrochemical products is one of the strategic goals of developing countries. In this strategic direction, the occurrence of critical situations is inevitable. Threats such as the constraints on raw material and products inventories, facilities capacity limitation, the uncertainty of business environment parameters, and choosing the wrong supplier will put an end to the efficient operation of the supply chain. To confront the above threats, a resilient and effective supply chain network was designed under minor and non-minor disturbances, which was in line with the structure of supplying the final products of petrochemicals (polyethylene) in the country. To make an integrated resilient system, the process of identifying the disturbances and developing preventive and reactive resilient strategies was implemented and a combination of resilience strategies was defined for each of the upstream operational and downstream levels of the supply chain network. In the present study, a feasibility programming model was developed based on the credibility constraint to deal with epistemic uncertainties. To cope with the changing environment of the business market, the flexibility approach was combined with the soft constraints of the problem. The above combination was implemented in the framework of the new realistic and robust model and tested using data from a national project. In an actual operating space, the processes of sensitivity analysis and comparison of models were performed, indicating the desired results and the effectiveness of the proposed models. They demonstrated the reliability and operability of the proposed models. In this regard, it is suggested for future research to examine and evaluate the proposed model in the design of a supply chain network for converting-manufacturing industries such as the cement industry and other petrochemical products. By providing an innovative algorithm with a time-reducing approach, the problem can be solved.

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