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Designing an agile supply chain network for perishable products with resilient suppliers

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Abstract

This article attempts to design the integrated supply chain of perishable products with considering agility and resilience. For this purpose, in the first stage, the evaluation and selection of suppliers are done with the network data envelopment analysis model based on resilience indicators, and the two groups of main and backup suppliers are selected through the evaluation. In the next step, the four-tier supply chain including suppliers, production centers, distribution centers, and customers is considered. In order to increase the agility of the integrated supply chain, there is a relationship between the distribution centers. In order to be close to the real environment, the demand for new products is considered as uncertainty, which is represented by a fuzzy number. To avoid wasting resources, a sales discount strategy has been considered for products that are approaching their expiration time. Due to the complexity of the model and the high solution time by MIP, a decomposition algorithm for column generation is considered, which significantly improves the solution time. The proposed model is used in the dairy industry.
Keywords: Network Data Envelopment Analysis, perishable supply chain network, resilient and agile, perishable, sale discount, column generation

1-Introduction

Efficient management of logistics activities is considered an important source of creating a competitive advantage for organizations because it can satisfy customers and their specific needs in the shortest time with high quality while at the minimum cost(Melo et al., 2009). Due to rapid changes in the current economic situation, companies must pay close attention to the structure and process of their supply chain networks (SCN)(Petridis, 2015). Thus, achieving an efficient SCN is one of the most essential strategic issues for organizations(Farahani et al., 2017).. Nowadays, customers' demands for fresh and best quality products have increased. Perishable products can be used during their lifetime and then should be discarded. Many industries, from discrete manufacturing to process industries and from supply to distribution are perishable, imposing certain constraints on various SC processes including purchasing, production planning, inventory management, and distribution planning(Amorim et al., 2013). Due to their short lifetime, these products should be distributed as soon as possible and should reach the customer in the shortest possible time without shortage. Accordingly, it is necessary to design an agile SCN.SC of perishable product due to the short lifetime is more complex and vulnerable (Noya et al., 2016). These complexities and specific characteristics of perishable products increase the risk of SC disruption. To reduce

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SC disruption, it is essential to evaluate its components, identify the propagation mechanisms of the risks(Deng et al., 2019)and select the chain components resiliently.

Customer demand must be satisfied to preserve its share of the competitive market(Sabouhi et al., 2018). With the loss of the market, returning to the market is difficult, and may cause various financial losses to the company. Therefore, the companies should attempt to satisfy customers' demands and maintain the market while paying attention to the perishability of the product. Thus, a mechanism should be adopted to provide the product in any situation according to the protocols of quality and expiration date, reaching the customer plain in a timely and safe manner. Due to the short shelf-life of products, a suitable sales strategy should also be adopted to minimize the perishability of the product. Considering that suppliers include a crucial part of the SC, evaluating and selecting the right supplier helps the company to provide the right quality products in the right quantity at the right price and time(Kuo et al., 2010). These suppliers must be resilient to potential disruptions to minimize vulnerability during disruption. Thus, in the first stage, we will evaluate and select suppliers based on the resilience criterion, and then we will use the selected suppliers in the integrated design of the supply chain.

Companies need production planning to prepare their products, and some uncertain parameters make the production and supply of raw materials difficult. Due to seasonal and climatic changes, the amount of milk production is uncertain, and companies may face a shortage of milk at certain times of the year. To prevent such a disruption in the supply of raw materials for the dairy industry, the resilience strategies of multiple suppliers and the contraction with backup suppliers are considered in this study. In emerging economies, the decision to make a change is one of the main characteristics of any business that makes it more difficult to succeed and survive, and due to changing customer needs, it faces stiff competition and an uncertain environment with high demand fluctuations. These changes require a high speed of action, faster response, and more flexibility. One of the paradigms of the SC is agility, which helps companies to sense sudden and temporary changes in the SC and respond quickly and flexibly to them in today's volatile market(Dubey et al., 2018). These changes require a high speed of action, faster response, and more flexibility for businesses. Competition in the SC forces suppliers, manufacturers, and distributors to operate seamlessly throughout the SC and to work and coordinate with each other(Rooeinfar et al., 2016). Therefore, an integrated SC design is essential to achieve an SC with a competitive advantage. Researchers have rarely jointly considered resilience and agility in an integrated SC.

This paper presents a two-phase approach to SCND from the perspective of resilience and agility, taking into account the characteristics of perishable products. Since raw material suppliers form the first phase of the SC, the evaluation and selection of suppliers based on resilience indices can affect the overall resilience of the supply chain. Thus, in the phase stage, suppliers are evaluated and selected based on resilience criteria. Then, in the second phase, with the suppliers selected in the first stage, the integrated SCND model is presented, which includes inventory and routing decisions.

A proposed integrated SCN consists of resilient suppliers, manufacturers, distributors (with cross-linking), and customers with uncertain demand. Also, in a discrete-time horizon, by applying the sales discount strategy for products that have a short time to their lifetime, we increase the number of sales and prevent the loss of resources. For this purpose, A Mixed-Integer Programming model is presented by considering the transverse relationship between distributors and considering the time reduction strategy of selling perishable products.

The use of supply chain problem-solving algorithms is also one of the active fields in research that many authors have used heuristic, meta-heuristic algorithms, and exact solution methods to solve the SCND problem (Kheirabadi et al., 2019). To achieve an exact solution in this research, the column generation algorithm is used, which is one of the most popular exact solution methods used in research. The column generation algorithm uses the decomposed structure of the problem and solves it far better than the MIP model solved through CPLEX by decomposing the problem and achieving the optimal solution without considering all available patterns. Based on the literature in the field of perishable supply chain network design, this article presents the following contributions:

- Most models in the literature did not consider resilience and agility issues simultaneously. To address this shortcoming, this study combines the resilience and agility aspects and provides an integrated model for the resilient and agile supply chain of perishable products.
- The evaluation of raw material suppliers based on resilience aspects is influenced by many factors, all of which include the SCND problem in increasing its computational complexity. These papers present a two-step approach to avoid high computational complexity. Evaluates the resilience performance of suppliers in one phase and the design of an integrated agile supply chain network in the second phase.
- Consideration of realistic assumptions is rarely seen in the literature. In this article, we help to improve the literature by considering realistic assumptions such as the appropriate strategy for selling perishable products and considering the cross-sectional relationship between distributors.
- Column generation method is applied to the model, which is capable of solving large-scale problems in a reasonable time.

Given the above-mentioned considerations, this paper developed a novel multi-objective, multi-product, multi-period for resilience, and agility perishability SC. The rest of the article is given in the following section. After the introduction section, a literature review in the field of supply chain design of perishable products is provided. The third section describes the model and its assumptions. The model is solved and its sensitivity analysis is done in the fourth section finally an example related to the dairy industry is considered and the results are presented. Finally, our results and findings from this study are presented in section 6.

2- Literature review

The literature of this paper is generally reviewed according to two main categories: Network Data Envelopment Analysis, A perishable product supply chain network design. However, the main focus of this study is on the perishable product supply chain network.

2-1- Network Data Envelopment Analysis (NDEA)

Data Envelopment Analysis (DEA) is a non-parametric evaluation method for measuring the relative efficiency of decision-making units (DMUs) that considers several inputs and outputs with different weights. In traditional DEA methods, DMUs are considered black boxes, meaning that the internal structure of DMUs is often overlooked. As the focus of research on operational processes is a decision unit with initial inputs and final outputs that cannot identify sources of inefficiency in DMUs and does not consider the intermediate outputs of the DMUs(Liu, 2014).

Liang, Yang, Cook, and Zhu (2006) use the concepts of participatory and non-cooperative games in performance appraisal concerning two-stage DMUs. For two-stage models, there are two approaches in the form of cooperative and non-cooperative models from the perspective of game theory(Li, 2017). In non-cooperative models, one of the stages is more important than the other stage (follower).In the first step, the leader's performance is calculated without considering the follower's performance. Then, by keeping the leader performance score constant, the follower performance is calculated in the second step. But in the cooperative model, both stages are equally important and the efficiency of both stages is calculated simultaneously(Hosseinzadeh Lotfi et al., 2012).

(Kao and Hwang, 2008)proposed a model in which the outputs of the first stage were considered entirely as the inputs of the second stage. (Zha and Liang, 2010)presented a two-stage parametric model in series in which, in addition to the kao model, the first stage inputs were used freely in both stages. (Yu and Shi, 2014)proposed a two-stage parametric model in which dedicated inputs were used for the second stage and part of the outputs of the first stage were used as inputs in the second stage. (Jianfeng, 2015) proposes a two-stage DEA model considering simultaneously the structure of inputs and intermediate measures in efficiency evaluation and decomposition.(Wu et al., 2016)proposed a new DEA model to evaluate the environmental efficiency of a two-stage system with undesired outputs. (Izadikhah et al., 2018)Presented a two-stage model in series in which each unit consists of two sub-DMU, and the part of the primary inputs were used jointly input in the first and second stages. Also, in the proposed model, the output of the first stage could be considered as a complete input or as a part or not used in the second stage. In the beginning, non-cooperative models were solved, and then the cooperative model was implemented by changing the appropriate variable turned into a linear model. Summary of literature review of this section in the table1 is summarized.

Table1. A literature review of Network Data Envelopment Analysis

method	Intermediate product	Shared input	Shared output
Kao and Hwang (2008)	-	-	-
. Zha and Liang (2010)-		*	-
Yu and Shi (2014)	*	-	-
Jianfeng (2015)	*	*	-
Wu(2016)	*	*	-
Izadikhah et al., 2018	*	*	-
Proposed method	*	*	*

2-2- Perishable Product Supply Chain Network

(Yavari and Zaker, 2019) designed the green closed-loop of perishable products while considering that the disruption in the network of the electrical system can disrupt the environmental and economic goals of perishable products. Two interdependent layers were considered so that in the first layer of the product, the SCN consists of manufacturers, distribution centers, and retailers. The goals of the modeling are to minimize carbon emissions and the total cost of the network. Similarly,(Yakavenka et al., 2020) developed the green fruit supply chain network while taking into account its perishability. Loading points, entry points, locating distribution centers, and transportation modes were determined to send the products to the demand areas. By solving the model, a balance was obtained between sustainability goals. Furthermore, they examined the possible effects of some on the logistic cost by analyzing the sensitivity of the preferred parameter.

Likewise, (Behzadi et al., 2017)proposed a model by selecting the optimal risk management strategies for disruption at the harvest time and production disruption and tactical decisions in the SC planning of perishable products aiming at maximizing the expected profits. Their results showed that a combination of resilient and flexible strategies is effective in reducing the risk of supply disruption, especially when products have a limited shelf-life. The intended strategies included backup supply, moderating disruption probability, and multiple suppliers. In another study, (Banasik et al., 2017)introduced a closed-loop SC for the mushroom industry. The proposed linear programming model was mixed-integer linear programming consisting of two components. The first one included decisions about the location of the factories producing the compost and soil to reduce the cost of transportation, as well as decisions related to the amount of production of each raw material in each period and the amount of production in each factory to meet customer demand and create the least waste and allow wasted materials to re-enter the chain and use these as a raw material for production. The second component of the model encompassed decisions at the harvest and production planning level. (Saif and Elhedhli, 2016)also developed the mathematical model of the cold SC while taking into account environmental considerations. Then, they tested their model in the meat and vaccine industry and proposed an efficient solution to the problem presented with the Lagrangian approach and simulation. The results represented that environmental impacts can be reduced by up to about 1% without increasing the total cost. (Colicchia et al., 2016)further proposed an eco-efficient SCN and developed three optimization models for minimizing distribution costs and CO_2 emissions and combining the two, respectively. Based on the results, environmental performance could only be improved with a slight increase in distribution costs .Moreover, (Meneghetti and Monti, 2015) designed an automated storage and recovery optimization model with temperature control in mind. The configuration of the shelf, as well as the levels and volume of the cold cell, were taken into account to minimize the annual cost of automated storage and optimized energy needs. In the same vein, Validi et al., (2014) presented a multi-objective model based on total cost minimization and carbon emissions in the dairy industry distribution system. Transportation routes were ranked aiming at reducing costs, carbon emissions, and sustainable geographical location of routes. Additionally,(Dai et al., 2018) presented a location inventory problem in an SCN with mixed nonlinear integer programming and developed an optimization model for perishable products with fuzzy capacity and carbon emission constraints. The proposed model was solved using a hybrid genetic algorithm and hybrid harmony search, followed by comparing LINDO. The results revealed that capacity and carbon constraints have no significant effect on total costs. In their study, Savadkoohi et al., (2018) proposed a multi-period, multi-product location-inventory model for designing a pharmaceutical SC concerning the perishability of pharmaceutical item items and then explored the pharmaceutical industry with a possible programming technique. Zahiri et al., (2018) also introduced the pharmaceutical SCN while considering perishability, substitutability, and quantity discount, and considered the demand and price uncertain. The objective functions of their model were to minimize costs and the maximum unmet demand. Similarly, Diabat et al., (2019) developed a robust two-objective optimization model for an SC design that is resilient to disaster scenarios aiming at minimizing the time and cost of products to customers after a disaster. The results showed that whenever problems in the original model and communications increase, the time to transfer products to customers becomes longer while the time with the deployment of mobile bases to collect products is shorter. Biuki et al., (2020) also presented a multi-objective mixed-linear integer programming model to design a sustainable SCN taking into account product perishability. Their model consisted of two phases. In the first phase, suppliers' performance was evaluated based on sustainability. After excluding the suppliers, they developed a multi-objective optimization model for an SC design in the second phase.

Furthermore, Jouzdani and Govindan, (2021) proposed a multi-objective, multi-vehicle, and multi-product, mathematical programming model to optimize the cost, energy consumption, and traffic congestion. Based on the results, environmental effects may represent a significant increased by emphasizing the economic aspect for products with a high perishability rate, and the social impact may also increase for road networks with high congestion. By controlling the freshness and carbon emissions of perishable products , a 15% economic compromise can greatly improve the sustainability of SCN design ,(Liu et al., 2021) optimized the integrated production and distribution, and routing of inventory in emerging markets to create a sustainable perishable product SC. They also analyzed the effect of vehicle speed on economic cost, carbon emissions, and product freshness. Further, Sazvar et al., (2021) introduced a resilient and sustainable mathematical model by considering resilience criteria such as capacity redundancy, lead time ratio, and customer de-service level to prevent potential disturbances. The results of the proposed model represented that having a redundancy fails to permanently increase the total costs in the SC. Finally, Suryawanshi et al., (2021) offered a model of an online grocery service, where the company procures its products from local suppliers to minimize product delivery delays, and a backup strategy is designed to enhance resilient SC scheduling. In the proposed model, the characteristics of the region that is served, the order window time, the order quantity, and the distance of the customers were considered, and the disruption caused by foreign suppliers was addressed in their study. The main characteristics of the studies are compared in table 2. In the first part, the names of the authors are given. The second part of the table deals with the characteristics of Sustainability, Resiliency, and agility. In the third part, the decision variables are listed and in the fifth part, the number of levels used in the design of the supply chain is studied. In the sixth part of the table, the method used to solve the presented models is mentioned, and in the seventh part, the price discount used in the supply chain is discussed, and in the last part, the studied industry is mentioned in each of the articles. By expressing the characteristics and comparing the reviewed articles in the field of SCN of perishable products, it can be seen that little attention has been paid to the simultaneous consideration of sustainability, resiliency, and agility. Also, the price discount strategy for selling products when the product is nearing the end of their lifetimes was not found in previous research. Thus, the developed practical model is presented with the following assumptions:

- As the expiration time approaches, a price discount is considered.
- There is a cross-link between distributors.

Table 2. Literature review of Perishable SCND

Article	Characteristic					Decision Variables				Number of echelons	Uncertainty				Solution Method		DISCOUNT		Case study
	Sustainability			Resiliency	agility	Location	Transportation	Routing	Inventory		probability	Fuzzy	Stochastic	Robust	exact	metaheuristic	purchase	Sales	
	En.	So.	Ec.																
Validi et al. (2014)	*							*		3						*			Dairy
Meneghetti and Monti (2015)	*				*	*				2					*				Frozen Food
Colicchia et al. (2016)	*						*			3					*				Chocolate
Saif and Elhedhli (2016)	*					*	*		*	3						*			Meat and Vaccine
Banasik et al. (2017)	*					*				2					-				Mushroom
Zahiri et al (2017)			*		*	*	*		*	4		*			*		*		pharmaceutical
Behzadi et al. (2017)				*			*		*	2			*		*				fruit
Sazvar et al. (2018)	*	*					*		*	2						*			-
Dai et al (2018)	*		*		*	*	*		*	3		*				*			-
Savadkoohi et al(2018)			*			*			*	3		*			*				pharmaceutical
Diabat,et al(2018)				*	*	*	*	*	*	4				*	*				blood
Yakavenka et al. (2019)	*	*	*		*		*			2					*				fruit
Mohammad Yavari and HamedZakera (2019)	*		*	*		*	*		*	4			*		*				Dairy
Biuki et al. (2020)	*	*				*	*	*	*	4		*				*	*		-
Dutta and Shrivastava (2020)						*	*			3			*						Milk
JavidJouzdani, KannanGovindan(2021)	*	*			*	*	*		*	2	*				*				Dairy
Liu et al(2021)	*		*		*	*	*	*	*	3					*				emerging markets
Sazvar et al(2021)	*	*	*	*	*	*	*			3				*	*				vaccine
Suryawanshi(2021)	*		*	*	*		*		*	3			*			*			Perishable pro
(Yadav and Kumar, 2022)	*		*					*		1		*			*				Vaccine
This study	*		*	*	*	,	*	*	*	4		*			*			*	dairy

3- Problem description and proposed methodology

The SCN considered in this study includes four levels raw material suppliers, production centers, distribution centers, and customers. Raw material suppliers are first evaluated and selected based on resilience and agility indicators using an NDEA model.

Selected suppliers of raw materials, by supplying raw materials, send them to the production centers for final processes, and the production centers, after the production of the product, send these to the distribution centers. At this level, distributors have warehouses and store part of their products in their warehouses. Distribution centers send their final products to their customers through vehicles before perish. This is done before it becomes unusable on the way to the shelf. There is a cross-link between distributors to prevent product shortages to meet customer demand. Figure 1 shows the framework of the proposed supply chain network design.

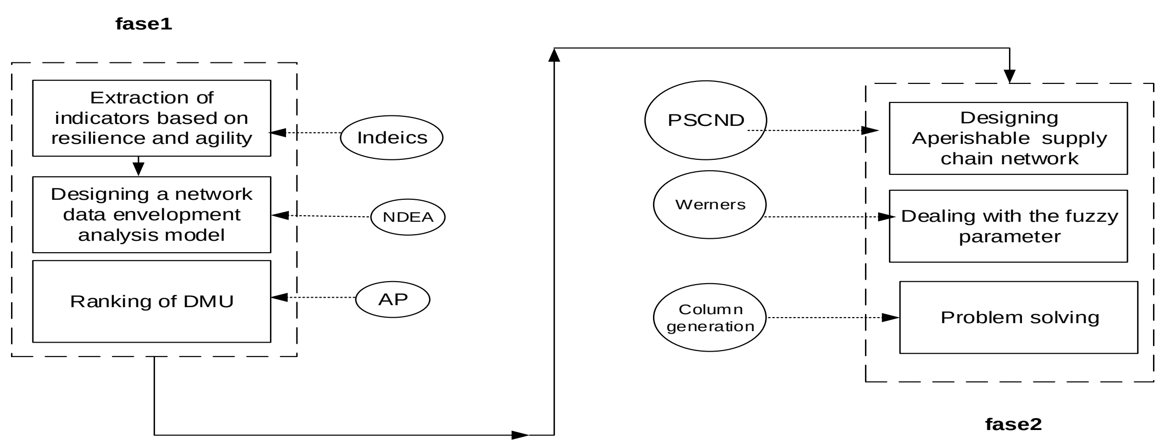

Fig.1. Research framework

The product is distributed to customers by vehicles in the form of routing. The main model of a perishable multi-level supply chain network can be modeled according to the following assumptions:

- Major distribution centers will be considered hub locations.
- Shortages are not allowed and all customers' demand for all products must be met.
- The mathematical model of product distribution is multi-product and multi-period.
- The initial inventory of each product in the first period is zero.
- Each product has a shelf life after which it expires and is discarded
- To approximate the model of allocating demand to the real environment, the customer demand parameter is uncertainty, which is expressed as a fuzzy number.

According to the above assumptions, the main purpose of this study is to increase supply chain resilience, increase the revenue of the entire supply chain network by considering the time discount strategy, increase the agility of the distribution system and reduce the maximum product delivery time to customers. To achieve these goals, resilient suppliers must be evaluated and selected, and the optimal allocation of flow between facilities, the optimal routing of vehicles, and the optimal amount of inventory in the warehouses of production and distribution centers must be identified.

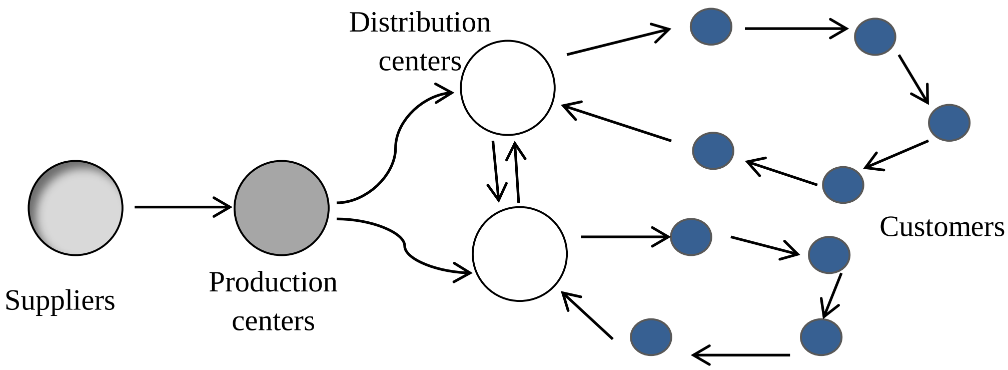

Fig 2. Structure of proposed perishable supply chain network

In the second phase, we will design SCN with four layers in the form of multi-product and multi-period through a two-objective programming model. The structure of the proposed SCND model is shown in figure 2.

3-1- The proposed DEA model

In this study, according to their proposed approach, our proposed model is developed as follows.

- Consider a two-stage DEA model in which each DMU consists of two sub-DMUs in series.
-The intermediate outputs of sub-DMU in stage1 could be considered as a complete input or as a part or not used in the second stage.
- Part of the inputs was used jointly as an input in the first and second stages.
-parts of the outputs were used jointly as an output in the first and second stages.
-For units with the same efficiency score, the Anderson and Peterson methods are used to rank the units uniformly.

Figure 3 shows the proposed model in this study and table 3 lists the variables and parameters of the proposed model.

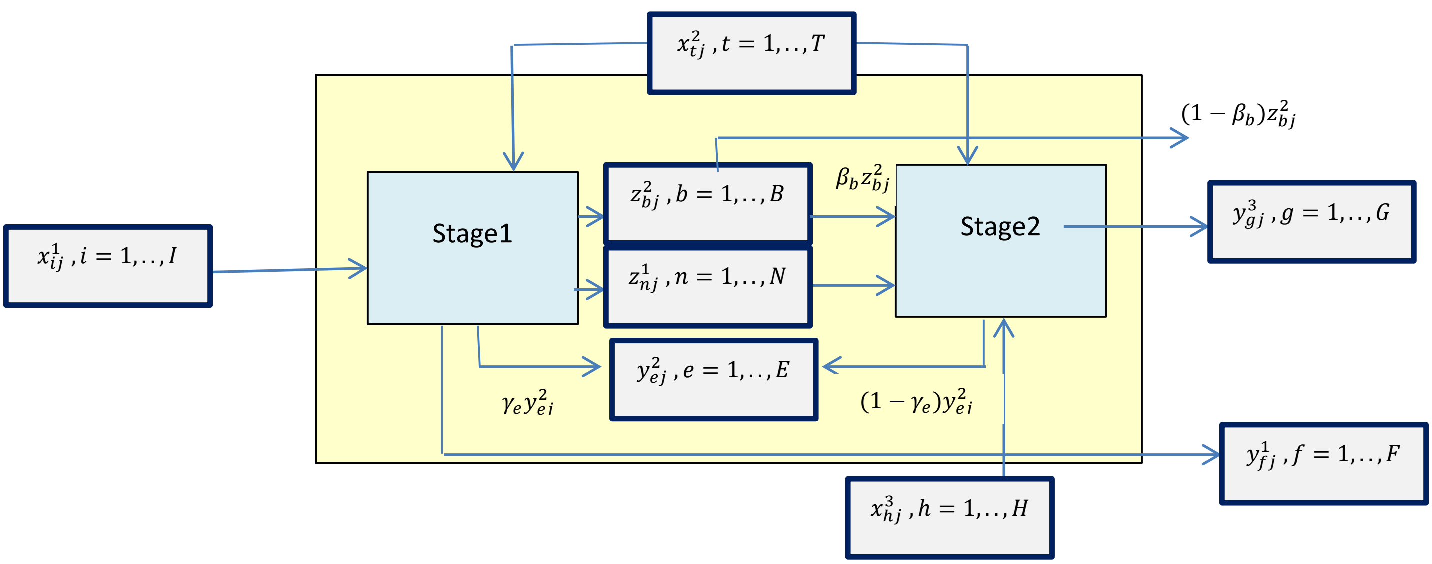

Fig 3. The proposed two-stage DEA model

Table 3. Parameters and variables used

Indicator	parameter	Relevant variable	Description
Input	x_{ij}^1	v_i^1	The Input of stage 1
Input	x_{tj}^2	v_t^2	Jointly input of stage1 and stage2
Input	x_{hj}^3	v_h^3	Input of stage 2
Input & output	z_{nj}^1	W_n^1	The output of stage1 and Input of stage2
Input & output	z_{bj}^2	W_b^2	The Partial output of stage1 and Input of stage2
output	y_{fj}^1	u_h^1	The output of stage1
output	y_{ej}^2	u_e^2	Jointly input of stage1 and stage2
output	y_{gj}^3	u_g^3	The output of stage2
non- cooperative	-	θ_{1p}^U	The upper bound of the efficiency of Stage 1 of DMU p
non- cooperative	-	θ_{1p}^L	The Lower bound of the efficiency of Stage 1 of DMU p
non- cooperative	-	θ_{2p}^U	The upper bound of the efficiency of Stage 2 of DMU p
non- cooperative	-	θ_{2p}^L	The lower bound of the efficiency of Stage 2 of DMU p
cooperative	-	$The\ overall$	The Overall efficiency of DMU p

DEA models are presented according to the leader-follower relationship analysis.

$$\theta_{1p}^U = \max \sum_{d=1}^{D} \widehat{W_d^1} Z_{dp}^1 + \sum_{b=1}^{B} \widehat{W_b^2} Z_{bp}^2 + \sum_{e=1}^{E} \widehat{\vartheta_e^2} y_{ep}^2 + \sum_{f=1}^{F} \widehat{u_f^1} y_{fp}^1$$

$$\sum_{i=1}^{I} \widehat{v_i^1} x_{ip}^1 + \sum_{t=1}^{T} \widehat{\mu_t^2} x_{tp}^2 = \lambda \qquad (10)$$

$$\sum_{d=1}^{D} \widehat{W_d^1} Z_{dp}^1 + \sum_{b=1}^{B} \widehat{\varphi_b^2} Z_{bp}^2 + \sum_{t=1}^{T} (\widehat{v_t^2} - \widehat{\mu_t^2}) x_{tp}^2 + \sum_{h=1}^{H} \widehat{v_h^3} x_{hp}^3 = \lambda$$

$$\sum_{d=1}^{D} \widehat{W_d^1} Z_{dj}^1 + \sum_{b=1}^{B} \widehat{W_b^2} Z_{bj}^2 + \sum_{e=1}^{E} \widehat{\vartheta_e^2} y_{ej}^2 + \sum_{f=1}^{F} \widehat{u_f^1} y_{fj}^1 - \left(\sum_{i=1}^{I} \widehat{v_i^1} x_{ij}^1 + \sum_{t=1}^{T} \widehat{\mu_t^2} x_{tj}^2 \right) \leq 0 \quad \forall \quad j = 1, \dots, n$$

$$\sum_{g=1}^{G} \widehat{u_g^3} y_{gj}^3 + \sum_{e=1}^{E} (\widehat{u_e^2} - \widehat{\vartheta_e^2}) y_{ej}^2 - \left(\sum_{d=1}^{D} \widehat{W_d^1} Z_{dp}^1 + \sum_{b=1}^{B} \widehat{\varphi_b^2} Z_{bj}^2 + \sum_{t=1}^{T} (\widehat{v_t^2} - \widehat{\mu_t^2}) x_{tj}^2 + \sum_{h=1}^{H} \widehat{v_h^3} x_{hj}^3 \right) \leq 0 \quad \forall \ j = 1, \dots, n$$

$$0 \leq \widehat{\varphi_b^2} \leq \widehat{W_b^2} \qquad \forall b = 1, \dots, B \quad , \qquad 0 \leq \widehat{\mu_t^2} \leq \widehat{v_t^2} \qquad \forall t = 1, \dots, T$$

$$\theta_{2p}^L \leq \lambda \leq \theta_{2p}^U$$

$$\widehat{W_d^1}, \widehat{W_b^2}, \widehat{\varphi_b^2}, \widehat{\vartheta_e^2}, \widehat{u_f^1}, \widehat{v_i^1}, \widehat{v_t^2}, \widehat{v_h^3}, \widehat{u_g^3}, \widehat{u_e^2}, \widehat{\mu_t^2} \geq 0 \qquad \forall\ d = 1, \dots, D\ ;\ b = 1, \dots, B\ ,$$

$$h = 1, \dots, H \ ;\ I = 1, \dots, M; t = 1, \dots, T, e = 1, \dots, E\ ,; f = 1, \dots, F, g = 1, \dots, G$$

3-1-1- Anderson-Peterson or super efficiency method

Basic data envelopment analysis models divide the units under evaluation into efficient or inefficient units but cannot rank efficient units. In 1993, Anderson and Patterson proposed a method for ranking efficient units by modifying basic data envelopment analysis models, which makes it possible to determine the most efficient unit. The formulation of different linear programming models in this model is the same as the previous models, with the difference that the constraint related to the unit under evaluation, which creates a 1 score efficiency, is removed from the possible production set. In this case, the efficiency of the units under study can be equal to a number greater than one. Their proposed model is model 11.

$$\max\ z = \sum_{r=1}^{s} u_r y_{ro}$$

$$\sum_{i=1}^{m} v_i\, x_{io} = 1 \tag{11}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \le 0 \qquad j = 1, \dots, n, j \neq o$$

$$u_r \ge 0 \quad r = 1, \dots, s\ , v_i \ge 0\ \ i = 1, \dots, m$$

Wherex_{ij} and y_{rj} are input and output of DMU_j with u_r and v_i weights respectively.

3-2- Proposed SCND formulation

The proposed perishable supply chain network model with the following objective functions and constraints is proposed.

3-2-1- Objective function

Definitions of sets, parameters, and variables used in modeling are given in the tables 4 to 6.

Table 4. Sets used in the proposed model

Symbol	Definition
k	Index of suppliers, i=1,2,…,|K|
b	Index of backup suppliers, b=1,2,…,|B|
f	Index of factory, f=1,2,…|F|
i	Index of distribution centers, i=1,2,…|I|
j	Index of customers, j=1,2,…,|J|
r	Index of raw materials, r=1,2,…|R|
p	Index of products, p=1,2,…|P|
v	Index of vehicles, v=1,2,…|V|
t, t'	Index of period in planning horizon, t,t'=1,2,…,|T|
n, n'	Index of nodes belonging to distribution centers and customers. $n,n' \in N = I \cup J$

Table 5. Parameters used in the proposed model

Symbol	Definition
Pr_{ipt}	unit product price at period t
λ_{ipt}	Price discount coefficient of p product at period t
$C_{nn'vt}$	Unit transportation cost between nodes through vehicle v in period t
$CY_{ii'pt}$	Unit transportation cost between distribution centers in period t
$CIT_{ipt't}$	Unit perishability cost of p product in period t Which has been received in the period of t' and not sold during its lifetime
$CI_{ipt't}$	unit inventory holding cost of p product in the distribution center I in period t Which has been received in the period'
CS'_{fipt}	Unit production and transportation cost for product p shipped from production center f to distribution center I in period t
CIF_{fpt}	period
CS_{kfrt}	Unit purchasing and transportation cost for raw material r shipped from supplier k to production center f in period t
CBS_{bfrt}	Unit purchasing and transportation cost for raw material r shipped from back up supplier b to production center f in period t
D_{jpt}	The Demand of customer j for product p in period t
$period$	The time it takes for vehicle v to move from one node to another
$capF_{fp}$	The capacity of production center f for product p
cap_{fp}	The Capacity of the production center f to maintain and store product p
$capI_{ip}$	The capacity of the distribution center i for product p
$capk_{krt}$	The capacity of suppliers for raw materials r
lp	shelf life of products
p_t	The duration of a lifetime that includes a price discount
M	A big number

Table 6. Variables used in the proposed model

Symbol	Definition
$I_{ipt't}$	Inventory level of product p in distribution center I at the end of period t received at t' time
S_{fipt}	Quantity of products p shipped from production center f to distribution center i in period t
$Y_{ii'pt}$	period
SS_{kfrt}	Quantity of raw material r shipped from supplier k to production center f in period t
BS_{bfrt}	Quantity of raw material r shipped from backup supplier b to production center f in period t
IF_{fpt}	Inventory level of product p in production center f at the end of period t
W_{njvt}	1 If vehicle v travels from node n to node n';0 otherwise
Z_{ijt}	1 If customer j is assigned to distribution center i in period t.
AT_{jvt}	Time to reach node j through vehicle v in period t
C_{max}	The Maximum time that vehicles can transport products in all periods

The proposed model of supply chain network design for perishable products is modeled as follows:

The first objective function of F1 maximizes the amount of profit, which includes revenue from sales at the original price in a lifetime, Revenue from the sale of the product, taking into account the discounted, costs of transportation of product from distributors to customers, transportation costs between distributors, costs of perishability when products not sold during its lifetime, costs of maintaining inventory in distribution centers, Costs of transporting the product from the production center to the distribution centers, costs of maintaining inventory in the production center Costs of transportation and purchase of raw materials from the main supplier to the production center, Costs of transportation and purchase of raw materials from backup supplier to production center.

$$
\begin{aligned}
Max \quad F1 = & \sum_{i\in I}\sum_{p\in P}\sum_{t'\in T}\sum_{\substack{t\in T;\\ t\le t'+lt-p_t-1}} pr_{ipt}\,.\left(I_{ipt'(t-1)} - I_{ipt't}\right)\\
& + \sum_{i\in I}\sum_{p\in P}\sum_{t\in T} pr_{ipt}\left(\left(\sum_{f} S_{fipt} - \sum_{\substack{i'\\ i'\ne i}} Y_{ii'pt} + \sum_{\substack{i'\\ i'\ne i}} Y_{i'ipt}\right) - I_{iptt}\right)\\
& + \sum_{i\in I}\sum_{p\in P}\sum_{\substack{t'\in T\\ t}}\sum_{\substack{t\in T\\ t'+lt-p_t\le t\le t'+lt-2}} pr_{ipt}(1-\lambda_{ipt}).\left(I_{ipt'(t-1)} - I_{ipt't}\right)\\
& - \sum_{n'\in N}\sum_{n\in N}\sum_{v\in V}\sum_{t\in T} C_{nn'vt} W_{nn'vt} - \sum_{i\in I}\sum_{i'\in I}\sum_{p\in P}\sum_{t\in T} CY_{ii'pt} Y_{ii'pt}\\
& - \sum_{i\in I}\sum_{p\in P}\sum_{t'\in T}\sum_{\substack{t\in T\\ t=t'+lt-1}} CIT_{ipt't} I_{ipt't} - \sum_{i\in I}\sum_{p\in P}\sum_{t'}\sum_{t<t'+lt} CI_{ipt't} I_{ipt't}\\
& - \sum_{i\in I}\sum_{i'\in I}\sum_{p\in P}\sum_{t\in T} CS'_{fipt} S_{fipt} - \sum_{f\in F}\sum_{p}\sum_{t} CIF_{fpt} IF_{fpt} - \sum_{k\in K}\sum_{f\in F}\sum_{r\in R}\sum_{t\in T} CS_{kfrt} SS_{kfrt}\\
& - \sum_{b\in B}\sum_{f\in F}\sum_{r\in R}\sum_{t\in T} CBS_{bfrt} BS_{bfrt}
\end{aligned}
$$

The second objective function minimizes the maximum time of product delivery to customers

$$F2 = C_{max} \tag{2}$$

The third expression of the first objective function will be explained in detail in Section 3.2.3.

3-2-2- Constraints

The constraints of the proposed model are described in equations (3) to (24).

$$\sum_{i\in I} Z_{ijt} = 1 \qquad \forall j \in J \forall t \in T; \tag{3}$$

$$\sum_{n}\sum_{v\in V} W_{njvt} = \sum_{i} Z_{ijt} \;\forall j \in J \forall t \in T; \tag{4}$$

$$\sum_{n}\sum_{v\in V} W_{jnvt} = \sum_{i} Z_{ijt} \;\forall j \in J \forall t \in T; \tag{5}$$

$$\sum_{n'} W_{nn'vt} = \sum_{n'} W_{n'nvt} \;\; \forall\, n \in N \quad \forall\, v \in V; \;\; \forall\, t \in T \tag{6}$$

$$\sum_{n} W_{invt} + \sum_{n} W_{njvt} \leq 1 + Z_{ijt} \quad \forall i \in I \; \forall j \in J \; \forall v \in V \; \forall t \in T \tag{7}$$

$$AT_{jvt} \geq td_{ijvt} - M(1 - W_{ijvt}) \quad \forall i \in I \; \forall j \in J \; \forall t \in T \; \forall v \in V \tag{8}$$

$$AT_{nvt} \geq AT_{jvt} + td_{jnvt} - M(1 - W_{jnvt}) \quad \forall j \in J \; \forall n \in N \; \forall v \in V \; \forall t \in T \tag{9}$$

$$C_{max} \geq AT_{ivt} \quad \forall i \in I \; \forall t \in T \; \forall v \in V \tag{10}$$

$$I_{iptt} + \sum_{\substack{t' \in T \\ t' < t}} I_{ipt't} = \sum_{f \in F} S'_{fipt} + \sum_{\substack{t' \in T \\ t' < t}} I_{ipt'(t-1)} - \sum_{j \in J} Z_{ijt}\, D_{jpt} - \sum_{\substack{i' \in I \\ i' \neq i}} Y_{ii'p(t-1)} + \sum_{\substack{i' \in I \\ i' \neq i}} Y_{i'ipt} \quad \forall i \in I \; \forall t \in T \; \forall p \in P; \tag{11}$$

$$I_{iptt} \leq \sum_{f \in F} S'_{fipt} + \sum_{\substack{i' \in I \\ i' \neq i}} Y_{i'ipt} - \sum_{\substack{i' \in I \\ i' \neq i}} Y_{ii'pt} \quad \forall i \in I \; \forall t \in T \; \forall p \in P \tag{12}$$

$$I_{ipt't'} \geq I_{ipt't} t' < t, \quad i \in I \; p \in P \; t \in T \tag{13}$$

$$I_{ipt't} \geq I_{ipt'(t+1)} t' < t, \quad i \in I \; p \in P \; t \in T \tag{14}$$

$$I_{ipt't} = 0 \quad \forall t \geq t' + lt_p \; i \in I, \quad p \in P, t \in T \tag{15}$$

$$IF_{fpt} = \sum_{r \in R} \sum_{p \in P} \alpha_{rp}\, SS_{kfrt} + \sum_{r \in R} \sum_{b \in B} \alpha_{rp} BF_{bfrt} + IF_{fp(t-1)} - \sum_{i \in I} SP_{fipt} \quad \forall f \in F, \forall p \in P, \forall t \in T \tag{16}$$

$$\sum_{i \in I} S'_{fipt} \leq capF_{fp} \quad \forall f \in F \; \forall p \in P \; \forall t \in T \tag{17}$$

$$IF_{fpt} \leq cap_{fp} \quad \forall f \in F \; \forall p \in P \; \forall t \in T \tag{18}$$

$$\sum_{t' \in T} I_{ipt't} \leq capI_{ip} \quad \forall i \in I, \quad p \in P, t \in T \tag{19}$$

$$I_{iptt} + \sum_{\substack{i, i' \in I \\ i \neq i'}} Y_{ii'pt} + \sum_{\substack{i, i' \in I \\ i \neq i'}} Y_{i'ipt} \leq M. \sum_{j \in J} Z_{ijt} \; (20) \quad \forall i \in I, p \in P, t \in T \tag{20}$$

$$\sum_{b \in B} YS_{bfrt} * M \geq \sum_{k \in K} (SS_{kfrt} - capk_{krt}) \quad \forall f \in f, \forall r \in R, \forall t \in T \tag{21}$$

$$\left(\sum_{b \in B} YS_{bfrt} - 1 \right) * M \leq \sum_{k \in K} (SS_{kfrt} - capk_{krt}) \; \forall f \in f, \forall r \in R, \forall t \in T \tag{22}$$

$$\sum BF_{bfrt} \leq capb_{brt} * \sum_{f \in F} ys_{bfrt} \; \forall b \in B, \forall r \in R, \forall t \in T \tag{23}$$

$$\sum_{f \in F} SS_{kfrt} \leq capk_{krt} \tag{24}$$

$$I_{ipt't}, S_{fipt}, SS_{kfrt}, BS_{bfrt}, IF_{fpt}, AT_{jvt}, C_{max} \geq 0 \; \forall i \in I, p \in P, f \in F, t, t' \in T, b \in B, j \in J, r \in R, v \in V \tag{25}$$

$$W_{njvt}, Z_{ijt} \in \{0,1\} (26) \quad \forall i \in I, t \in T, j \in J, v \in V, n \in N = I \cup J \tag{26}$$

Constraint (3) specifies the allocation of each customer to distribution centers in each period. Constraints (4) and (5) specify the entry and exit routes for each customer in each period. Constraint (6) ensures that the input and output vehicles are the same for node n. Constraint (7) defines the routes between nodes belonging to the distribution center I for the vehicle's initial motion. Constraints (8) and (9) specify the arrival time of vehicles for each node. Constraint (10) calculates the arrival time of the last vehicle. Constraint (11) guarantees the balance of inventory in the distribution center. Constraint (12) calculates the maximum amount of inventory remaining in each period. Constraint (13) and (14) indicates that inventory during the production period must be greater than inventory after the production period. Constraint (15) indicates that inventory after expiration must be zero. Constraint (16) determines the inventory level balance of any products in the factories. Constraints (17) to (19) indicate the capacity of the centers. Constraint (20) ensures that products can be shipped from the distribution center to another distribution center and can have inventory if the center is selected. Constraint (21) to (23) ensures that in the event of a shortage of raw materials due to the non-delivery of the main suppliers, the raw materials will be supplied by the backup suppliers. Constraint (24) indicates the capacity of the main suppliers. Finally, constraint (25) and (26) applies the non-negativity and binary restrictions on the model, respectively.

3-2-3- Consider selling discounts due to perishability

Consider a product whose expiration date has passed and its value has reached zero; If the price was discounted at a certain time before the expiration date, many customers who anticipated being able to consume the product in the remaining time until its expiration date would be eager to buy the discounted product. So if you can change the way based on a reliable forecast of customer behavior, dynamically and over time, you can expect to earn more money from your perishable goods business. The sales manager sells the product at the approved price, but due to the short life of the product and the fact that the product is destroyed after the expiration date, gives a discount on the sale so that the product is sold before the expiration date. Thus, we consider the time of product life so that the remaining products after that time have a price discount. We display this time in P_t.

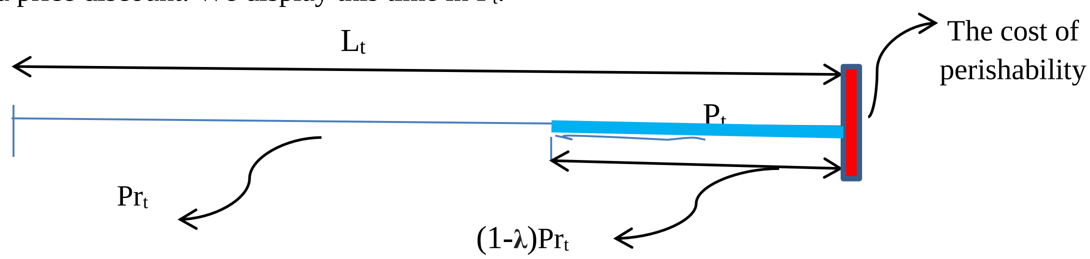

Fig 4. Discount price consideration

As shown in figure4, the price Pr_t is for time $L_t - P_t$ and the price $(1-\lambda)Pr_t$ is for time P_t that λ is the amount of the discounted rate. Considering the discount in this period, it is predicted that the product will not remain until the end of the period, and if the lifetime of the product expires, the cost of perishability will be included in the supply

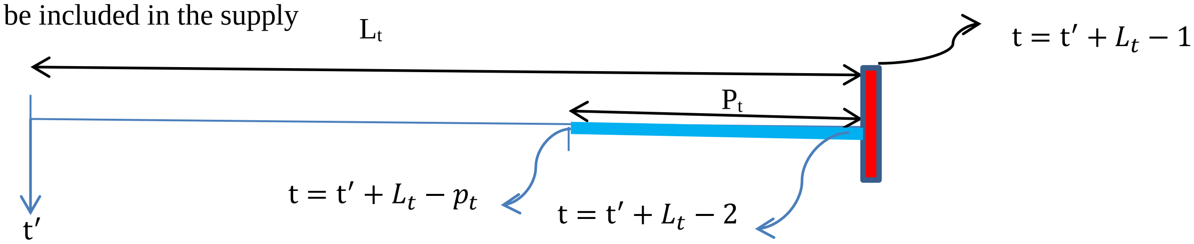

Fig 5. The start times of the discounted price

Since each of the products has a time of arrival at the distribution center and its lifetime starts from the time of arrival at the distribution center, so considering the time of arrival of the product, (i.e. t')and the current time(t), the selling price of the products at the original price and the discounted price is determined. The start times of the discounted price are shown in figure 5.

3-2-4- Dealing with uncertainty

In general, there are two main types of data uncertainty, random uncertainty and epistemic uncertainty(Torabi et al., 2015). The stochastic random uncertainty arises from the random nature of the data, in which probability distributions are estimated based on available historical data sufficient to model such uncertainty. It is common to use a stochastic programming approach to deal with this type of uncertainty. Epistemic uncertainty, on the other hand, deals with the inaccurate nature of data resulting from a lack of knowledge about their possible distribution. To deal with epistemic uncertainty, a possibilistic programming is often used(Sabouhi et al., 2018). Due to the fact that this product considered in this study is new and not enough historical information is available, the demand parameter is considered a fuzzy number**.** The constraints in which there is demand is (27) which are as follows.

$$II_{iptt} + \sum_{t'<t} II_{ipt't} = \sum_{f} S'_{fipt} + \sum_{t'<t} II_{ipt'(t-1)} - \sum_{j} ZZ_{ijt}\,\widetilde{D_{jpt}} - \sum_{\substack{i' \\ i'\neq i}} YY_{ii'p(t-1)} + \sum_{\substack{i' \\ i'\neq i}} YY_{i'ipt}\ \forall i\in I \forall t\in T \forall p \in P; \tag{27}$$

To better deal with the fuzzy demand parameter, the following variable is changed in restricts (28) to (31).

$$II_{iptt} + \sum_{t'<t} II_{ipt't} = \sum_{f} S'_{fipt} + \sum_{t'<t} II_{ipt'(t-1)} - \sum_{j} Dz_{ijpt} - \sum_{\substack{i' \\ i'\neq i}} YY_{ii'p(t-1)} + \sum_{\substack{i' \\ i'\neq i}} YY_{i'ipt}\quad \forall i \in I \quad \forall\, t \in T\ \ \forall p \in P; \tag{28}$$

$$Dz_{ijpt} + M\left(1 - ZZ_{ijt}\right) \geq \widetilde{D_{jpt}}\ \forall i \in I \quad \forall\, t \in T \qquad \forall \mathrm{j} \in \mathrm{J} \tag{29}$$

$$Dz_{ijpt} - M\left(1 - ZZ_{ijt}\right) \leq \widetilde{D_{jpt}}\ \forall i \in I \quad \forall\, t \in T \qquad \forall \mathrm{j} \in \mathrm{J} \forall p \in P \tag{30}$$

$$\sum_{P} Dz_{ijpt} \leq MZZ_{ijt}\ \ \forall i \in I \quad \forall\, t \in T \qquad \forall \mathrm{j} \in \mathrm{J} \forall p \in P \tag{31}$$

In this section, due to the change, we made in the content constraint of the fuzzy parameter, we use the Werners method (Werners, 1988). In modeling, if a number of constraints have a fuzzy source, the model is called asymmetric.

$$\max z = cx\ \ s.t. \quad (Ax)_i \leq \breve{b_i} \quad i = 1,2,\dots,m \quad , \ \ x \geq 0 \tag{32}$$

The focus of this method is on the objective function and determining the membership function for it. Bth source is considered as $\widetilde{b_i} \rightarrow [b_i, b_i + p_i]$in which case the fuzzy model will be as follows.

$$\mathrm{z}^0 = \max \quad \mathrm{cx} \ \ \mathrm{s.t.} \quad (\mathrm{Ax})_\mathrm{i} \leq \mathrm{b_i} \quad \mathrm{i} = 1,2,\dots,\mathrm{m} \quad \text{and} \quad \mathrm{x} \geq 0 \tag{33}$$

$$\mathrm{z}^1 = \max \quad \mathrm{cx} \ \ \mathrm{s.t.} \quad (\mathrm{Ax})_\mathrm{i} \leq \mathrm{b_i} + \mathrm{p_i} \qquad \mathrm{i} = 1,2,\dots,\mathrm{m} \quad \text{and} \quad \mathrm{x} \geq 0 \tag{34}$$

Where θ is between 0 and 1 and $b_i + p_i$is the maximum value that the source can take. The degree of membership for the fuzzy constraint will be as follows.

$$\mu_o(x) = \begin{cases} 1 & if \;\; cx \geq z^1 \\ 1 - \dfrac{(z^1 - cx)}{(z^1 - z^0)} & if \; z^0 \leq \; cx \leq z^1 \\ 0 & if \;\; cx < z^0 \end{cases} \tag{35}$$

If $\alpha = min\{\mu_0(x), \mu_1(x), \mu_2(x), \dots, \mu_m(x)\}$ is defined and we use the max-min operator, we will have:

$$\max \alpha \;\; s.t. \; \mu_0(x) \geq \alpha; \; \mu_i(x) \geq \alpha \quad \forall i = 1,2, \dots, m\alpha \in [0,1] \; and \; x \geq 0 \tag{36}$$

In this case, we are looking for the answer that obtains the maximum value of the membership function for the two types of proposed membership functions.

4- The proposed solution method

In this section, the solution algorithm is presented. Because the proposed supply chain model can be solved in a long time, it is not able to solve it even for large dimensions, the branch and price algorithm, which is an exact optimization method, has been used. This method is similar to the branch and bound method, except that the column generation method is used to solve problems in each branch instead of a linear relaxation. In this method, not all the variables used in the problem are considered, but are gradually added to the problem until we reach optimization. Therefore, it is possible to solve the problem with a smaller number of variables and at a more appropriate time without examining all the variables. In this method, first, the restricted master problem (RMP) is created, which includes a subset of the variables of the main problem. Variables that are in the RMP must be the solution to the main problem. Subsequent variables are identified by solving a sub-problem optimization problem and added to RMP that may help improve the current solution(Lübbecke, 2010). In fact, these algorithms solve a problem by iteratively adding the variables to RMP. Because in RMP only a subset of the possibilities is being used, the optimal solution of RMP is not necessarily the optimal solution of MP. It does not even produce a valid lower bound for OP. In order to improve the solution, a pricing subproblem (SP) is needed.

Dual multipliers are considered for constraints. A negatively reduced cost will mean that the set of new variables improves the value of the RMP. Of course, the value of the new variables must be the solution.

4-1- Master problem (MP)

Consider an optimization problem in the form below, in which constraint set $Dx \geq d$is a set of difficult constraints.

$$\text{OP: } Min \quad c^t x \tag{37}$$

$$st: \quad Ax \geq b \tag{38}$$

$$Dx \geq d \tag{39}$$

$$x \geq 0 \tag{40}$$

Suppose P is a Polyhedral associated with x vectors that satisfy difficult constraints with non-negative conditions.

$$P = \{x \in R_+^n | Dx \geq d\} \tag{41}$$

That x can be decomposed according to the Representation Theorem as equation (42).

$$x = \sum_{q \in Q} p_q \, y_q + \sum_{r \in R} p_r \, y_r \sum_{q \in Q} y_q = 1 \quad y \in R_+^{|Q|+|R|} \tag{42}$$

Where p_q are the extreme points and p_r are the extreme rays of P, where Q and R are finite. Thus, any feasible solution for OP can be expressed as a convex combination of extreme points and extreme rays of P, which, in addition to this set, satisfies Ax≥b constraints. So the OP problem can be rewritten as.

$$MP\colon \min \sum_{q\in Q} c_q\, y_q + \sum_{r\in R} c_r\, y_r \tag{43}$$

$$st\colon \quad \sum_{q\in Q} a_q\, y_q + \sum_{r\in R} a_r\, y_r \geq b \tag{44}$$

$$\sum_{q\in Q} y_q = 1 \tag{45}$$

$$y \geq 0 \tag{46}$$

4-2- The restricted master problem (RMP)

The MP has | Q | + | R | variables. So the size of the problem is very large. Usually the MP variables are less than the OP. But in larger sizes, it is difficult to solve with standard methods. For this reason, the RMP problem was introduced. RMP formulation is the same as MP, except that RMP uses a subset of vertices Q and R($|Q'| \leq |Q|\ , |R'| \leq |R|$).

$$RMP \coloneqq \min \sum_{q\in Q'} c_q y_q + \sum_{r\in R'} c_r y_r\ (37) \tag{47}$$

$$st\colon \ \sum_{q\in Q'} a_q\, y_q + \sum_{r\in R'} a_r\, y_r \geq b \tag{48}$$

$$\sum_{q\in Q'} y_q = 1 \tag{49}$$

$$y \geq 0 \tag{50}$$

Since RMP uses only a subset of extreme points and extreme rays, the optimal RMP solution is not necessarily the optimal MP solution. It does not even produce a valid lower bound for OP. A pricing subproblem (SP) is required to improve the solution.

4-3- The pricing subproblem

For each of the constraints (38) and (39) we consider the double coefficients $\pi_1$andπ_2, respectively. The negative value of the reduced cost means that a new set of variables will improve the objective function. But these new variables must be feasible in the OP problem with hard constraints Dx≥d. Therefore the following sub-problem will be solved:

$$SP\colon \min\ (C^T - \pi_1^T A).\, x - \pi_2 \tag{51}$$

$$st\colon \quad Dx \geq d \tag{52}$$

$$x \geq 0 \tag{53}$$

The SP problem can have three different states:

State1: The optimal value of SP is negative and all the reduced costs are positive and there is no possibility of improvement in RMP and the existing set of R and Q determines the optimal solution.

State2: The optimal value is negative but finite. In this case, a new set of vertices reduces the value of the RMP objective function that must be added to the RMP.

State3: SP is infinite, in which case the extreme rate must be added to the RMP.

4-4- Column generation method implementation

To solve the proposed supply chain model, the initial answer is first presented. This initial answer is known as the initial pattern. These patterns will be used in later steps to generate columns and add decisions. For this purpose, the following transformation is suggested.

$$\boldsymbol{c}_{nvt(pz_n)} = \boldsymbol{a}_{nvt(pz_n)} * \sum_{j} \boldsymbol{c}_{njvt} \quad \forall \boldsymbol{n} \in (\boldsymbol{I} \cup \boldsymbol{j}) \tag{54}$$

The index $\boldsymbol{pz_n}$ represents the nth pattern. The corresponding parameter is defined by the binary variable$\boldsymbol{YZ_{pz,v}}$. By transformation; the MP problem is presented as follows.

$$z_{MP} = \sum_{pz \in PZ} \sum_{v \in V} YZ_{pz,v} * \sum_{n e I \cup J} \sum_{t \in T} a_{nvt(pz_n)} * c_{nvt(pz_n)} \tag{55}$$

$$\sum_{pz \in PZ} \sum_{t \in T} \sum_{v \in V} \mathrm{a}_{nvt(pz_n)} . \mathrm{YZ}_{pz,v} = 1 \qquad \forall \mathrm{n} \in (\mathrm{I} \cup \mathrm{j}) \tag{56}$$

The following sub-problem will be as follows:

$$\boldsymbol{z_{sub}} = \sum_{n' \in (I \cup j)} \sum_{j \in J} \sum_{v \in V} \sum_{t \in T} (\boldsymbol{C}_{n'jvt} - \boldsymbol{\pi}_j \boldsymbol{W}_{njvt}) \tag{57}$$

$$\boldsymbol{z} = \boldsymbol{F_1} + \boldsymbol{0.5.F_2} \tag{58}$$

$$\boldsymbol{F_1} = \boldsymbol{0.5} * (\boldsymbol{z_{sub}} + \boldsymbol{e} + f + g + h + L + O + N - (a + b + c)) \tag{59}$$

St.(1) to (26) (60)

The column generation method is an iterative method in which possible solutions are added to the RMP until its optimal value is improved. Figure 6 illustrates the column generation algorithm as a flowchart.

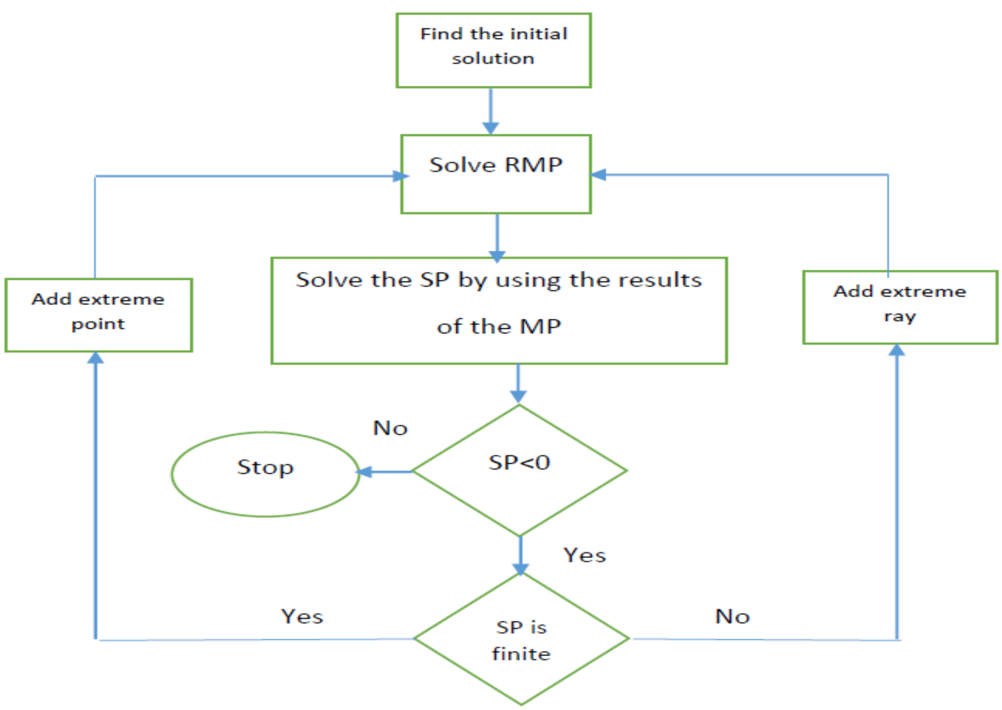

Fig 6. Column generation algorithm

5- Case study

In this section, the four-level supply chain of Pegah dairy products company is examined. 45 milk suppliers are selected and evaluated, and after evaluating and selecting the top suppliers, 2 main suppliers and 2 backup suppliers will be used in case of disruption or shortage. Also, the two selected production centers and the new product of Low-fat and high-fat probiotic, and stir yogurt are examined. There are two distribution centers for storing products and distributing them to customers. Also, three chain stores that have significant demand as customers are included in the supply chain, where the products are distributed by two vehicles. In this section, according to the evaluation, the most important evaluated indicators in the dairy industry are evaluated. In order to collect information, milk industry experts have been used who, in accordance with the considered indicators, have provided the information of the branches to the research or their expert opinions according to the Likert scale of strongly disagree, disagree, neutral, agree, strongly agree. According to the two-stage model of input and output evaluation for each DMU, so the input and output cases considered in each step are presented in table 7.

Table7. An indicator of evaluation

Indicator	Description
Adaptation to technology	5-Point Likert assessment of the company's production technology compliance based on production standards
Policy planning	A score of 0 to 20 is intended to conform the company's policy to the vision
Redundancy policies	Scoring 0 to 50 Assessing compliance with regulated supply chain policies based on redundancy notification policies at the lower levels of the supply chain
Whiplash effect control	Scoring 0 to 50 Noise control related to whip effects along the supply chain by applying appropriate Kalman analytical filters.
Noise reduction	Success in controlling the number of pulses disrupting the supply and distribution process
Delay in strategy determination	The Score obtained by 20 experts Assessed the agility of the organization based on a score (0-100)
Timely delivery	The Scores obtained by 20 experts assessed the agility of the organization based on a score (0-100) for each expert in the assessment of commitment to the schedule of delivery of commitments
Company credit	Company Credit Based on Evaluation and Analysis of Economic Experts with Success in Business Based on a 5-point Likert scale.
Financial strength	The amount of working capital of the crop unit
responsiveness	Rapid response to change, exploiting, and delivering a customer-centric product, scoring by the 5-Point Likert assessment

Figure 7 shows the two-stage model of network data envelopment analysis, which is considered the first stage subunit in terms of resilience and the second stage subunit in terms of agility.

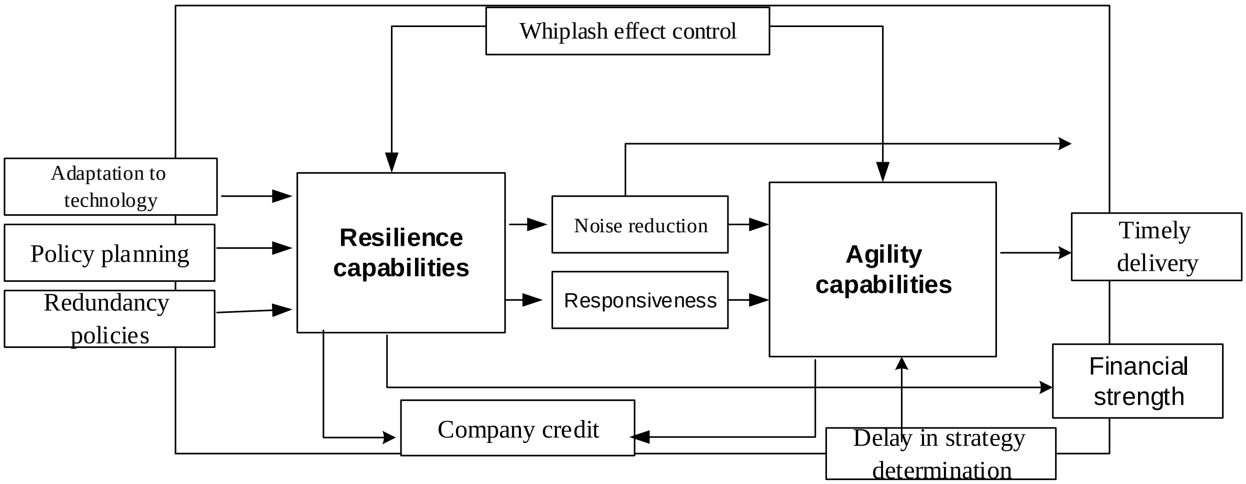

Fig 7. The proposed two-stage of NDEA

Table 8 shows the results of the proposed model that 9 units are efficient and are uniquely ranked using the Anderson-Peterson model.

Table 8. The Efficiency obtained from the proposed model

DMU	*TET(U)1J*	*TET(L)2J*	*TET(U)2J*	*TET(L)1J*	*E1*	*E2*	*TETA*	*RANK*	*TETA-AP*
1	1	0.01	0.76	0.74	1	0.76	0.76	19	0.76
2	0.76	0.01	0.57	0.5	0.76	0.57	0.4309	35	0.4309
3	0.85	0.01	1	0.85	0.7928	1	0.7928	17	0.7928
4	0.66	0.01	0.81	0.66	0.6594	0.81	0.5341	31	0.5341
5	0.54	0.01	0.53	0.35	0.5357	0.53	0.2839	39	0.2839
6	1	0.63	0.63	1	1	0.63	0.063	45	0.063
7	1	1	1	1	1	1	1	5	1.5351
8	1	0.51	0.68	0.92	1	0.68	0.68	23	0.68
9	0.83	0.16	1	0.36	0.83	1	0.83	15	0.83
10	0.73	0.54	0.89	0.73	0.7028	0.8900	0.6255	26	0.6255
11	0.53	0.003	1	0.46	0.5257	1	0.5257	32	0.5257
12	1	1	1	1	1	1	1	3	2.1587
13	0.83	0.49	0.93	0.36	0.83	0.9300	0.7728	18	0.7728
14	1	0.69	1	0.71	1	1	1	9	1.0552
15	0.45	0.01	0.25	0.45	0.446	0.2500	0.1115	43	0.1115
16	0.66	0.2	0.38	0.58	0.6432	0.38	0.2444	41	0.2444
17	0.4	0.01	0.41	0.4	0.4	0.41	0.164	42	0.164
18	1	0.17	0.47	1	1	.47	0.47	33	0.47
19	0.64	0.34	0.58	0.43	0.64	0.58	0.3712	36	0.3712
20	0.81	0.17	1	0.5	0.81	1	0.81	16	0.81
21	0.63	0.27	0.52	0.6	0.63	1	0.63	25	0.63
22	0.72	0.04	0.85	0.71	0.72	0.85	0.612	27	0.612

Table 8. Continued

DMU	*TET(U)1J*	*TET(L)2J*	*TET(U)2J*	*TET(L)1J*	*E1*	*E2*	*TETA*	*RANK*	*TETA-AP*
23	1	0.71	0.73	1	1	0.73	0.73	20	0.73
24	0.55	0.02	1	0.32	0.55	1	0.55	29	0.55
25	1	0.46	0.46	1	1	0.46	0.46	34	0.46
26	1	1	1	1	1	1	1	6	1.3903
27	0.92	0.08	1	0.89	0.92	1	0.92	13	0.92
28	0.45	0.49	0.77	0.45	0.45	0.77	0.3465	37	0.3465
29	0.64	0.05	0.84	0.64	0.64	0.84	0.5376	30	0.5376
30	1	1	1	1	1	1	1	1	2.2253
31	0.42	0.02	0.67	0.4	0.42	0.67	0.2814	40	0.2814
32	1	0.65	0.65	1	1	0.65	0.65	24	0.65
33	1	0.27	0.56	0.94	1	0.56	0.56	28	0.56
34	1	1	1	1	1	1	1	2	2.1760
35	1	0.47	1	1	1	1	1	12	0.9213
36	1	0.52	1	1	1	1	1	8	1.1297
37	1	0.39	0.85	1	1	0.85	0.85	14	0.85
38	0.81	0.003	0.89	0.81	0.81	0.89	0.7209	21	0.7209
39	1	1	1	0.86	1	1	1	7	1.3680
40	0.39	0.03	0.8	0.34	0.39	0.8	0.312	38	0.312
41	1	0.95	0.95	1	1	0.95	0.95	11	0.95
42	1	1	1	1	1	1	1	4	1.7396
43	1	0.96	0.96	1	1	0.96	0.96	10	0.96
44	0.45	0.004	0.16	0.4	0.45	0.16	0.072	44	0.072
45	1	0.61	0.7	0.89	1	0.7	0.7	22	0.7

Before presenting the results of the realistic case problem solving, we use the column generation method to solve 5 experimental problems to show the performance of this solution method in terms of computational time. Table 9 presents the size of each test problem, the optimal target value, the computational time using the column generation method, and the computational time using GAMS 24.1.1 software. Table 10 shows the solution time improvement by the column generation algorithm.

Table 9. Size of the problems

Problem	Sets								
	$\|I\|$	$\|J\|$	$\|V\|$	$\|P\|$	$\|T\|$	$\|F\|$	$\|K\|$	$\|B\|$	$\|R\|$
1	3	4	3	3	3	2	2	2	2
2	3	7	4	4	5	3	3	3	3
3	4	8	4	5	6	4	4	3	3
4	4	10	4	7	5	3	3	3	3
5	4	15	5	8	5	3	3	3	3
Realistic problem	2	3	2	3	5	2	2	2	2

Table 10. Performance of column generation

Problem	Column generation		MIP
	Weighted objective function	time	time
1	75735.091	2.122(s)	5.44
2	218958.317	8.689	9.922
3	199271.193	174.420	197.24
4	15490000	533	762
5	250812582	21655	28820
Realistic problem	889678.296	19.54	25.21

5-1- Managerial insights

According to the output of vehicle variables v1, it first returns to the distributor from the distribution center I1 by passing through the customer nodes j1, j3. Also, the vehicle v2 returns from the i2 distributor to the distributor's point by passing the customer j2 node. Also, the time to reach each node is in a specific shape, which is clearly shown in figure 8. According to the amount of demand and costs and revenues and capacity of the centers, the values of the variables were determined as the numbers in figure 8. Due to the required capacity in supplying raw materials by the main supplier, a backup supplier was not established
.

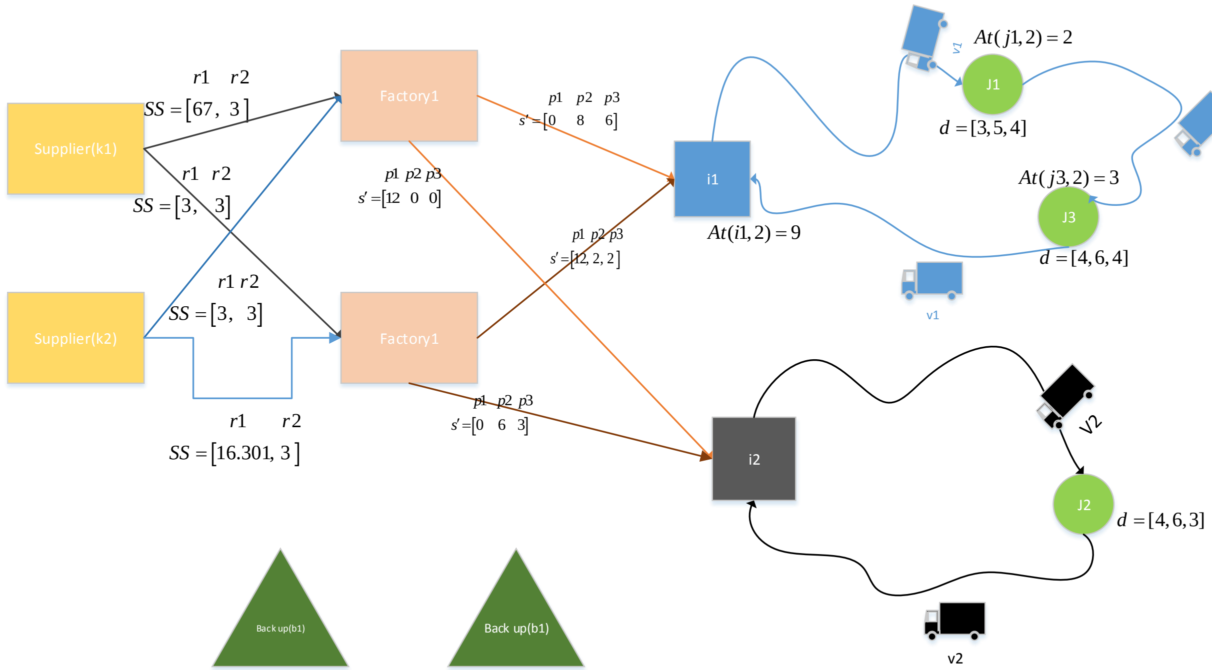

Fig 8. Model output

The sensitivity analysis of the capacity parameter of the first production center for the second product is investigated in table 11 to examine its effects as a managerial analysis.

Table11. The sensitivity analysis

parameter	changes rate	s'_{fipt}	F1	F2	Weighted objective function
$CAPf_{f1,p2}$	+10%	$s'(f1,i1,p2,2)=9.6$	1873541.8	9	936775.4
	0%	$s'(f1,i1,p2,2)=8$	1779347.6	9	889678.296
	-10%	$s'(f1,i1,p2,2)=7.2$	1750259.8	9	875134.4
	-20%	$s'(f1,i1,p2,2)=6.4$	1695240.3	9	847624.65

As shown in table 11, with the reduction of the capacity of the second product in the first production center, the amount of delivery to the distributors have decreased, as a result, the profitability of the entire supply chain has decreased.

According to figure 8, the amount of revenue from sending the product from the first production center was higher than the second production center, so by reducing the capacity in table 11 and reducing the shipment, it led to a decrease in profit. Also, with the increase of the relevant capacity, the amount of shipment from the first production center has increased because it has more profitable effects on the shipment of goods. Then, in order to obtain the Pareto front, the epsilon augmented-2 method has been used (Mavrotas and Florios, 2013), and the payoff table12 shows the result.

Table 12. Pay off table

	Delivery time (F1)	Supply chain profit(F2)
F1	6	1415200
F2	22	10731000

By specifying the number of 10 points and other parameters of the augmented ε-constraint, the Pareto Front boundary is shown in figure 9.

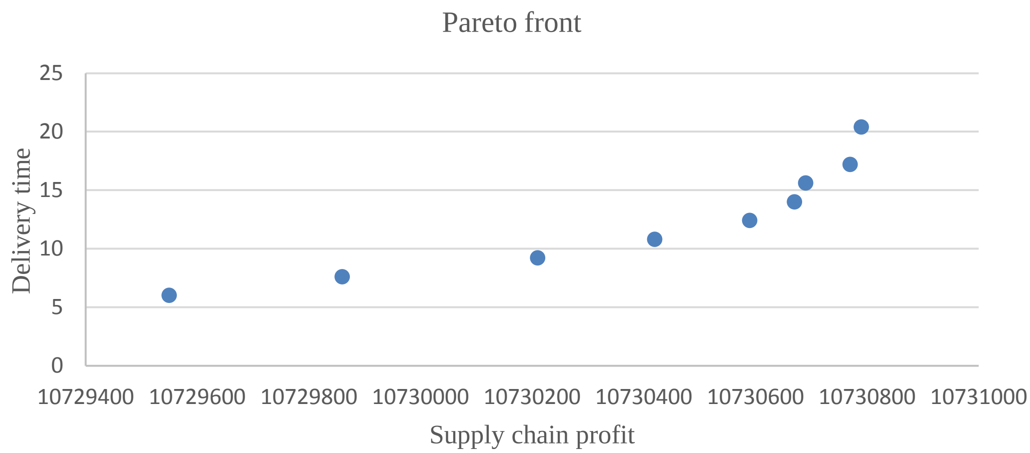

Fig 9. Pareto front of the augmented ε-constraint

6- Conclusion

In this paper, a new model for integrated network design of perishable multi-period products and multi-product under uncertainty is proposed, in which attention is paid to supply chain agility and resilience. The proposed model consists of two phases, the first phase includes the process of evaluation and selection of suppliers based on resilience indicators, and the second phase is designed for agile supply chain network of perishable products. To avoid wasting resources and making more profit, for products approaching the expiration date, a discounted sales strategy has been considered that has received less attention in previous research. As the proposed problem is NP Hard, to solve the model in optimal time, a decomposition algorithm of column generation was presented, which improves the problem-solving time. 5 test problems were solved with the proposed method, which significantly reduced the solving time. The proposed method was also used for a realistic problem in the dairy industry. There are some limitations in this study. Capacity of centers, transportation cost and inventory cost are assumed as constant parameters for simplification, while in the real-world problems, they cannot be considered as a constant rate.

It is suggested that for future studies, reverse supply chain and scenario-based stochastic programming be considered. It is also recommended to use accelerators to improve the solution time of the proposed algorithm.

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