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Flexible and Robust Optimization Combination for Reliable Forward-Reverse Logistic Network Design using Benders' Decomposition Method

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Abstract – *Over the past few years, understanding sustainability issues such as cost savings and pollution reduction in the industry has led to the design of closed-loop logistics networks with hybrid facilities Also, the occurrence of sudden disturbances and the damages caused by them has developed the use of reliability approaches The present study has applied the strategy of reliable support facilities in the multi-product forward-reverse logistics network and has used stochastic programming to model the disorder To face the decision-maker ambiguity in the confidence levels, the constraints, and objectives of the problem, and in continuation, to ensure the optimality of the above classes, flexible-robust combination programming has been employed, presented in the form of a mixed-integer linear mathematical programming model Then Benders decomposition algorithm is proposed to solve the model, which with a subset of optimization cuts and appropriate convergence rate, improved optimal solutions are produced for optimal planning path.*

Keywords– *Supply Chain, Reliability, Disruption, Flexibility, Robust, Benders' decomposition*

I. INTRODUCTION

In today's competitive world, due to the products' short life cycle, market Globalization, an increase in customers' knowledge and preferences, and changes in demand patterns, simply improving the organization's internal processes is insufficient for remaining competitive and possessing a significant market share. With this mindset, supply chain techniques and management were developed. Tsai et al., 2021 The supply chain, in general, is a chain that incorporates all actions of product flow and material conversion from the stage of preparation of crude substance to the scene of delivery of the final harvest to the customer (Coenen et al.,2018).

Due to social, environmental, and economic factors, the reverse logistics network (RLN) has received much attention (Alshamsi,2015). The reverse network includes gathering, categorizing, reviewing, and purchasing consumer goods. Another goal for reverse logistics activities is to convert consumers' second-hand products into marketable reusable products (Behzadi, 2018). The reverse supply chain network is becoming integral to supply chain network design as environmental approaches and optimal consumption of recycled products and related wastes evolve. (Homayouni and Pishvaee, 2020).

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Various unpredictable events, such as terrorist acts, natural disasters, sanctions, epidemic diseases, and so on, have occurred in recent years, demonstrating that our world is becoming increasingly uncertain and vulnerable. Furthermore, supply chain networks appear weaker than in the past due to diverse industries and work activities, decentralized production, increased outsourcing, reduced supplier numbers, and a focus on inventories. Furthermore, they have been subjected to risk and disruption, and existing uncertainty has been heightened (Tolooie et al., 2020). When a set of facilities is built and deployed in the real world, one or more of them may malfunction and fail to function correctly. In other words, they may be unable to provide adequate service in critical situations such as natural disasters, severe weather, labor strikes, sabotage, terrorist attacks, or changes in system ownership, facilities, or systems. Failures in facilities can increase costs throughout the supply chain and seriously threaten corporate market share.

Many studies on reliable supply chain network design have focused on the complete disruption of network facilities (Peng et al., 2011, Vahdani et al.,2012, Jabbarzadeh et al.,2014, Fazli-Khalaf et al.,2019, Fazli-Khalaf et al.,2020). Other studies have addressed minor disruption and have used definite parameters as a fraction of the service capacity of vulnerable facilities to model the disorder (Azad et al., 2012, Hamidieh & Fazli-Khalaf,2017; Rahmani & Mahoodian,2017). Another way to model the disruption of an unknown parameter in the interval (0,1) is to describe it as a proportion of the service capacity of susceptible facilities lost due to the occurrence of the disturbance. (Hamidieh & Arshadikhamseh,2021). However, another less discussed method is to model disruption as an uncertain spectrum that varies with the severity of the disorder, which is followed in the current study with a potential approach. Researchers have devised various approaches to dealing with this shortcoming: a scenario-based process that considers all possible scenarios of a facility failure. (Lan et al.,2015, Hamidieh & Fazli-Khalaf, 2017, Haghjoo et al.,2020); nonlinear probability expression (Shen et al.,2011); and the strategy of reliable backup facilities (Hatefi et al.,2014, Fazli-Khalaf et al.,2020).

In the present research, the possible parameters determining the occurrence of the disruption have been defined to model the disorder. Reliable and non-reliable facilities have been considered to consider the model's reliability and deal with the interruption. The first type of facility is protected against disruption by spending more and using schemes such as outsourcing contracts, physical retrofitting, etc., and are called reliable facilities. Another type of facility for which it is impossible to retrofit is the unreliable facility. The occurrence of the disturbance is defined as probable and with different probabilities.

Another point is the existence of multiple uncertainties in today's business environment. In the real world, modeling uncertainty is unavoidable and needs to be seriously considered in supply chain networks (Dehghan et al.,2019). Practical approaches, including fuzzy programming, robust optimization, and stochastic programming, deal with uncertainties in different modeling conditions (Hatefi et al.,2014). Stochastic programming is developed based on previous data on problem parameters that have been used in many supply chain papers (Vahdani & Mohammadi, 2015, Badri et al., 2016, Jerbia et al.,2018, Pourmehdi et al.,2020) as Maia Chiara Magnanini (2021) presents an analytical methodology to support the optimization of manufacturing systems configuration and reconfiguration subject to evolving production needs. Through performance linearization, the proposed method incorporates a stochastic analytical model for evaluating the performance of manufacturing lines in a mixed integer programming problem. This model advantage is demonstrated in a line configuration problem, where buffer capacities must be optimized to minimize costs while meeting the target performance.

Nevertheless, it is impossible to design practical scenarios for many business problems. Also, reliable historical data are not available to estimate the probability distribution of uncertain parameters, so another alternative approach is fuzzy programming, which deals with parametric uncertainty (Pishvaee & Razmi, 2012, Farrokh et al., 2018, Dehghan et al. 2019).

Fuzzy mathematical programming is classified into two general categories: Possibilistic programming and flexible programming. Possibilistic programming is used to model parameters with cognitive uncertainty of the problem using the possibility distribution.

In a recent study, Sheng-Long Jiang (2022) developed an optimal oxygen distribution strategy with uncertain demands and proposed a robust two-stage optimization (TSRO) model with budget-based uncertainties that outline initial distribution decisions. It protects with little conservatism. As the supply chain network design dimensions develop, mathematical modeling becomes more complex. In this regard, the Benders decomposition algorithm has been developed as a precise approach to reduce the complexity of the problem, which breaks down the main problem into smaller subscales to reduce the complexity of the situation in fewer repetitions to converge to the optimal solution. In other words, it guarantees accurate and optimal solutions (Mardan et al.,2019). The main framework of this algorithm is based on the principle that complex variables make problem-solving difficult. The problem-solving process is simplified by considering a constant value for complex variables and breaking the problem into several small ones. A problem with complex variables becomes a dual format, which arises with complex constraints (Keyvanshokouh et al.,2015). The Benders method's primary problem is divided into the leading free problem with complex variables and several sub-problems. Moreover, the concept of shadow prices and primary-dual relations moves towards solving the complexity of the supply chain network design problem (Kalantari Khalil Abad & Pasanadideh, 2020).

The Benders decomposition method achieves the optimal solution of infinite iterations. Using the Benders decomposition algorithm in vast supply chain network problems, the convergence rate decreases due to the low quality of the answers obtained from the basic mathematical model of the problem (Kalantari Khalil Abad & Pasanadideh, 2020). The present study follows an approach that increases the convergence rate and produces accurate optimal solutions. Therefore, selecting the appropriate initial solutions from a Robust-flexible programming model and obtaining the proper values of the dual problem variables, Adds the desired initial cuts to the main problem.

The essential research in the reliable supply chain field is presented in Table 1 and is compared based on the most critical features of the present study.

Table I. Classification of reviewed papers over the last twenty years

Paper	Problem Features				Uncertainty Check								Output					Solution Method
					Disruption Severity		Uncertainty Type		Uncertainty Programming									
	Forward	Forward-Reverse	Single product/Period	Multi-product/Period	Minor	Complete	Parameter	Flexibility	Deterministic	Stochastic	Robust	Fuzzy	Transportation	Location/allocation	Demand/Return	Facility capacity	Production amount	
Pishvaee et al. (2011)				*	*	*	*	*			*		*	*	*			CPLEX
Pishvaee and Razmi (2012)				*	*	*	*	*				*	*	*				fuzzy
Zeballos et al. (2012)	*			*			*			*			*	*	*			CPLEX

Keyvanshokooh et al.(2013) -			*						*				*	*		*	*	CPLEX
Ramezani et al. (2013)	*		*			*	*	*		*			*	*		*		CPLEX
Amin and Zhang (2013)				*		*	*	*		*			*	*				CPLEX
Soleimani and Govindan (2014)				*		*	*	*		*			*	*				CPLEX
Zeballos et al. (2014)				*				*		*			*	*				CPLEX
Tsushi Nishia, Okihiro(2016)					*			*		*				*			*	CPLEX
Farrokh M and others(2017)		*					*			*	*	*	*		*			Stochastic, fuzzy
M. Farrokh, A. Azar(2018)				*	*					*			*			*	*	Fuzzy Programming
Atefeh Hassanpour, Jafar Bagherinejad (2019)						*		*	*						*			Genetic
Nazari V,Ghodratnama A(2019)	*			*		*	*				*		*				*	Robustness
Fazli Khalaf M and others(2019)		*		*	*		*				*		*		*	*	*	Robustness Possibilistic

Govindan et al. (2020)		*		*	*		*					*	*		*		*	FDEMATEL-FANP
Rahmanniyay F. et el.(2020)				*			*					*	*					FMOLP
Andrés Polo et el.(2020)	*					*					*						*	MILP-robustness
Gholizadeh H. et el.(2020)	*			*			*			*		*	*					Robust-Heuristic
Hamidieh A, Arshadikhamesh A (2021)				*		*	*						*	*				e Flexible Possibilistic-Robust
Moradi S, Sangari M(2021)	*			*					*		*		*					Robust Optimization
Johnson, Aric R. et al.(2021)	*			*			*				*		*			*		Robustness, resilience
Hailei Gong, Zhi-Hai Zhang(2022)		*			*		*				*				*			Benders' Robust
Current research		*		*		*		*	*		*	*	*	*		*	*	CPLEX, Benders' Robust, Flexible

Reviewing the research literature and comparison in table 1, the supply chain network design has been considered a disruption. Lately, legislative guidelines and the tension of non-administrative associations have persuaded organizations to think about economic issues in their choices. A synchronous plan of forward and reverse coordinated factors can get us far from sub-optimality brought about by independently handling these two stages (forward and reverse strategies).

Nonetheless, the following critical points have been overlooked:

- Design of a reliable Forward-Reverse Logistic in a flexible-probabilistic framework.

- Simultaneous coverage of parametric uncertainties and disturbances
- Increases the model's reliability by applying the strategy of reliable facilities and defining the severity of the possible disruption.
- Using a flexible-robust hybrid approach to deal with parametric uncertainty
- Increase the convergence speed in determining the optimal solution by using an exact algorithm for solving the problem

A reliable model for designing a capacitated forward-reverse logistics network with hybrid facilities can address random facility disruptions and the epistemic uncertainties embedded in the input data.

- The unexpected disruptions at hybrid facilities play an essential role in forward and reverse flows.

Incorporating the following reliability concepts into the developed model:

- A credibility measure for equality constraints is defined in the proposed reliability model.
- Using a credibility-constrained programming approach to deal with incompleteness and imprecise input data.
- A sharing strategy allows products to be shipped from reliable hybrid facilities to unreliable ones to compensate for lost capacities.
- Imposing capacity restrictions at reliable and unreliable hybrid facilities and other facilities embedded in the logistics network. Taking into account partial and total capacity disruptions at unreliable hybrid facilities. Due to the threat of disruptions, the capacity of unreliable facilities may be partially reduced. As a result, they can continue to serve their customers by utilizing the remainder of their available capacity.
- When disruptions occur, locating two types of facilities, namely reliable and unreliable hybrid facilities;

In the present study, a reliable facility strategy has been used, ensuring product flow in the supply chain network based on the sharing strategy. In this regard, when the supply chain network is faced with the lost capacity of the facility, products are shipped from reliable mixed facilities to non-reliable facilities. Also, for perturbation modeling, an uncertain parameter is defined that disappears with the occurrence of the perturbation and ensures network reliability. This paper develops a flexible-robust programming model to design a reliable multi-product, multi-level closed-loop supply chain network. Moreover, in the current situation, which exacerbates disorders such as epidemic diseases across the network, the parameters determining the disruption occurrence are defined with stochastic programming. The remainder of this paper provides a comprehensive definition and modeling of the problem and is developed based on a Flexible-Robust Programming approach. Then, the Benders decomposition algorithm is implemented in the model. The computational outcomes and responsiveness examination make the fundamental administrative knowledge about a dependable Forward-Revers Logistic.

Managers can reduce overabundance limit gambles by making the existing limit more adaptable.

II. STATEMENT OF THE PROBLEM & PROPOSED RELIABLE MODEL

An Integrated Closed-loop Logistics network (ICLL) is the network structure, as demonstrated in *Fig*(1). In the model under discussion, hybrid facilities are used in forward and reverse directions, which improves network sustainability while reducing transportation costs (Hatefi et al.,2014).

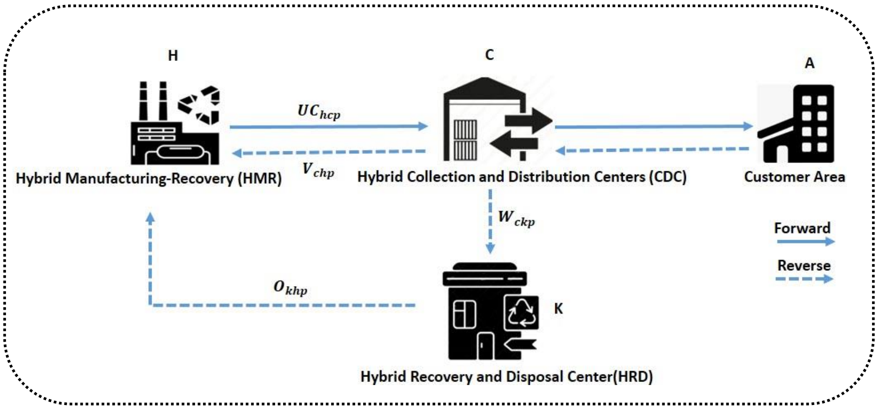

Fig 1. Reverse-Forward Integrated Logistic Network

As manifested in Fig (1), the new products of the HMR center are transferred to customer areas through CDC centers to correspond to the customers' demands in forwarding flows. In reverse order, defective products go through two stages of inspection. In the first stage, products with less recovery capability are organized in the CDC center and transferred to the HMR center for reproduction. In the HRD center, the final inspection is performed on the returned products, and they are grouped into two pallets that can be destroyed and recovered. Defective products of higher quality are shipped to the HMR center for reproduction.

Moreover, low-quality products are transferred to the safe disposal process. The average disposal speed indicates the quality of defective products because defective products are recyclable with high quality, and low-quality returned products should enter the safe discarding process. Also, assuming the customer areas are clear, the objective function is to find the optimal number of facilities required (CDC, HMR, and HRD centers) and the best locations and financial flows, with the least cost collected for network design. Accomplishing the target appertain includes uncertain and particular items in the ICLL Network Configuration. CDC and HMR capabilities play a crucial role in reverse and forward networks. For simplicity, we assume that only CDC facilities are prone to potential malfunctions. Accordingly, reliability issues are considered as CDC facilities. When the facilities are subject to disorder, similar reliability significances can be thought out.

In each C knot, a CDC center can be placed with a specified cost of $\tilde{F}U_c$ that might be rejected with a probability of $q_c(0 < q_c < 1)$,or a reliable CDC center with the cost of $\tilde{F}R_c$ Can be placed, which can never be rejected. Facility disruptions have occurred in unreliable facilities, provided the reputable facilities were preserved versus these disruptions. The cost of reputable CDC facilities is more than the unreliable CDC facilities (meaning that $\tilde{F}R_c > \tilde{F}U_h; \forall_c$). A device can become reliable using various protective programs within the physical strength range of facilities up to commodity purchase contracts. Accordingly, this paper assumed that part or all of the capacity of the facilities was destroyed after the disruption and could no longer provide services to the determined customers. In this regard, we suppose that unreliable CDC facilities can lose a part of the capacity of dispensation or collection in case of disruption. Thus, they can provide customers with the extant capacity of dispensation in the forward direction. It is worth noting that they can offer services to the discard and HMR centers with the remaining collection capacity in the reverse order. Deduction of capacity loss for unreliable CDC facilities is defined ; the pc and p'_c Symbols signify collection and distribution capacities percentages in CDC facilities C that is ruined in disruption.

The sharing strategy is thought out in the forward flow, enabling reliable CDC facilities to share the new products with unreliable CDC facilities to rectify the lost capacities. In this case, the latest products of the reliable CDC facilities will be transferred to unreliable facilities whose capacities are disrupted.

III. PROBLEM NOTATIONS AND FORMULATION

The model was proposed by considering the assumptions of the problem formulated and taking into account a multi-product network. Indices, this multi-product model's parameters, and the resulting answers to two problems were solved and assessed. The following symbols were employed to design the mathematical programming model:

Set:

H: Set of Potential HMR centers Quantity ($h \in H$)

A: Set of demand Zones ($a \in A$)

C: Set of potential CDC centers Quantity ($c \in C$)

P: Set of product types ($p \in P$)

K: Set of potential disposal centers Quantity ($k \in K$)

Parameters:

Ad: Average disposal fraction

$\tilde{r}_{ap}$: The Return rate of consumed products *p* from demand zone *a*

$\tilde{d}_{ijp}$: Transportation cost per unit of products *p* from the center *i* to center *j* so that $i, j \in H, C, K, A$.

$\tilde{d}_{ap}$: The Demand for products *p* in the zone *a*

$\tilde{\eta}_c$: Collection capacity of CDC center *c* in the reverse direction

$\tilde{\gamma}_c$: Distribution capacity of CDC center *c* in the forward direction

$\tilde{F}_h$: Fixed cost of opening the HMR center *h*

$\tilde{\tau}_h$: Recovery capacity of HMR center *h* in the reverse direction

$\tilde{\varphi}_{hp}$: Production capacity of p-type product for HMR center *h* in the forward flow

$\widetilde{FU}_c$: Fixed cost of opening the unreliable CDC center *c*

$\widetilde{FR}_c$: Fixed cost of opening the reliable CDC center *c*

$\widetilde{FD}_k$: Fixed cost of opening the disposal center *k*

$\tilde{\rho}_k$: Disposal capacity of disposal center *k*

Γ_{kp}: The recovery rate of p-type products in the HRD center *k*

$\widetilde{cdr}_{cp}$: Collection cost per unit of product *p* at CDC center *c*

$\widetilde{cpf}_{hp}$: Production cost per unit of product *p* at HMR center *h*

$\widetilde{cpr}_{hp}$: Recovery cost per unit of product *p* at HMR center *h*

$\widetilde{Cap'_c}$: Uncertainty fraction of disrupted collection capacity at opened unreliable CDC center *c* (reverse)

$\widetilde{Cap_c}$: Uncertainty fraction of disrupted distribution capacity at opened unreliable CDC center *c* (forward)

ϱ_c: Determinant parameter of disruption occurrence at CDC center with Bernoulli distribution

q_c: Disruption probability in unreliable CDC center *c*

$\widetilde{cp}_{kp}$: Inspection/Disposal cost per unit of scrapped product *p* at disposal center *k*

$\widetilde{cdf}_{cp}$: Distribution cost per unit of product *p* at CDC center *c*

Variables:

Z_k: Binary variable; 1 if disposal center *k* is opened, 0 otherwise.

AU_{ca}: Binary variable; 1 if the demand zone *a* is assigned to unreliable CDC center *c* in the forward direction, 0 otherwise.

W_{ckp}: Quantity of scrapped products *p* shipped from CDC center *c* to disposal center *k*

AR_{ca}: Binary variable; 1 if the demand zone *a* is assigned to reliable CDC center *c* in the forward direction, 0 otherwise.

BR_{ca}: Binary variable; 1 if the demand zone *a* is assigned to reliable CDC center *c* in the reverse direction, 0 otherwise.

V_{chp}: Quantity of recoverable p-type products shipped from CDC center c to HMR center *h*

BU_{ca}: Binary variable; 1 if the demand zone *a* is assigned to unreliable CDC center *c* in the reverse direction, 0 otherwise.

YU_c: Binary variable; equals one if unreliable CDC center *c* is opened, 0 otherwise.

YR_c: Binary variable; equals one if reliable CDC center *c* is opened, 0 otherwise.

$T_{c'cp}$: Quantity of products *p* trans-shipped from reliable CDC center c' to unreliable CDC center *c* at a disrupted situation $c \neq c'$

O_{khp}: Quantity of recoverable p-type products from HRD center k to HMR center *h*

X_h: Binary variable; 1 if HMR center *h* is opened, 0 otherwise.

UC_{hcp}: Quantity of products *p* shipped from HMR center *h* to CDC center *c*

Problem formulation is as follows, which is minimizing total cost:

$$\min \sum_h \tilde{F}_h X_h + \sum_c \widetilde{FR}_c YR_c + \sum_c \widetilde{FU}_c YU_c + \sum_k \widetilde{FD}_k Z_k + \sum_h \sum_c \sum_p \left(\tilde{d}_{hcp} + \widetilde{cpf}_{hp}\right) UC_{hcp} + \sum_c \sum_a \sum_p \left(\tilde{d}_{clp} + \widetilde{cdf}_{cp}\right) \tilde{d}_{lp} (AR_{ca} + AU_{ca}) + \sum_a \sum_c \sum_p \left(\tilde{d}_{acp} + \widetilde{cdr}_{cp}\right) \tilde{r}_{lp} \tilde{d}_{lp} (BR_{ca} + BU_{ca}) + \sum_c \sum_k \sum_p \left(\tilde{d}_{ckp} + \widetilde{cp}_{kp}\right) W_{ckp} + \sum_c \sum_h \sum_p \left(\tilde{d}_{chp} + \widetilde{cpr}_{hp}\right) V_{chp} + \sum_{c'} \sum_{c \neq c'} \sum_p q_c \tilde{d}_{c'cp} T_{c'cp} + \sum_c \sum_a \sum_p \tilde{d}_{cap} UD_{cap} + \sum_k \sum_h \sum_p \tilde{d}_{khp} O_{khp} \quad (1)$$

$$\sum_c AR_{ca} + \sum_c AU_{ca} = 1 \quad \forall a \quad (2)$$

$$\sum_c BR_{ca} + \sum_c BU_{ca} = 1 \quad \forall a \quad (3)$$

$$\sum_c YR_c \geq 1 \quad (4)$$

$$YR_c + YU_c \leq 1 \quad \forall c \tag{5}$$

$$AR_{ca} \leq YR_c \quad \forall c, a \tag{6}$$

$$BR_{ca} \leq YR_c \quad \forall c, a \tag{7}$$

$$T_{c'cp} \leq MYR_{c'} \quad \forall c', c \neq c', p \tag{8}$$

$$T_{c'cp} \leq \tilde{\gamma}_c YU_c \quad \forall c', c \neq c', p \tag{9}$$

$$\sum_{c'} T_{c'cp} + \tilde{\gamma}_c\big(1 - \varrho_c \widehat{Cap_c}\big) YU_c \geq \sum_a \tilde{d}_{ap} AU_{ca} \quad \forall c, p \tag{10}$$

$$\sum_c T_{c'cp} + \sum_a \tilde{d}_{ap} AR_{c'a} \leq \tilde{\gamma}_{c'} YR_{c'} \quad \forall c', p \tag{11}$$

$$\sum_c UC_{hcp} + \sum_{c'} T_{c'cp} \geq \sum_a \tilde{d}_{ap} AU_{ca} \quad \forall c, p \tag{12}$$

$$\sum_h V_{chp} = \sum_a (1 - Ad) \tilde{r}_{ap} \tilde{d}_{ap} (BR_{ca} + BU_{ac}) \quad \forall c, p \tag{13}$$

$$\sum_k W_{ckp} = \sum_a Ad \tilde{r}_{ap} \tilde{d}_{ap} (BR_{ca} + BU_{ac}) \quad \forall c, p \tag{14}$$

$$\sum_h O_{khp} = \sum_c \Gamma_{kp} W_{ckp} \quad \forall k, p \tag{15}$$

$$\sum_h \sum_c UC_{hcp} \geq \sum_a \tilde{d}_{ap} \quad \forall p \tag{16}$$

$$\sum_c UC_{hcp} \leq \tilde{\varphi}_{hp} X_h \quad \forall h, p \tag{17}$$

$$\sum_c V_{chp} + \sum_k O_{khp} \leq \tilde{\tau}_h X_h \quad \forall h, p \tag{18}$$

$$\sum_h UC_{hcp} \leq \tilde{\gamma}_c (YU_c + YR_c) \quad \forall c, p \tag{19}$$

$$\sum_h \tilde{d}_{ap} AU_{ca} \leq \tilde{\gamma}_c YU_c \quad \forall c, p \tag{20}$$

$$\sum_a \tilde{r}_{ap} \tilde{d}_{ap} BU_{ac} \leq \big(1 - \varrho_c \widehat{Cap'_c}\colon\big) \tilde{\eta}_c YU_c \quad \forall c, p \tag{21}$$

$$\sum_a \tilde{r}_{ap} \tilde{d}_{ap} BR_{ac} \leq \tilde{\eta}_c YR_c \quad \forall c, p \tag{22}$$

$$\sum_c W_{ckp} \leq \tilde{\rho}_k Z_k \quad \forall k, p \tag{23}$$

$$X_h, YR_c, YU_c, Z_k, AR_{ca}, AU_{ca}, BR_{ca}, BU_{ac} \in \{0,1\} \qquad \forall h \in H, \forall c \in J, \forall a \in A, \forall k \in K \tag{24}$$

$$UC_{hcp}, UD_{cap}, W_{ckp}, V_{chp}, T_{c'cp} \geq 0 \qquad \forall h \in H, \forall c, c' \in J, \forall a \in A, \forall k \in K, \forall p \in P \tag{25}$$

In which M is the significant positive number. The target function (1) is minimizing the full costs, including:

- the determined costs of open facilities,
- production and transportation,
- the anticipated joint product costs from reliable CDC facilities to unreliable CDC facilities.

The first item of those four items demonstrates the worth of HMR facilities, reliable CDC facilities, unreliable CDC facilities, and recycling centers. The fifth sentence shows the transport cost from HMR to the CDC and the processing cost in HMR centers. The sixth item displays the fees of the customers sent to unreliable and reliable CDC centers in the forward direction and the cost of the distribution process in CDC facilities. The seventh item shows the customers sent to unreliable and reliable CDC centers fees in reverse order and the costs of the collection process in CDC facilities. The eighth and ninth items manifest the transport cost from CDC centers to recycling centers and HMR and the cost of the recovery process in HMR facilities and the recycling center. The last sentence demonstrates the anticipated distribution costs, which are the expected cost of the joint products from CDC to unreliable centers in distribution.

In the formulated model, restrictions (2) and (3) guarantee that any client area shall be given to CDC facilities in the reverse and forward flow. Constraint (4) displays that at least one dependable CDC center should be open to the robust strategy of sharing in troubling conditions. Constraint (5) demonstrates that neither reliable nor unreliable CDC facilities can be open vis-a-vis in C potential group. Restrictions (6) and (7) strengthen the development of the reliable CDC center in the probable C group in case there were customers in reverse and forward flow. The restriction (8) underwrites that the products can be transferred to unreliable CDC facilities during the disruption if the reliable CDC device is in the probable c' Knot. The restriction (9) guarantees that the products cannot be transferred to the potential C group in troubling conditions, but there is an unreliable CDC device. Constraint (10) indicates that for the unreliable CDC center placed in a C knot, the total products transferred from the reliable CDC facilities and the accessible capacity after distribution must be more than or equal to the allocated customer request.

The constraint (11) manifests that the reliable CDC opened in the potential c'Group, the total products transferred from this facility to unreliable CDC facility and the whole customer's request allocated to it should not be more than its capacity. Constraint (12) indicated that the total flows entered by the unreliable CDC center located in the C knot could not be less than the actual demands allocated to the customers. The constraints (13) to (15) guarantee the flow of goods reverse. Restrictions (17) and (18) strengthen the conditions on the capacity of manufacturing and restoration in HMR centers. Constraints (19) to (22) maintain the restrictions on dispensation and muster capacities in CDC facilities in the reverse and forward flows. Bear in mind that the lost distribution capacity in the unreliable CDC centers can be improved by the strategy of sharing that is complemented into the forward turn. The constraint (23) guarantees the ability of the HRD center against the return flow of goods for the final inspection. Finally, restrictions (24) to (25) indicate the dual and flow variables and constraints.

IV. THE PROPOSED SOLUTION MIXED FLEXIBLE-ROBUST PROGRAMMING AND BENDERS DECOMPOSITION

A. The primary model of flexible programming (FP.)

Several uncertain parameters are effective in the decision-making process in the industrial environment, which according to what Hamidieh and Naderi proposed (2018), can be divided into two main groups. It is one of the changing business market conditions, and the second group is related to the lack of sufficient knowledge about the parameters. Parameters that disorders caused by sanctions are essential factors in its emergence.

Therefore, to deal with uncertainty in deciding on conditions and responding quickly to customer demand, the efficient method they have developed is, in fact, a flexible approach, leading to the definition of the objective function of the problem in the following form. The parameters β.γ.δ.ϑ.σ α indicate the minimum level of satisfaction with flexible constraints. Assume that $\tilde{r}_a.\tilde{d}_a.\widetilde{\varphi}_{ip}.\tilde{\rho}_k\ \widetilde{\tilde{\tau}_a.y_c}$. Fuzzy numbers are triangular and can be represented by three prominent points: for $\tilde{d}_a$, then $(d_a^p.d_a^m.d_a^o)$ .For other fuzzy numbers, the same fuzzy number is assumed. Based on the fuzzy ranking method proposed by Yager (Karyati, 2018), for example, they can be DE fuzzy for $\tilde{d}_a$ as follows:

$$\left(d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3}\right) \tag{25}$$

The parameter $\varphi_d\ .\acute{\varphi}_d$ is the side margin of the triangular fuzzy number $\widetilde{d}_a$, which is defined as follows.

$$\varphi_d = d_a^o - d_a^m \tag{26}$$

$$\acute{\varphi}_d = d_a^m - d_a^p \tag{27}$$

We follow the same process for other fuzzy parameters.

$$\min \sum_h \tilde{F}_h X_h + \sum_c \widetilde{FR}_c YR_c + \sum_c \widetilde{FU}_c YU_c + \sum_k \widetilde{FD}_k Z_k + \sum_h \sum_c \sum_p \left(\tilde{d}_{hcp} + \widetilde{cpf}_{hp}\right) U_{hcp} + \sum_c \sum_a \sum_p \left(\tilde{d}_{cap} + \widetilde{cdf}_{cp}\right) d_a (AR_{ca} + AU_{ca}) + \sum_a \sum_c \sum_p \left(\tilde{d}_{acp} + \widetilde{cdr}_{cp}\right) \tilde{r}_{ap} \tilde{d}_{ap} (BR_{ca} + BU_{ca}) + \sum_c \sum_k \sum_p \left(\tilde{d}_{ckp} + \widetilde{cp}_{kp}\right) W_{ckp} + \sum_c \sum_h \sum_p \left(\tilde{d}_{chp} + \widetilde{cpr}_{hp}\right) V_{chp} + \sum_{c'} \sum_{c \neq c'} \sum_p q_c \tilde{d}_{c'cp} T_{c'cp} \tag{28}$$

$$\sum_c AR_{ca} + \sum_c AU_{ca} = 1 \quad \forall a \tag{29}$$

$$\sum_c BR_{ca} + \sum_c BU_{ca} = 1 \quad \forall a \tag{30}$$

$$\sum_c YR_c \geq 1 \tag{31}$$

$$YR_c + YU_c \leq 1 \quad \forall c \tag{32}$$

$$AR_{ca} \leq YR_c \quad \forall c, a \tag{33}$$

$$BR_{ca} \leq YR_c \quad \forall c, a \tag{34}$$

$$T_{c'cp} \leq MYR_{c'} \quad \forall c', c \neq c', p \tag{35}$$

$$T_{c'cp} \leq (\mathrm{y}_c + (y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3})(1-\beta)) YU_c \quad \forall c', c \neq c', p \tag{36}$$

$$\sum_{c'} T_{c'cp} + (\mathrm{y}_c + (y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3})(1-\beta))\left(1 - \varrho_c \widehat{Cap_c}\right) YU_c \geq \sum_a (d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) AU_{ca} \quad \forall c, \tag{37}$$

$$\sum_c T_{c'cp} + \sum_a (d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) AR_{c'a} \leq (\mathrm{y}_c + (y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3})(1-\beta)) YR_{c'} \quad \forall c', p \tag{38}$$

$$\sum_h U_{hcp} + \sum_{c'} T_{c'cp} \geq \sum_a (d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) AU_{ca} \quad \forall c, p \tag{39}$$

$$\sum_h V_{chp} = \sum_a (1 - Ad)(\mathrm{r}_a - r_a^m + \frac{\varphi_r - \acute{\varphi}_r}{3})(1-\delta))(d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha))(BR_{ca} + BU_{ac}) \quad \forall c, p \tag{40}$$

$$\sum_k W_{ckp} = \sum_a Ad(\mathrm{r}_a - (r_a^m + \frac{\varphi_r - \acute{\varphi}_r}{3})(1-\delta))(d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha))(BR_{ca} + BU_{ac}) \quad \forall c, p \tag{41}$$

$$\sum_h \sum_c U_{hcp} \geq \sum_a d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha) \quad \forall p \tag{42}$$

$$\sum_c U_{hcp} \leq (\varphi_h + (\varphi_h^m + \frac{\varphi_\varphi - \acute{\varphi}_\varphi}{3})(1-\gamma)) X_h \quad \forall h, p \tag{43}$$

$$\sum_c V_{chp} \leq (\tau_h + (\tau_h^m + \frac{\varphi_\tau - \acute{\varphi}_\tau}{3})(1-\vartheta)) X_h \quad \forall h, p \tag{44}$$

$$\sum_h U_{hcp} \leq (\mathrm{y}_c + (y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3})(1-\beta))(YU_c + YR_c) \quad \forall c, p \tag{45}$$

$$\sum_h (d_{ap} - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) AU_{ca} \leq (\mathrm{y}_c + (y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3})(1-\beta)) YU_c \quad \forall c, p \tag{46}$$

$$\sum_a (\mathrm{r}_a - r_a^m + \frac{\varphi_r - \acute{\varphi}_r}{3})(1-\delta))(d_a - (d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) BU_{ac} \leq \left(1 - \varrho_c \widehat{Cap'_c}\right)(\eta_c + \tilde{\eta}_c(1-\lambda)) YU_c \quad \forall c, p \tag{47}$$

$$\sum_a (\mathrm{r}_a - r_a^m + (\frac{\varphi_r - \acute{\varphi}_r}{3})(1-\delta))(d_a - (d_a^m + (\frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha))BR_{ac} \leq (\eta_c + \eta_c^m + (\frac{\varphi_\eta - \acute{\varphi}_\eta}{3})(1-\lambda))YR_c \quad \forall c,p \tag{48}$$

$$\sum_c W_{ckp} \leq \left(\rho_k + \left(\rho_k^m + \frac{\varphi_\rho - \acute{\varphi}_\rho}{3}\right)(1-\sigma)\right) Z_k \qquad \forall k,p \tag{49}$$

$$X_h, YR_c, YU_c, Z_k, AR_{ca}, AU_{ca}, BR_{ca}, BU_{ac} \in \{0,1\} \qquad \forall h \in H, \forall c \in J, \forall a \in A, \forall k \in K \tag{50}$$

$$U_{hcp}, W_{ckp}, V_{chp}, T_{c'cp} \geq 0 \qquad \forall h \in H, \forall c, c' \in C, \forall a \in A, \forall k \in K, \forall p \in P \tag{51}$$

This section uses each flexible planning method of Dr.Pishvaee (2012). Accordingly, it is assumed that we have a set of fuzzy parameters; the constraints in which these parameters exist are flexible (i.e., soft conditions). Flexible constraints are formulated linguistically and their degree of satisfaction. According to the above, the model can be shown as follows. According to Cadenas, Verdegay(1997), and Piedro et al.(2009), fuzzy numbers indicate soft constraint violations. Accordingly, Model (1) can be rewritten as follow:

$$\min \sum_h \tilde{F}_h X_h + \sum_c \widetilde{FR}_c YR_c + \sum_c \widetilde{FU}_c YU_c + \sum_k \widetilde{FD}_k Z_k + \sum_h \sum_c \sum_p (\tilde{d}_{hcp} + \widetilde{cpf}_{hp}) U_{hcp} + \sum_c \sum_a \sum_p (\tilde{d}_{cap} + \widetilde{cdf}_{cp}) d_a (AR_{ca} + AU_{ca}) + \sum_a \sum_c \sum_p (\tilde{d}_{acp} + \widetilde{cdr}_{cp}) \tilde{r}_{ap} \tilde{d}_{ap} (BR_{ca} + BU_{ca}) + \sum_c \sum_k \sum_p (\tilde{d}_{ckp} + \widetilde{cp}_{kp}) W_{ckp} + \sum_c \sum_h \sum_p (\tilde{d}_{chp} + \widetilde{cpr}_{hp}) V_{chp} + \sum_{c'} \sum_{c \neq c'} \sum_p q_c \tilde{d}_{c'cp} T_{c'cp} + \sum_a \Gamma((y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3})(1-\beta)) + \theta((d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) + \varsigma((r_a^m + \frac{\varphi_r - \acute{\varphi}_r}{3})(1-\delta)) + \sum_h \varepsilon((\varphi_h^m + \frac{\varphi_\varphi - \acute{\varphi}_\varphi}{3})(1-\gamma)) + \varpi((\tau_h^m + \frac{\varphi_\tau - \acute{\varphi}_\tau}{3})(1-\vartheta)) + \sum_c \Delta(\eta_c^m + (\frac{\varphi_\eta - \acute{\varphi}_\eta}{3})(1-\lambda)) + \sum_k \psi((\rho_k^m + \frac{\varphi_\rho - \acute{\varphi}_\rho}{3})(1-\sigma)) \tag{52}$$

$\Gamma.\theta.\varsigma.\Delta.\varpi.\varepsilon.\psi$ are the degree of stability for each of the fuzzy parameters; also, $d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3}$ determines the possible violation of any flexible constraint.

B. Total Process of Benders' Decomposition Algorithm

At first, we need to find a possible answer to the main problem, which is carried out by solving the main issue without any cut. Then, the achieved solutions will be introduced to the subproblem by the main problem, and the subproblem will be solved. If the problem is not feasible, and the dual answer of the subproblem is infinite, a finite aspect is taken from the double, by which a feasible cut is produced, and this cut will be added to the main problem. If the subproblem is feasible and has an optimal answer, the produced optimality cut will be added to the main problem using these optimal answers to the dual subproblem. The upper bound will be updated if the obtained solution provides an upper bound. Then, the main problem will be solved again using the new cut, and the lower bound will be updated. This will be repeated until the distance between the upper and lower bound is not less than a specific amount.

In the above-formulated problem X_h,YR_c,YU_c ,Z_k,AR_{ca},AU_{ca},BR_{ca}, and Bu_{ca} Variables are considered the complex variables of the problem.

Table II. Details of Numerical Tests

Number of Product Types	*Number of Customer Areas*	*Number of HRD Centers*	*Number of CDC Centers*	*Number of HMR Centers*	*Problem Number*
2	8	3	5	5	1
3	9	6	9	8	2

C. Solving the Main Problem

The variable W_{ckp}, V_{chp}, $T_{c'cp}$ Changes in the main problem by the GAMS solver is shown in Fig (2):

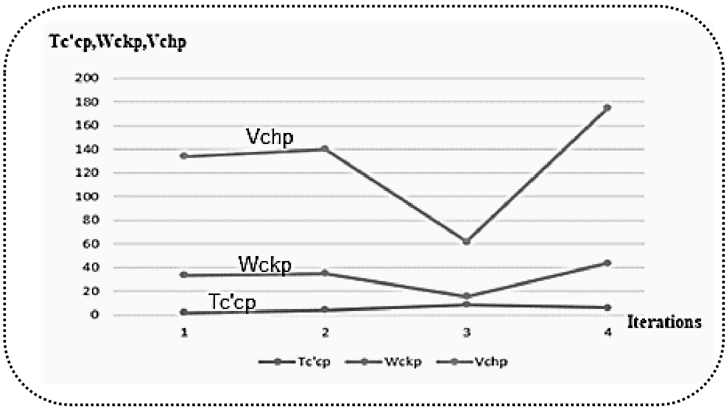

Fig 2. GAMS result of variable W_{ckp}, V_{chp}, $T_{c'cp}$ changes versus iterations-main problem

D. Solving the Problem Using Benders' Decomposition Method

Starting Stage (Zero stage):

In this stage, k=1,$\varepsilon = 0.1$, and $\varphi_{aB} = -1000$ are assumed, and we will solve the following subproblem.

$$\min \sum_h \tilde{F}_h X_h + \sum_c \widetilde{FR}_c YR_c + \sum_c \widetilde{FU}_c YU_c + \sum_k \widetilde{FD}_k Z_k + \sum_h \sum_c \sum_p \left(\tilde{d}_{hcp} + \widetilde{cpf}_{hp}\right) U_{hcp} + \sum_c \sum_a \sum_p \left(\tilde{d}_{cap} + \widetilde{cdf}_{cp}\right) d_a (AR_{ca} + AU_{ca}) + \sum_a \sum_c \sum_p \left(\tilde{d}_{acp} + \widetilde{cdr}_{cp}\right) \tilde{r}_{ap} \tilde{d}_{lp} (BR_{ca} + BU_{ca}) + \sum_c \sum_k \sum_p \left(\tilde{d}_{ckp} + \widetilde{cp}_{kp}\right) W_{ckp} + \sum_c \sum_h \sum_p \left(\tilde{d}_{chp} + \widetilde{cpr}_{hp}\right) V_{chp} + \sum_{c'} \sum_{c \neq c'} \sum_p q_c \tilde{d}_{c'cp} T_{c'cp} + \sum_a \Gamma\left(\left(y_a^m + \frac{\varphi_y - \phi_y}{3}\right)(1-\beta)\right) + \theta\left(\left(d_a^m + \frac{\varphi_d - \phi_d}{3}\right)(1-\alpha)\right) + \varsigma\left(\left(r_a^m + \frac{\varphi_r - \phi_r}{3}\right)(1-\delta)\right) + \sum_h \varepsilon\left(\left(\varphi_h^m + \frac{\varphi_\varphi - \phi_\varphi}{3}\right)(1-\gamma)\right) + \varpi\left(\left(\tau_h^m + \frac{\varphi_\tau - \phi_\tau}{3}\right)(1-\vartheta)\right) + \sum_c \Delta\left(\eta_c^m + \left(\frac{\varphi_\eta - \phi_\eta}{3}\right)(1-\lambda)\right) + \sum_k \psi\left(\left(\rho_k^m + \frac{\varphi_\rho - \phi_\rho}{3}\right)(1-\sigma)\right) \quad (53)$$

$$\min \sum_h \tilde{F}_h X_h + \sum_c \widetilde{FR}_c YR_c + \sum_c \widetilde{FU}_c YU_c + \sum_k \widetilde{FD}_k Z_k + \sum_h \sum_c \sum_p \left(\tilde{d}_{hcp} + \widetilde{cpf}_{hp}\right) U_{hcp} + \sum_c \sum_a \sum_p \left(\tilde{d}_{cap} + \widetilde{cdf}_{cp}\right) d_a (AR_{ca} + AU_{ca}) + \sum_a \sum_c \sum_p \left(\tilde{d}_{acp} + \widetilde{cdr}_{cp}\right) \tilde{r}_{ap} \tilde{d}_{lp} (BR_{ca} + BU_{ca}) + \varphi \quad (54)$$

$$with\ S.T. (29) \sim (35) \qquad \varphi \geq -1000 \quad (55)$$

$$X_h, YR_c, YU_c, Z_k, AR_{ca}, AU_{ca}, BR_{ca}, BU_{ac} \in \{0,1\} \qquad \forall h \in H, \forall c \in C, \forall a \in A, \forall k \in K \quad (56)$$

Also, ${Z_{AB}}^{(1)}$ =1809959.922

First Stage:

k=1

In this stage, we will solve the following subproblem:

$$min \sum_c \sum_k \sum_p \left(\tilde{d}_{ckp} + \widetilde{cp}_{kp}\right) W_{ckp} + \sum_c \sum_h \sum_p \left(\tilde{d}_{chp} + \widetilde{cpr}_{hp}\right) V_{chp} + \sum_{c'} \sum_{c \neq c'} \sum_p q_c \tilde{d}_{c'cp} T_{c'cp} + \sum_a \Gamma\left(\left(y_a^m + \frac{\varphi_y - \phi_y}{3}\right)(1-\beta)\right) + \theta\left(\left(d_a^m + \frac{\varphi_d - \phi_d}{3}\right)(1-\alpha)\right) + \varsigma\left(\left(r_a^m + \frac{\varphi_r - \phi_r}{3}\right)(1-\delta)\right) + \sum_h \varepsilon\left(\left(\varphi_h^m + \frac{\varphi_\varphi - \phi_\varphi}{3}\right)(1-\gamma)\right) + \varpi\left(\left(\tau_h^m + \frac{\varphi_\tau - \phi_\tau}{3}\right)(1-\vartheta)\right) + \sum_c \Delta\left(\eta_c^m + \left(\frac{\varphi_\eta - \phi_\eta}{3}\right)(1-\lambda)\right) + \sum_k \psi\left(\left(\rho_k^m + \frac{\varphi_\rho - \phi_\rho}{3}\right)(1-\sigma)\right) \quad (57)$$

$$With\ S.T. (36) \sim (51)$$

The problem becomes unfeasible by solving the subproblem for outputs of stage zero. The constraints that can make the problem unfeasible by a slack variable can be written to be violated. This error in the target function can be fined with a positive and sufficiently large coefficient. Thus, we will rewrite the subproblem as follows:

$$min \sum_c \sum_k \sum_p \left(\tilde{d}_{ckp} + \widetilde{cp}_{kp}\right) W_{ckp} + \sum_c \sum_h \sum_p \left(\tilde{d}_{chp} + \widetilde{cpr}_{hp}\right) V_{chp} + \sum_{c'} \sum_{c \neq c'} \sum_p q_c \tilde{d}_{c'cp} T_{c'cp} + \sum_a \Gamma(\left(y_a^m + \frac{\varphi_y - \acute{\varphi}_y}{3}\right)(1-\beta)) + \theta((d_a^m + \frac{\varphi_d - \acute{\varphi}_d}{3})(1-\alpha)) + \varsigma((r_a^m + \frac{\varphi_r - \acute{\varphi}_r}{3})(1-\delta)) + \sum_h \varepsilon((\varphi_h^m + \frac{\varphi_\varphi - \acute{\varphi}_\varphi}{3})(1-\gamma)) + \varpi((\tau_h^m + \frac{\varphi_\tau - \acute{\varphi}_\tau}{3})(1-\vartheta)) + \sum_c \Delta(\eta_c^m + (\frac{\varphi_\eta - \acute{\varphi}_\eta}{3})(1-\lambda)) + \sum_k \psi((\rho_k^m + \frac{\varphi_\rho - \acute{\varphi}_\rho}{3})(1-\sigma)) + M(u_1 + u_2 + u_3 + u_4 + u_5 + u_6 + u_7 + u_8) \tag{58}$$

$$T_{c'cp} \leq M \; YR_{c'} \quad \forall c' \;,\; c \neq c', p \tag{59}$$

$$T_{c'cp} \leq \left[(2\beta - 1)\gamma_c^p + (2 - 2\beta)\gamma_c^m\right] YU_c \quad \forall c',\; c \neq c', p \tag{60}$$

$$\sum_{c'} T_{c'c} + \left[(2\beta - 1)\gamma_c^p + (2 - 2\beta)\gamma_c^m\right](1 - \varrho_c \widehat{Cap}_c) YU_c \geq \sum((2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o) AU_{ca} \quad \forall c, p \tag{61}$$

$$\sum_c T_{c'cp} + \sum_c \left[(2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o\right] AR_{c'a} \leq \left[(2\beta - 1)\gamma_{c'}^p + (2 - 2\beta)\gamma_{c'}^m\right] YR_{c'} + \text{u1} \forall c', p \tag{62}$$

$$\sum_h U_{hcp} + \sum_{c'} T_{c'cp} \geq \sum_a \left[(2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o\right] AU_{ca} \forall c, p \tag{63}$$

$$\sum_h V_{chp} = \sum_a (1 - Ad) r_{ap}^m \left[(2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o\right](BR_{ac} + BU_{ac}) \quad \forall c, p \tag{64}$$

$$\sum_k W_{ckp} = \sum_a (Ad r_{ap}^m \left[(2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o\right](BR_{ac} + BU_{ac}) \quad \forall c, p \tag{65}$$

$$\sum_h \sum_c U_{hcp} + u2 \geq \sum_a \left[(2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o\right] \tag{66}$$

$$\sum_c U_{hcp} \leq ((2\beta - 1)\varphi_{hp}^p + (2 - 2\beta)\varphi_{hp}^m) X_h + \text{u3} \quad \forall h, p \tag{67}$$

$$\sum_c V_{chp} \leq ((2\beta - 1)\tau_h^p + (2 - 2\beta)\tau_h^m) X_h + \text{u4} \quad \forall h, p \tag{68}$$

$$\sum_h U_{hcp} + u5 \leq ((2\beta - 1)\gamma_c^p + (2 - 2\beta)\gamma_c^m)(YU_c + YR_c) \quad \forall c, p \tag{69}$$

$$\sum_a ((2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o) AU_{ca} \leq ((2\beta - 1)\gamma_c^p + (2 - 2\beta)\gamma_c^m) YU_c + \text{u6} \quad \forall c, p \tag{70}$$

$$\sum_a r_{ap}^m ((2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o) BU_{ac} \leq (1 - \varrho_c \widehat{Cap}'_c)((2\beta - 1)\eta_c^p + (2 - 2\beta)\eta_c^m) YU_c + \text{u7} \quad \forall c, p \tag{71}$$

$$\sum_a r_{ap}^m ((2 - 2\beta)d_{ap}^m + (2\beta - 1)d_{ap}^o) BR_{ac} \leq ((2\beta - 1)\eta_c^p + (2 - 2\beta)\eta_c^m) YR_c \quad \forall c, p \tag{72}$$

$$\sum_c W_{ckp} \leq ((2\beta - 1)\rho_k^p + (2 - 2\beta)\rho_k^m) Z_k + \text{u8} \quad \forall k \tag{73}$$

$$X_h, YR_c, YU_c, Z_k, AR_{ch}, AU_{ca}, BR_{ac}, BU_{ca} \in \{0,1\}, \forall h \in H, \forall c \in C, \forall a \in A, \forall k \in K \tag{74}$$

$$U_{hcp}, W_{ckp}, V_{chp}, T_{c'cp} \geq 0 \quad \forall h \in H, \forall c, c' \in C, \forall a \in A, \forall k \in K,, \forall p \in P \tag{75}$$

The output results of stage one, including variables changes versus iterations by GAMS, are shown in *Fig* (3):

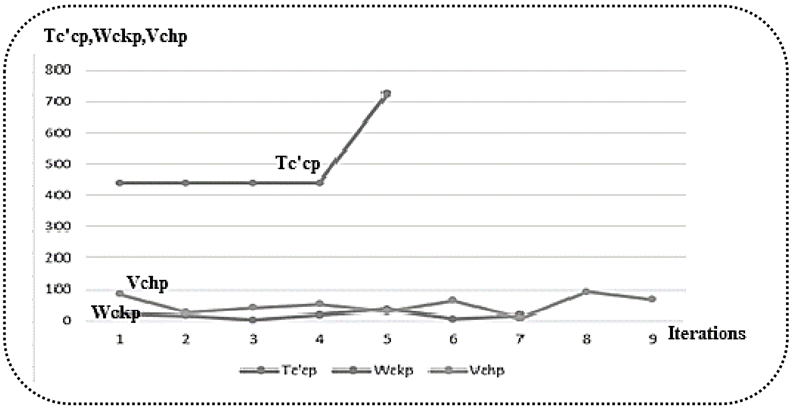

Fig 3. GAMS result of variable W_{ckp}, V_{chp}, $T_{c'cp}$ changes versus iterations-step 1

${Z_{uB}}^{(1)}$ =1,881028*10^8 +1810959=189913759; Therefore, the cut constraint will be added to the problem.

Second Stage:

By taking into account that ${Z_{UB}}^{(1)} - {Z_{aB}}^{(1)} > \varepsilon$ Thus, the condition of termination is not met.

Third Stage:

K=2 is considered, and the model of stage one is solved by adding a cut constraint. Then we will return to stage one and continue the steps as much as possible to meet ${Z_{UB}}^{(1)} - {Z_{aB}}^{(1)} > \varepsilon$ condition.

V. COMPUTATIONAL TESTS & RESULTS OF SENSITIVITY ANALYSIS

To demonstrate the applicability and validity of the proposed model, various numerical tests were carried out, and the results were reported. To do so, two test problems were considered, and their sizes are provided in Table 2. The triangular fuzzy parameters were guaranteed based on the research by Lia (1992), in which three dominant points, i.e., the most pessimistic, probable, and optimal amounts, of which should be estimated for determining each ambiguous parameter. Thus, (ξ^m) the most probabilistic amount for any fuzzy parameter is initially proved accidentally by the assigned monotonous distribution in Table 3.

The equivalent concentric deterministic model was coded in GAMS 23.5/CPLEX 12.2 optimization software, and all numeral tests were solved using a computer, Pentium dual-core, 2.8 GHz, 16GB RAM.

In the FP model, the sensitivity analysis of each parameter that shows the degree of stability of the fuzzy parameters is investigated. In the primary stage, all parameters are assumed to be 0.5, then the changes in each parameter are examined. The sensitivity analysis for each parameter is shown in *Fig* (5) below. In the first sensitivity analysis, α.β = 0.5 is assumed.

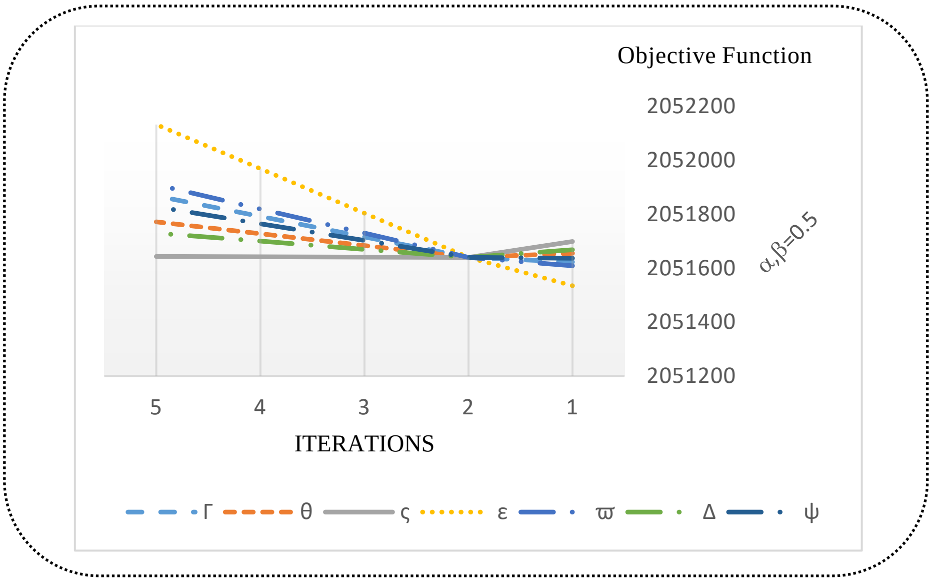

Fig 4. Objective function changes against robustness degree of fuzzy parameters by iterations 1

The results show in Fig(4) that in the first iteration, the parameters are assumed to be 0.4, in the second iteration equal to 0.5, in the third iteration equal to 0.6, and in the fourth and fifth iterations 0.7 and 0.8, respectively. Comparing the results of each parameter, it can be seen that in the second iteration of all parameters, the values are the same, so the objective function is equal. The results also show that the value of the parameter ε has a more significant effect, and the parameter ς has a negligible impact on the objective function changes. Since the objective function is of the minimum type, the best value for the parameters Γ.ϖ.ε.ψ occurred in the first iteration, 0.4, and for the parameters θ.ς.Δ. In the second iteration, it is 0.5.

In the second case in Fig (5), all the above hypotheses are true, except that α.β = 0.4 is assumed. The results show that the target function values decrease in all iterations by decreasing these two parameters. The behavior of the objective function changes by changing these two parameters and the parameter θ. Since the objective function is a minimization function, α.β = 0.4 is a better option.

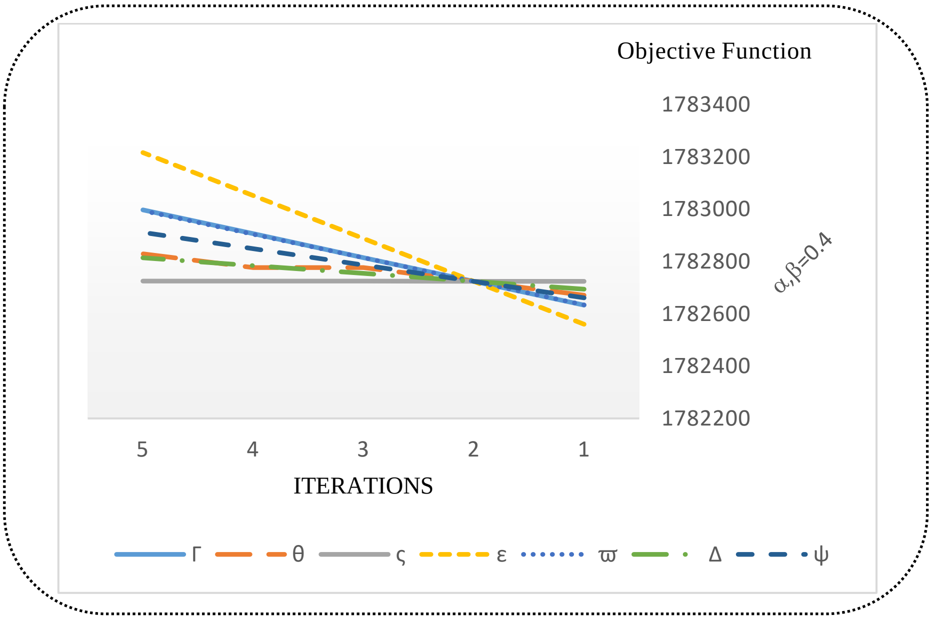

Fig 5. Objective function changes against robustness degree of fuzzy parameters by iteration 2

In the second problem-solving stage, we considered the Benders decomposition algorithm to accelerate the process. This algorithm is based on the initial problem analysis into two main problems and a subproblem. The problem's computational complexity is significantly reduced by proving the vector of complex variables of the problem. The vector of complex variables then corrects the problem by applying shear plates and converging to optimal values. The subproblem includes continuous variables and related constraints, while the main problem includes integer variables and one continuous variable that interrelates two problems. Optimal solving of the main problem provides a lower bound for the target. A dual is solved for the subproblem using the results obtained from solving the main problem by proving the integer variables as the input of the subproblem. Using these results, an upper bound can be defined for the general objective of the problem. Also, dual solving of the subproblem will be employed for constructing a Benders' cut, which includes the added continuous variables to the main problem. In the next repetition, this cut is added to the main problem, and by solving this problem, a lower bound vision is obtained from the general situation, which is guaranteed not to be worse than the current lower bound. Thus, the main problem and the repetitive subproblem are solved until reaching a termination condition, i.e., reducing the distance between the upper and lower bound from a small number. Benders' decomposition method gets an optimal answer in a finite number of repetitions.

The results of employing the proposed deterministic model are summarized in various validity levels in Table 3. Table 4 summarizes the degrees of simplicity level (β levels) reported using the limited validity coding model. By considering any test problem, the proved costs of facilities opening, the optimal amount of the target function, and the whole transport costs, such as the transportation costs of the products between the facilities and the anticipated distribution costs pertinent to the sharing strategy, were established. Following the results, the optimal concrete function increases the problem's simplicity in two test stages. The cost of opening neither changed nor enhanced. Accordingly, it can be demonstrated that the transport costs are enhanced in cases where the opening cost is not changed, such as levels β 0.55, 0.6, and 0.65 in the test. The calculated times for both problem tests are reported in Table 4.

Table III. The sources of model parameters accidental generation

Parameter	*Related accidental distribution*	*Parameter*	*Related accidental distribution*
$\tilde{r}_a$	Uniform (0.7,0.8)	cdf_h	Uniform (1.5,4)
$\tilde{d}_a$	Uniform (80,150)	$c\tilde{p}r_h$	Uniform (3,5)
$\tilde{\tau}_h$	Uniform (250,400)	$c\tilde{p}f_h$	Uniform (3,6)
$\tilde{\varphi}_h$	Uniform (550,800)	$c\tilde{d}r_h$	Uniform (1.5,3)
q_c	Uniform (0.025,0.15)	$\tilde{c}p_k$	Uniform (2,4)
$\tilde{\eta}_c$	Uniform (150,350)	$\tilde{F}U_h$	Uniform (180,000;260,000)
$\tilde{\gamma}_c$	Uniform (250,350)	$\tilde{F}D_k$	Uniform (150,000;220,000)
$\tilde{\rho}_k$	Uniform (150,250)	$\tilde{F}_h$	Uniform (320,000;480,000)
p_c, p'_c	Uniform (0.1,0.5)	$\tilde{d}_{ab}$	Uniform (4,10)
Ad	0.2	$\tilde{F}R_c = 1/2 \times \tilde{F}U_h$	

Table IV. Summary of Results

B	*Test results of the first sample problem*				*Test results of the Second sample problem*			
	Objective Function	*Opening Cost*	*transportation cost*	*CPU time(s)*	*Objective Function*	*Opening Cost*	*transportation cost*	*CPU time(s)*
0.6	1626742.602	1615939.31	6592.987826	8.18	1840913.406	1830110.12	7460.995771	8.95
0.65	1641518.866	1630940.65	6812.501892	7.62	1833165.222	1822587	7607.857456	7.96
0.7	1656295.129	1645361.42	7045.512197	6.89	1825417.037	1814483.33	7764.919291	7.36
0.75	1662173.545	1650776.8	6128.481448	7.32	1825344.153	1813947.4	6730.096152	7.95
0.8	1668051.961	1658077.09	6881.466117	9.98	1825271.269	1815296.4	7530.06662	10.12
0.85	1668332.527	1657054.15	6830.88551	5.32	1824399.629	1813121.25	7469.892716	5.98
0.9	1668613.093	1657245.87	6417.595734	8.91	1823527.989	1812160.77	7013.408616	9.75
0.95	1692739.92	1681993.57	6590.833301	5.07	1823367.838	1812621.49	7099.44471	5.93
1	1716866.746	1705902.37	6405.55834	7.66	1823207.687	1812243.31	6802.311962	8.13

Sensitivity analysis 1 indicates the changes in objective function with β that show the changes in the β to the target function. It is clear from the results that by increasing β, the value of the target function decreases. In Problem 1, this decrease to β = 0.8 is slight and falls with a greater slope in subsequent iterations, as in Fig(6).

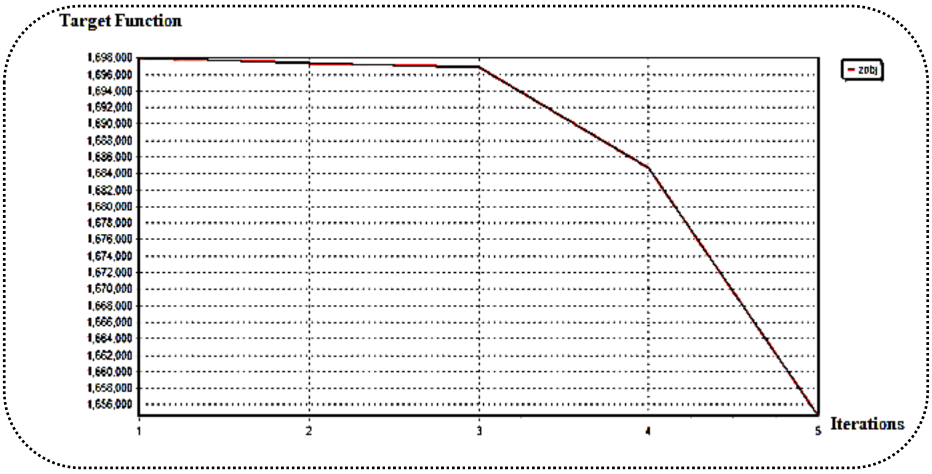

Fig 6. Sensitivity analysis of β for the problem one by iterations

In problem 2, the decrease in β = 0.6 to β = 0.8 is more noticeable. Therefore, it is clear from the results that the problem's dimensions effectively meet the optimal value of β, as shown in Fig(7).

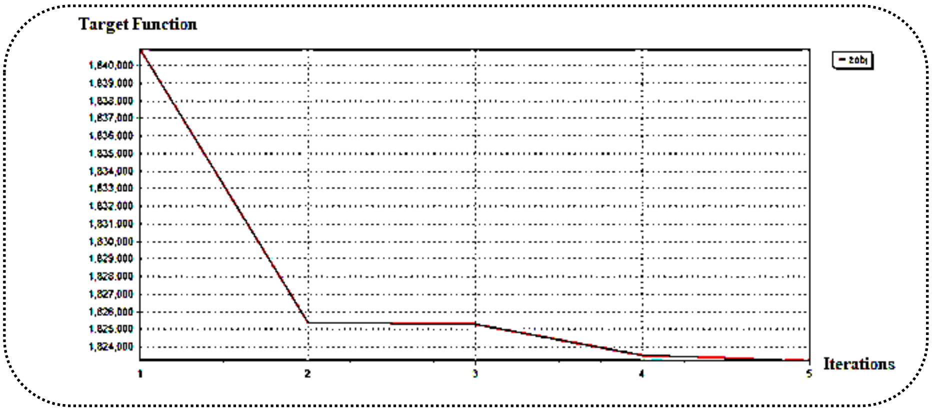

Fig 7. Sensitivity analysis of β for problem two by iterations

In this section, a sensitivity analysis was carried out to display the application of reliability pertinent to the proposed model for preventing disruptions. In this section, the researcher studied the impact of capacity disruption (i.e., changing the deduction of the respective capacity loss in the unreliable CDC facilities) in the sites of the unpredictable and reliable CDC facilities and the number of their locations, with the total network cost, transportation cost, the strategy of sharing the price, and the amount of the shipped products from the reliable CDC facilities to the unreliable CDC facilities after trouble. Thus, it was assumed that $p_c = p'_c$. It must be borne in mind that the sensitivity analysis on problem one is carried out with $\beta = 0/6$. The results are reported in Tables 6 and 7 and demonstrated graphically in *Fig*(12).

Sensitivity analysis 2 expresses changes in the objective function relative to P_c. As mentioned above, this analysis is intended for two different dimensions.

Table V. Comparing the results of the deterministic and proposed credibility models, the performance

Target function under realizations (Test problem 1)			*Target function under realizations (Test problem 2)*			
Proposed model (β = 0.8)	*Proposed model (β = 0.7)*	*Deterministic model*	*Proposed model (β = 0.8)*	*Proposed model (β = 0.7)*	*Deterministic Model*	
4187365	3874325.4	4326753.2	2810378	2727241.2	2947311.5	1
4136800	3896357.3	4268352.3	2863522	2797352.6	2986845.4	2
4285212	3857324.4	4397398.4	2882133	2836205.1	3167465.4	3
4296323	3925346.9	4478635.2	2876325	2820463.3	3078911.5	4
4315684	3987536.9	4529008	2968002	2836852	3216793.3	5
4271091	4024368.3	4569707.3	2982435	2931338.4	3147958	6
4461815	4039753.8	4730365.2	3052352	2886411.1	3268423.3	7
4311858	4136885.1	4687395.2	3124985	2963248.5	3278910.2	8
4274681	3987635.2	4517358.3	3044388	2897980.1	3294621.4	9
4474222	3974365.8	4687395.3	2984446	2867287.8	3030745.3	10
104313.06	85358.59	156440.28	99321.29	68337.784	25889.05	Standard deviation

Table VI. Sensitivity Analysis Results

Amount of shipped products	*Disruption cost*	*Transportation cost*	*Opening cost*	*YR(c)=1*	*YU(c)=1*	*Objective function*	$p_c = p'_c$
101.8	603.75	9929.47	1864997.591	1 2	4 5 6	1875512.171	0.2
110.08	690.1	10144.93	1865583.871	3 5	2 4 6	1875513.257	0.3
71.78	402.42	10903.54	1910015.539	4	1 2 6 7	1920160.469	0.4
142.37	847.94	9887.96	1914351.274	1	3 4 5 7	1925254.814	0.5
146.63	1139.69	10850.02	1955627.763	5	1 2 3 7	1965515.723	0.6

Table VII. Sensitivity Analysis result of Pc (p_c And p'_c show percentages of distribution and collection capacities at unreliable CDC facility c, which are lost as a result of the disruption)

$p_c = p'_c$	*Target function of problem no.1*	*Target function of problem no.2*
0.2	1875512.171	1936949.127
0.3	1875513.257	1974814.329
0.4	1920160.469	1977267.752
0.5	1925254.814	1994467.101
0.6	1965515.723	2006814.417

In this part, $p_c = {p'}_c$ was assumed. For problem 1, the value objective function increases by increasing this value. For problem 2, for Pc = 0.3, 0.4, there is no significant change in the objective function, which indicates that the number between the two is the best value for Pc in Fig(8) and Fig(9).

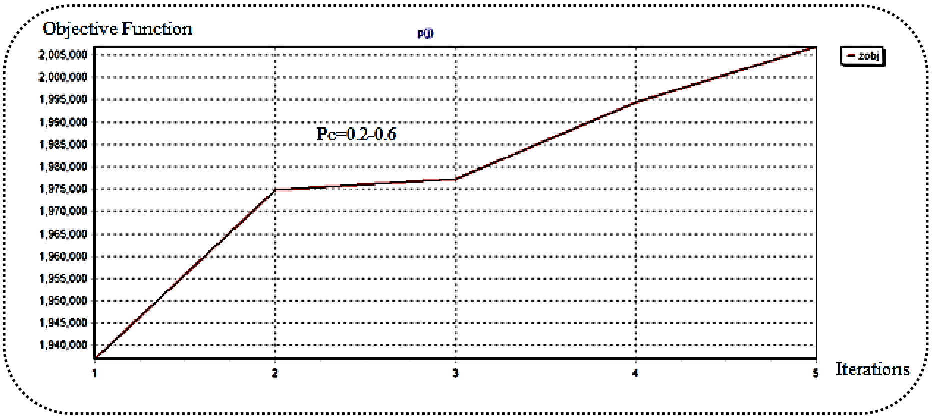

Fig 8. Sensitivity analysis of P_c in problem one by iterations

(Pc denotes the percentages of distribution capacities at unreliable CDC facility c, which are lost due to the disruption.)

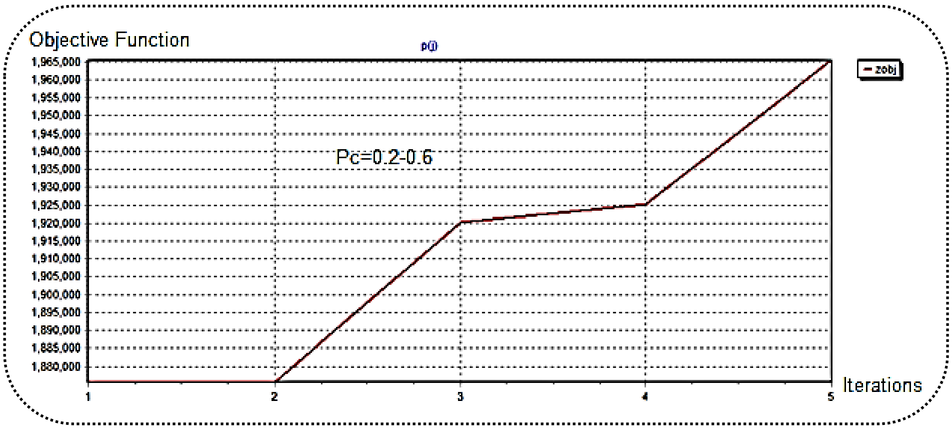

Fig 9. Sensitivity analysis of P_c in problem two by iterations

The binary variable bu (ac) results are such that, for example, it is equal to one for a = 1 and c = 3, but zero for a = 1 and c = 2.

By β Sensitivity analysis, we have increased the parameter value by 0.1 in each step during five repetitions. The base value is 0.4

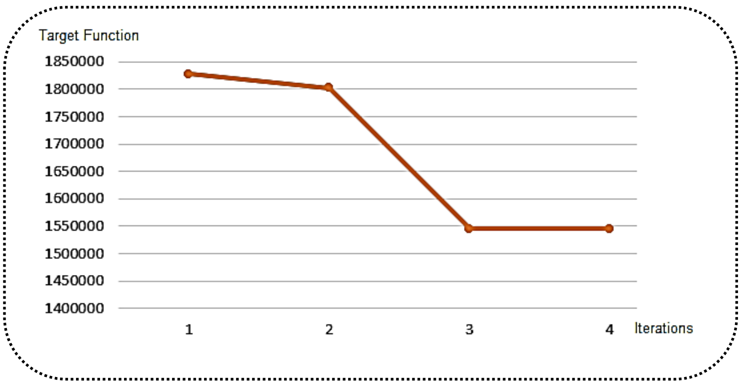

Fig 10. Sensitivity analysis of ϑ for the problem one by iterations

The results show that in iteration 3 ($\beta = 0.6$), the value of the target function decreases significantly, and this cost is almost equal to the results for $\beta = 0.7$ and 0.8, and we do not change much. By ϑ Sensitivity analysis, we have increased the parameter value by 0.1 in each step during five repetitions, as shown in Fig (10) and Fig(11), and the base value is 0.4.

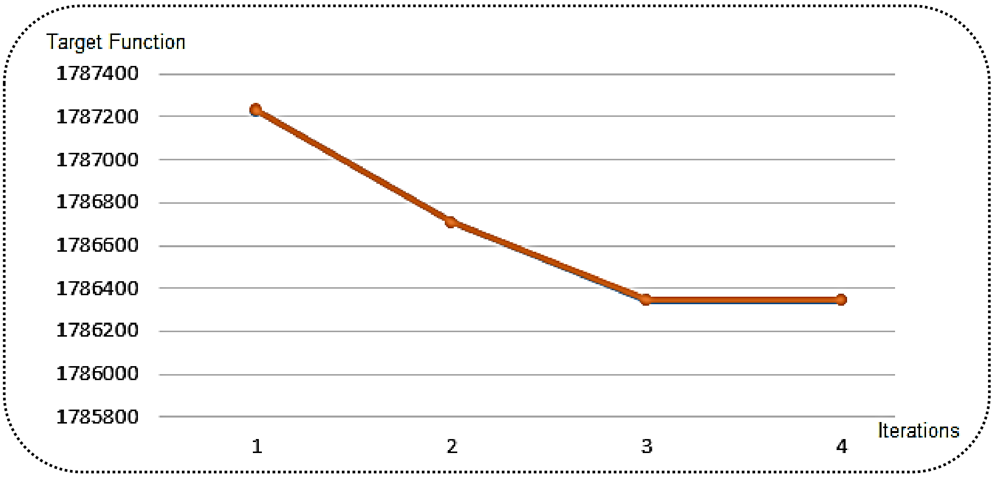

Fig 11. Sensitivity analysis of ϑ for problem two by iterations

It is clear from the results that by increasing this parameter, the cost decreases with a uniform slope to ($\vartheta = 0.6$) and then remains almost constant.

Table 6 first column, demonstrates the troubling capacity in the unreliable CDC equipment percentage. The fifth and second columns manifest the performance of the target and fixed costs of opening. The fourth and third columns indicate the reliable and unreliable areas of the CDC and its conquered numbers. Column no.6 reports the transport cost between customers and the equipment. The disruption costs are displayed in the seventh column, together with the strategy of sharing, which is the transport cost of the products from the reliable equipment of CDC to the unreliable items in trouble. Accordingly, the last column manifests the disruption in the production of the transferred products between unreliable and dependable CDC equipment. The reported results in columns no.1 and 2 of Table 6 increase the target performance by increasing capacity disruption. That is illustrated in Fig(12). Also, by increasing the deductions of capacity loss, the model assigns that more reliable CDC equipment must be carried out. Although, when the capacity disruption is low, much CDC equipment is unreliable. This issue indicates the impact of capacity disruption on the CDC's unreliable and reliable installations and their number (Columns 3 and 4, Table 6). When the activities are considerably disrupted, the fixed costs of opening do not change or increase. In the cases that by increasing the percentage of capacity disruption, the location of CDC unreliable and reliable installations is not changed (for instance, look at rows (6 to 7) or (8 to 10) in Table 5). It changes the number of products transferred from reliable CDC equipment to unreliable items, and the respective costs, i.e., disruption costs, are increased. In these cases, the cost of transport is increased. Fig no.8 Shows the behavior of the expenses of disruption and transportation at various levels of capacity disruption. Therefore, the strategy of sharing is approved in using capacity disruptions.

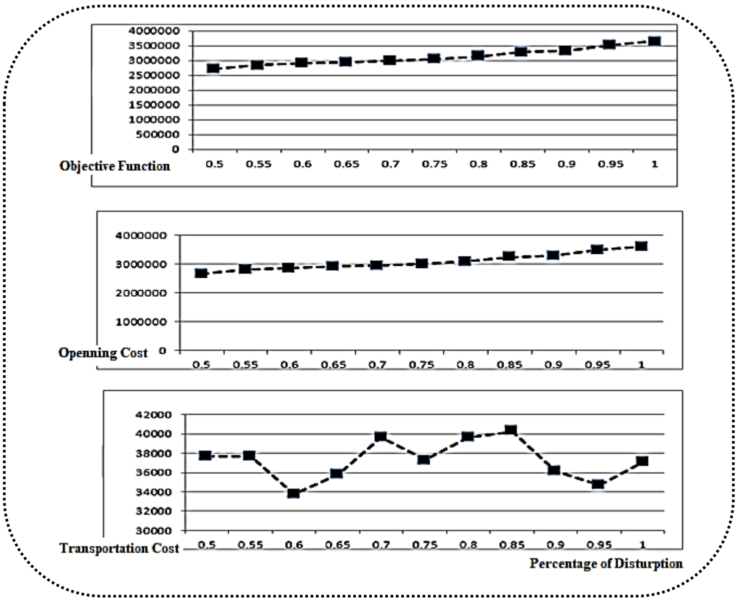

Fig 12. Percentage of Capacity disruptions against Objective function, opening cost, and transportation cost changes

VI. CONCLUSION

In the present study, a valid model was proposed for the reliability of the multi-product forward integrated logistic network against the risk resulting from disruptions in the random installations and the hazards pertinent to the uncertainty in the model's parameters.Actually this study follows an approach that increases the conflunce rate and produces accurate optimal result. Thus,opting the applicable original results from a robust-flexible programming model and carrying the proper value of the binary problem variables,adds the asked original cuts to the main problem.Some reliable concepts are employed to inspect and deal with unanticipated facility disruptions. Unplanned disruption is studied in the fixed equipment of the CDC. Thus, two types of equipment, CDC's unreliable or reliable abilities, are authorized to be placed in the respective network. Therefore, minor and general disruptions of capacity and a sharing strategy that improves service levels after trouble have been investigated.

By the uncertainty in network parameters, a validity-bounded programming outlook is created for the suggested model, the impact of disruptions of the capacity on the target performance, costs of opening and transport, costs of disruption, and value of the joint products among CDC equipment were investigated through sensitivity analysis. Considering the results of the execution of the proposed Benders model in GAMS software.The BD algorithm was proposed to solve the model.The algorithm is enhanced with valid inequalities, premises, input-output variant method , and scenario-based cuts,it is revealed that by increasing the dimensions of the problem and considering a more significant number of products, the time of solving the problem is increased by a considerable amount Besides, the target function of the problem and the opening cost is increased by increasing the dimensions of the problem; however, no fixed process was observed in the transport costs changes. In *Fig*(12) diagrams, the process of changes in cost can be followed. This model can be used as an integrated multi-product and two-stage for future studies.

Finally, some future research directions are given. This paper makes no mention of computational complexity. Due to the increase in computation time caused by increasing the problem size, proposing an exact or heuristic solution method is critical. It is also possible to incorporate reliability concepts into transportation and inventory decisions to create a more dependable supply chain network. Furthermore, the proposed reliability concepts can be applied to supplier issues to deal with supplier disruptions. A scenario-based approach to modeling the various types of disruptions (caused by natural, manufactured, or technological threats) and their impacts on facilities and transportation links would be of particular interest.

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