RAIRO-Oper. Res. 54 (2020) 369–391
https://doi.org/10.1051/ro/2018107

RAIRO Operations Research
www.rairo-ro.org

CUSTOMER RELATIONSHIP MANAGEMENT AND NEW PRODUCT DEVELOPMENT IN DESIGNING A ROBUST SUPPLY CHAIN

Esmaeel Rezaei[1], Mohammad Mahdi Paydar[1] and Abdul Sattar Safaei[1]

Abstract. New product development is a basic requirement for any company to survive in the competitive market. Most of the organizations realized that relying solely on the traditional competitive levers, such as increasing the quality, reducing costs, and distinguished provision of goods and services is not enough anymore. In addition to the aforementioned competitive advantages, a company needs to introduce new products and out-phase the old ones at the right time. In this research, the design of a supply chain network considering new product development is investigated. Here, the notion of customer relationship management is incorporated into the proposed mathematical model. Moreover, product demand that is inherently uncertain in the real situations is embedded in the proposed robust model. Objectives of new products development, and customer satisfaction along with maximization of the profit is considered in the model. Moreover, an improved multi-choice goal programming method is implemented to solve the model. Finally, the model performance is evaluated for a real-world case.

Mathematics Subject Classification. 90C11, 90C90, 90C29.

Received February 8, 2018. Accepted November 13, 2018.

1. Introduction

In today's competitive business world, companies are trying their best to survive in the competitive market by reducing costs, increasing customer satisfaction and market share, and creating value added processes in their supply chains. The rapid growth of technology and the quick changes in the pattern of consumption has led to shorter product life cycles. Traditional organizations tend to increase their competitiveness through improved products and processes at lower costs. Hence, major activities focused on increasing the efficiency. However, most organizations have realized that increasing the product quality and reducing the costs are not sufficient. Considering speed and flexibility in delivering the new products and services in a competitive market is of great importance for the customers. Since innovation is essential for organizational progress, organizations are trying to bring new products to the market more quickly. New product design and introducing it to the market is a key factor for survival in the business environment. Therefore, companies have to reduce new product development (NPD) costs and facilitate the introduction of new products.

Diversity of customers' needs, technological advances and competitive business climate are the factors that encourage the organizations to consider new products and goods. Organizations generally have to decide on how

Keywords. supply chain network design, new product development, customer relationship management, uncertainty, improved goal planning.

[1] Department of industrial engineering, Babol Noshirvani University of Technology, Babol, Iran.
*Corresponding author: paydar@nit.ac.ir, paydar.ie@gmail.com

to design products in NPD processes which usually begin with creating ideas associated with new products. Products closer to the customer requirements are more likely to attract profit. New products design based on innovative technology offer features and benefits that are not available in current markets.

However, developing an innovative product is inextricably bound up with key aspects and elements of the production process. Identifying customers' needs and providing exceptional benefits are the basis of value creation and new product development. In terms of value creation, new product development process should reinforce the positive features and alleviating the negative aspects along with increasing benefits and reducing the disadvantages and costs associated products. In order to have loyal customers, their complaints, suggestions, and ideas should be reviewed and incorporated into products design process. Because when the products enter the market, they must meet the customers' demands and requirements. Introducing new products and phasing-out old ones hugely impact the supply chain network and its design. Not responding to the changing environment push the manufacturing organizations on the verge of elimination in the competitive market.

NPD strategic planning, and preserving product quality and reducing costs are of great importance in the manufacturing organizations compared to non-manufacturing companies. In addition, the new product should comply with the needs and expectations of the customers in a timely manner. Each new product may need its own production line and supplier requirements. Therefore, organizations should develop their products according to the required costs and existing capabilities. Many researchers considered the NPD planning. Billington *et al.* [9] proposed two product rollover strategies namely: single-product roll, and dual-product roll. In the former, the old product is phased out and then the new product(s) enter the production cycle while in the latter, both the old and the developed product are produced simultaneously. In this study, a multi-product mathematical model in which the single-product roll and new product presentation are considered simultaneously is proposed.

In addition to innovation and new product presentation, customer relationship management (CRM) is also crucial in maintaining and increasing customer satisfaction. Customer relationship system encompasses many functions of e-commerce and traditional systems of communication with customers and suppliers. These systems play a critical role in the supply chain strategy implementation. CRM systems are incorporated into the supply chain to help suppliers in improving their performance in interacting with customers. This does not only lead to improved quality but also increases the speed of response to customer needs.

Companies that have accepted marketing philosophy, *i.e.*, have taken the customer and society into account, have established necessary operations in an effort to create and increase customer value. An important point that should be mentioned here is that CRM means customer relationship management, and not customer relationship marketing. Broader concept of marketing management includes production, human resources, services, sales, and research as well as development. Therefore, CRM requires organizational approaches at all levels of the business. A good supply chain to meet the requirements of customers in addition to what mentioned above, should acquire an understanding of the types and characteristics of the customers and then choose the appropriate strategy to meet their current and future demand. Moreover, uncertainty is one of the main factors that affect the configuration and coordination of supply chain and significantly affects its performance.

This study addresses the supply chain network design problem with a focus on NPD and CRM under demand uncertainty. In the proposed model, supply chain configuration with the introduction of new products to the market and CRM functions along with supply chain uncertainty is considered simultaneously. It is clear that the introduction of a new product in a supply chain to maintain a competitive advantage in the market is a necessity. The proposed model is considered to be dynamic regarding the supply chain design and in different periods responds correspondingly to the development and emergence of new products. Implementing the concept of CRM in the supply chain enables the chain to provide superior services to the customer and profit the entire chain. This is embedded in the proposed model as well.

The rest of this paper is organized as follows. A literature review is presented in Section 2 and a mathematical formulation is provided in Section 3. Sections 4 and 5 discuss the robust model and the solution procedure, respectively. A case study is presented in Section 6 and finally, the conclusion is provided in Section 7.

2. Literature review

The present study addresses the interaction of several different features, including supply chain design and NPD and out-phasing the old product as well as the CRM properties. The investigations on the aforementioned subjects are considered both individually and in combination as follows.

2.1. Supply chain network design

Supply chain can be defined as a coordinated and interconnected network of suppliers, manufacturers, distributors and retailers/customers. Over the years, many researchers have identified supply chain processes, however, in recent years they have paid special attention to the design, performance and analysis of the supply chains. Garavelli [17] proposed a flexible design for supply chain management and evaluated different supply chain configurations using a performance simulation model. Garavelli's major goal was presenting a model for evaluating the influence of different degrees of flexibility in the performance of a multi-product supply chain in which assembly facility, supplier sites and several customer types are taken into account and studied under the terms of demand uncertainty. Li and Womer [26] studied a supply chain design under resource constraints. This study presented a model based on a project schedule that was configured to be performed according to the supply chain design. Besides, the proposed model encompassed quality level and time constraints in the supply chain.

Francas and Minner [16] studied the production network configuration for the supply chain involving product recycling. In their study, a design for a network which reworks the returned goods was developed. Their main objective was to examine the decision-making capacity and to evaluate two types of production network configurations under uncertainty of customer demand and rate of return. Altiparmak *et al.* [2] addressed the supply chain network configuration with the aim of studying supply chain network design to satisfy customer demand at minimum cost and to decide on the available facility options. They investigated a multi-product and multi-level supply chain in which the number of customers as well as the number of potential sites for the establishment of the factory were specified. Finally, the results of genetic algorithm and Lagrangian relaxation approach to solve the problems of different sizes were compared and evaluated.

Oh *et al.* [32] proposed a flexible structure for reconfiguring the supply network. They evaluated the influence of flexible strategies for the supply chain network structure in the dynamic market environment and introduced a reconfiguration network for the supply chain. Kisomi *et al.* [24] proposed a mathematical model for supply chain configuration and supplier selection under uncertainty considering multiple layers, multiple parts, and multiple products with the objective of minimizing the total cost of supply chain network. The framework of their supply chain network comprised a forward flow from the heterogeneous capacitated supplier offering price discounts to customers and also a reverse flow from customer zones to disposal centers or production facilities.

2.2. New product development

The variability of the competitive rules in the business world, emphasizes the significance of the process of introducing new products to the market. Many studies have been conducted in this area of research among which the most related are discussed in what follows. Most of organizations realized that relying solely on the traditional competitive advantages, *e.g.*, increasing the quality, reducing cost, and differentiated ways of providing products and services are not enough. Instead, concepts such as agility and flexibility have gained considerable importance in the competition, and a trend toward presenting new products and services to the market is the reason for this change of attitude.

Van Kleef *et al.* [41] conducted a case study comparing different methods of NPD and analyzed their advantages and disadvantages. Koyuncu and Erol [25] took into account the limited resources in NPD with the aim of minimizing the time of product provision considering activities overlaps. They solved this particular problem for a real-world problem by using a modified particle swarm optimization algorithm and presented the results. Petrick and Echols [35] categorized the methods of NPD according to material and production systems as follows:

1. The new product is made using the available material and a new production system.
2. The new product is manufactured by new materials and the available production systems.
3. The new product is manufactured by new material, new components and new production systems.

Moreover, Kettunen *et al.* [23] presented a model for considering the conditions organizations face while developing new products. They investigated the right time of introducing products to the market and showed the positive and negative aspects of delaying or accelerating product introduction.

2.3. New product development in supply chains

Ever-increasing competition in the market forces companies to increase their pace of innovation. Innovation shortens the life of the products at the market. Mismanagement increases the cost of designing and producing new products and as a result the organization may fail to satisfy the needs and demands of customers. In addition, the new product should be released to the market at the right time. Each new product may require a new production line or new raw material suppliers. Therefore, organizations should consider the costs of required and available capacities regarding the new product design. The literature related to the new product development process is growing, however, the number of studies related to the regarding supply chain considerations is still scarce.

Petersen *et al.* [34] related the new product development to two factors in a model; the products design, and the supply chain design. The first factor is related to the ability of the experts of the organization to use the technology to design products, and the second one is related to the supply chain components and their flexibility in introducing the new product. It is possible that in different stages of manufacturing, organizations face increased demands for new products. In such cases, the company has to produce the new product to maintain its position in the market. This calls for supply chain reconfiguration for the production and distribution of the new product. However, Tracey and Neuhaus [39] believed that the development of new products is more important than costs in the supply chain. They stated that the main purpose of the supply chain is providing the product to the market on time.

Forza *et al.* [15] considered the selection of suppliers and their involvement in the scheduling for the development of new products and timely introduction of the new products to the market among the contributing factors to the success of new product development projects in a profitable supply chain. As a result, the supply chain decisions must be based on changes in the product market in order to gain a competitive advantage. This relies significantly on marketing and integration between different parts of the supply chain. Wang and Shu [42] studied the new product supply chain design with regard to the uncertain factors. The primary assumption in their study is the lack of reliable information on the specifications and requirements of new product supply chain design which in turn leads to uncertainty. As some of the most important parameters of decision making, the demand and delivery interval for the products are uncertain and can be modeled by fuzzy theory concepts. The aim of their study was modeling supply chains and developing a decision model for configuration and inventory strategies, with regard to customer satisfaction in terms of delivery interval.

Naraharisetti and Karimi [30] investigated the capacity allocation for the various suppliers of supply chain network. The functional aspect of their study concerned the chemicals production industry. They assumed that the varying amount ratios of raw material used to produce the products in different periods results in obtaining varying amount ratios in final products. Nepal *et al.* [31] proposed a bi-objective model for the supply chain for new product development. They defined an index, namely compatibility index, to measure the success of the chain. The objective of their model was maximizing this index and in turn minimizing the chain costs. Amini and Li [3] studied the supply chain network configuration, at the time a new product is to be produced, for a multi-level and single-product supply chain. They examined their proposed model incorporating the influence of volatility of demand during the new product development process on the supply chain configuration with the objective of profit maximization.

Moreover, Jafarian and Bashiri [20] proposed a multi-level dynamic supply chain model which included the raw material suppliers, component suppliers, manufacturers, distributors and customers. Their proposed model considered the time required to launch a new product in the supply chain which was optimized supply chain configuration. The configuration of the supply chain may vary from a period to another due to the introduction of the new product. Correspondingly, they conducted a sensitivity analysis on the impact of the entry time of a new product and the configuration. Afrouzy *et al.* [1] proposed a multi-objective model following a new approach to product development and studied the introduction of novel products with no similarities to the previous products. In their study, three types of products were taken into account and also the fuzzy stochastic method used for evaluating the uncertainty of demand and capacity parameters, and finally the multi-objective model solved using the goal programming method.

2.4. Customer relationship management

The customer relationship management is a set of approaches which provides a strong coherent and integrated vision of customers in the entire business range to ensure that each customer receives the most appropriate service level [22]. CRM is a comprehensive business strategy which integrates technologies, processes and all business activities around customers leading to establishing and maintaining a long-term and profitable relationship with customers [37]. Liou [27] considered the CRM as a key business strategy which can focus on customer needs and give coherence to a customer-centric approach throughout the entire organization. The customer

relationship management systems aid suppliers in maximizing their ability to interact with their customers' needs in the supply chain. This not only leads to improving the quality but also accelerates responding to customer needs [4].

CRM is based on the interchange of value between the customer and the organization with an emphasis on the value added created. This is the reason behind the endeavors of business owners for creation, improvement and promotion of their relationships with their customers. In other words, the objective of the CRM process is creating and maintaining advantages through interaction and keeping promises. The CRM is a business strategy which is improved in qualitative and quantitative aspects by technological advances and enables the companies to create a fruitful relationship based on the customers' earned and perceived value. The realization of CRM in the organization can only be achieved by applying all the necessary means and technologies.

2.5. Uncertainty in the supply chain

Many approaches have been proposed to optimize the supply chain design under uncertainty such as stochastic programming, fuzzy programming, fuzzy stochastic programming and robust optimization. In this study, robust optimization will be utilized to consider the uncertain parameters.

In recent year, there are some developments in robust optimization. In 1995, Mulvey *et al.* proposed an approach which focused on the integration of the goal optimization with distribution based on the scenario. In the early 70's, Soyster [38] presented a linear optimization model with a focus on generating possible solutions for a convex set. The results were very conservative; therefore, it could overlook the reliability of the robust solution. An important step towards the development of optimization theory was taken by Ben-Tal and Nemirovski [6], also independently by El Ghaoui and Lebret [14]. Bertsimas and Sim [7] proposed an approach that focused on the interaction between efficiency and robustness. Their model could flexibly adjust the level of conservatism of the robustness solution. The interesting aspect of their approach was that their model was linear.

Moreover, this notion is incorporated in different studies. Mirzapour Al-E-Hashem *et al.* [28] considered a supply chain consisted of several suppliers, producers, multiple locations and multiple periods and different customer types for integrated production planning under uncertainty of demand and costs. A multi-objective robust programming model for minimizing the chain costs and the maximum shortage for customers in all periods was proposed and was turned into a single-objective model for which the solutions were presented. Pishvaee *et al.* [36] examined a closed-loop multi-level single-period single-product supply chain with limited capacity for the customers of the first and second-largest market, collection center, inspection, recycling centers, redistribution centers and malls, and disposal centers, under uncertainty. In their model, the assumptions of uncertain parameters were considered as an uncertainty box. Aouam and Brahimi [5] proposed a coherent model

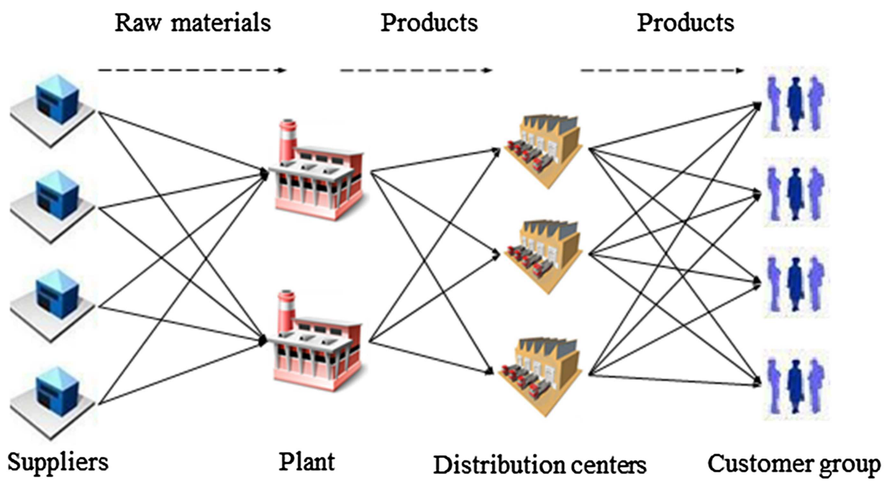

FIGURE 1. Structure of the proposed multi-echelon supply chain network.

of production planning under demand uncertainty and utilized Bertsimas robust optimization approach to handle the problem. Gholamian *et al.* [18] studied a supply chain including multiple suppliers and manufacturers and several kinds of customers. Their presented problem was a fuzzy non-linear multi-objective integer programming model for the multi-period and multi-product manufacturing problem. Paydar *et al.* [33] proposed a model for an engine oil closed-loop supply chain with multiple periods and multiple products under uncertainty in the capacity of vendors for supplying used engine oil. In their proposed model, two objective functions of maximizing profit and minimizing risk were considered and augmented ε-constraint was used for solving the bi-objective model. According to the obtained results, some analyses were performed on critical parameters. In a recent study, Jouzdani *et al.* [21] presented a mathematical model for robust supply chain network design and conducted a study of a real-world case of dairy industry. Their objective was to minimize the net present value of the total cost comprised of total fixed investment cost, the expected transportation cost, and the expected demand and supply violation costs. They presented a linearization method for the model and solved the linear model and provided an in-depth analysis of the results.

Moreover, the supply chain network design with the introduction of new products to the market and CRM functions is studied in this paper. Demand uncertainty is for introduced and current product is considered in the proposed model simultaneously.

3. Mathematical formulation

A mathematical model is developed for the integration of the multi-product and multi-period supply chain in which new products can be produced and introduced based on a centralized decision considering the CRM characteristics (see Fig. 1).

The products are created from the combination of a number of raw materials, and the purchase price of raw materials may vary among different suppliers with limited capacity in the planning horizon. Such a limitation applies for the manufacturer as well. Since suppliers, manufacturers, distribution centers and customer groups in the region are geographically dispersed, the transportation cost is considered. In the supply chain, the manufacturer has the capability to deliver new product, for which the feasibility of design, suppliers selection, the optimal cost of advertising, and product warranty as well as new product release time are to be decided.

The customer relationship is optimized through a separate objective function. Different solutions are recommended to improve the customer satisfaction rate. Advertisement and warranty products that significantly affect the customers' perspective are the main options. These factors represent the extent to which the costs for advertising and warranty of products impact the profitability of the entire supply chain. In this paper, it is modeled based on the third objective function.

Several studies in the field of new product development and design and customer relationship management are conducted individually. However, they are mostly descriptive and conceptual studies. In this section, a mathematical model for maximizing the profit of the supply chain considering the new product development and consideration of customer relationship management is presented. In the proposed model, products are divided into three categories: current products, developed products and new products.

3.1. Notations

Indices:

d index of distribution centers
f index of plants
g index of customer groups
i index of products
r index of raw materials
s index of suppliers
t index of periods
v index of warranty types (based on time duration)

It should be noted that the products are divided into five categories products that are being produced by the company; products that are the produced until the last planning period if there is a demand for it, products that are the developed form of old products and are destined for production; and new products that the company decides to produce during the planning horizon. The indices are as the follows, respectively:

$$i = \begin{cases} o(\text{old}) \quad\quad o = \text{first product} \\ j(\text{old} \to \text{new})\ j = \text{second product} \ \to \ \text{third product} \\ n(\text{new})\ n = \text{fourth product} \,\&\, \text{fifth product} \end{cases}$$

Input parameters:

Symbol	**Type**	**Meaning of the symbol**
B_{ir}	BOM (Bill of Material)	Number of raw material r needed to produce product i
$Codv$	CRM Cost	Cost of implementing the warranty to protect customers and encourage new customers to join customer group
C_{fi}	Production cost	Production cost per unit of product i in plant f
CD_d	Capacity	Capacity of distribution center d in period t
CF_{fit}	Capacity	Capacity of plant f for producing product i in period t
CR_{srt}	Capacity	Capacity of supplier s for preparing raw material r in period t
DF_{git}	Demand	Demand for product i at customer group g in period t
dl_i	NPD Time	New product designing time (period) of product i
EE_t	CRM cost	Maximum cost for advertising product i in period t
FC_{fi}	Production cost	Production fixed cost of product i in plant f
HD_{di}	Inventory holding cost	Inventory holding cost for product i in distribution center d
HF_{fi}	Inventory holding cost	Inventory holding cost for product i in plant f
HR_{fr}	Inventory holding cost	Inventory holding cost for raw materials r in plant f
IID_{id}	Initial inventory	Initial inventory in distribution center d for product i
IIF_{fi}	Initial inventory	Initial inventory in plant f for product i
IIR_{fr}	Initial inventory	Initial inventory in plant f for raw material r
NP_i	NPD Cost	Designing Cost of new product i
O_{iv}	CRM	Impact factor of warranty v on product i
P_{oj}	NPD	1if product o can be developed to product j; 0, otherwise

PD_i	Price	Sale price of product i
PS_{srt}	Price	Purchase price of raw material r from supplier s in period t
TCD_{dg}	Shipping cost	Shipping cost between distribution center d and customer group g
TCF_{fd}	Shipping cost	Shipping cost between plant f and distribution center d
TCR_{sf}	Shipping cost	Shipping cost per unit between supplier s and plant f
TP_{fi}	Production time	Hour needed to produce a unit of product i in plant f
W_i	CRM	Impact factor of advertising on product i
M	Number	Big number (positive)
Decision variables:		
Cob_{it}	CRM cost	Cost of advertising product i in period t
DP_{it}	NPD	1 if company decide to design product i in period t; 0,otherwise
ET_{it}	NPD	1 if product i is ready to enter the marketplace in period t and 0 otherwise
ID_{dit}	Inventory	Quantity of product i hold at distribution center d at the end of period t
IF_{fit}	Inventory	Quantity of product i hold at plant f at the end of period t
IR_{frt}	Inventory	Quantity of raw material r hold at plant f at the end of period t
PR_{fit}	Production	Quantity of product i produced at plant f in period t
X_{fdit}	Flow	Quantity of product i shipped from plant f to distribution center d in period t
Z_{sfrt}	Flow	Quantity of raw material r shipped from supplier s to plant f in period t
Y_{dgit}	Flow	Quantity of product i shipped from distribution center d to customer group g in period t
Od_{iv}	CRM	1 if warranty v selected for product i; 0, otherwise

3.2. Objective functions

$$\begin{aligned}\text{Max } f_1 = &\sum_g\sum_d\sum_i\sum_t PD_iY_{dgit} - \sum_s\sum_f\sum_r\sum_t PS_{srt}Z_{sfrt} - \sum_f\sum_i\sum_t (C_{fi}PR_{fit} + FC_{fi}ET_{it})\\ &- \sum_f\sum_r\sum_t HR_{fr}IR_{frt} - \sum_f\sum_i\sum_t HF_{fi}IF_{fit} - \sum_d\sum_i\sum_t HD_{dir}ID_{dit} - \sum_s\sum_f\sum_r\sum_t TCR_{sf}Z_{sfrt}\\ &- \sum_f\sum_d\sum_i\sum_t TCF_{fd}X_{fdit} - \sum_d\sum_g\sum_i\sum_t TCD_{dg}Y_{dgit} - \sum_i\sum_t NP_iDP_{it} - \sum_i\sum_v Cod_vOd_{iv}\\ &- \sum_i\sum_t Cob_{it}ET_{it}\end{aligned} \tag{3.1}$$

$$\text{Max } f_2 = \sum_{i\in j,n}\sum_f\sum_t PR_{fit} \tag{3.2}$$

$$\text{Max } f_3 = \sum_i\sum_t W_iCob_{it}ET_{it} + \sum_i\sum_v O_{iv}Od_{iv}. \tag{3.3}$$

The first objective function maximizes the total profit over the whole planning horizon. The first term includes the income from the sale of products and the second term calculates the cost of procurement of raw materials from suppliers. The third term gives the production cost of products in the company. The fourth, fifth, and sixth terms are for obtaining inventory holding cost of raw materials and products at the plants and distribution centers, respectively. The seventh, eighth, and ninth terms show the cost of shipping raw materials and products between suppliers, plants and distribution centers, respectively. The tenth term calculates the cost of designing new products in the planning horizon. Finally, the eleventh and twelfth terms formulate the cost of CRM represented by product warranty cost and the cost of advertising products in different periods, respectively.

Production and development of new product incur significance costs. However, to survive in the competitive market and keep the customer, firms have to present new products. Therefore, the second objective function maximizes the production of new products.

The third objective function maximizes the value of CRM cost. The objective function models the role of CRM in attracting more customers and make them loyal customers through advertising and serving warranty. This is based on the assumption that increasing the advertisement, the better warranty conditions, and higher customer satisfaction is gained. Hence, by increasing the number of customers, production rate increases which in turn leads to making more profit in the supply chain.

3.3. Constraints

In this section, the proposed model corresponding constraints are introduced.

Customer relationship management:

$$\sum_i Cob_{it} \leq EE_t \qquad \forall t \tag{3.4}$$

$$\sum_v Od_{iv} = 1 \qquad \forall i. \tag{3.5}$$

Inventory:

$$IR_{frt} = IR_{fr(t-1)} + \sum_s Z_{sfrt} - \sum_i B_{ir} PR_{fit} \qquad \forall f, t, r \tag{3.6}$$

$$IF_{fit} = IF_{fi(t-1)} + PR_{fit} - \sum_d X_{fdit} \qquad \forall f, i, t \tag{3.7}$$

$$ID_{dit} = ID_{di(t-1)} + \sum_f X_{fdit} - \sum_g Y_{dgit} \qquad \forall d, i, t \tag{3.8}$$

$$ID_{dit} = IID_{di} \qquad \forall d, i, t = 0 \tag{3.9}$$

$$IR_{frt} = IIR_{fr} \qquad \forall f, r, t = 0 \tag{3.10}$$

$$IF_{fit} = IF_{fi} \qquad \forall f, i, t = 0 \tag{3.11}$$

$$\sum_d Y_{dgit} \leq DF_{git} \qquad \forall g, i, t. \tag{3.12}$$

Capacity:

$$\sum_f Z_{sfrt} \leq CR_{srt} \qquad \forall s, r, t \tag{3.13}$$

$$\sum_i PR_{fit} TP_{fi} \leq CF_{ft} \qquad \forall f, t \tag{3.14}$$

$$\sum_f \sum_i \sum_t X_{fdit} \leq CD_d \qquad \forall d. \tag{3.15}$$

Production allowance:

$$PR_{fit} \leq M \times ET_{it} \qquad \forall f, t, i. \tag{3.16}$$

Rollover strategy:

$$\sum_{h=t+dl_i}^{DP_{jt} P_{oj}} > ET_{it} \qquad \forall t, (o, j \in i). \tag{3.17}$$

New product relations:

$$\sum_{h \geq t+dl_i} DP_{ih} \leq ET_{it} \qquad \forall (h \in t), (j, n \in i). \tag{3.18}$$

Domain of decision variables:

$$\sum_t DP_{it} = 1 \qquad \forall j, n \in i \tag{3.19}$$

$$X_{fdit}, Z_{sfrt}, Y_{dgit}, PR_{fit}, ID_{dit}, IR_{frt}, IF_{fit}, Cob_{it} \geq 0 \text{ and integer} \qquad \forall i, t, f, d, s, g, r \tag{3.20}$$

$$DP_{it}, ET_{it}, Od_{iv} \in \{0, 1\} \qquad \forall i, t, f, d, s, g, r. \tag{3.21}$$

Equations (3.4) and (3.5) relate to the concept of customer relationship management. Constraint (3.4) ensures that the advertising cost does not exceed the maximum allowed amount. Constraint (3.5) ensures that exactly one warranty option is applied to each product. Equations (3.6)–(3.8) show the balance of raw materials and products in the plants and products in the distribution centers, respectively. Equations (3.9)–(3.11) show the inventory of raw materials and products in the plants and distribution centers at the beginning of the planning horizon. Constraint (3.12) expresses the fact that material flow from the distribution centers to the customers should not exceed the corresponding demand. Equation (3.13) ensures that the raw materials transported from suppliers to the plants cannot exceed the supplier's capacity. Similarly, Equations (3.14) and (3.15) impose the limit on the capacity of each plant and distribution center in each period, respectively. Equation (3.16) is the manufacturer production allowance. Equation (3.17) models the ability and the decision of developing products at plants in based on rollover strategy. Inequality (3.18) shows the designing starting time. Equation (3.19) ensures that each developed or new product is designed only once during the planning horizon. Finally, constraints (3.20) and (3.21) enforce the binary and non-negative constraints on decision variables.

3.4. Linearization of the objective functions

In the first and the third objective functions, binary and integer variables are multiplied. For linearizing the model, the auxiliary integer variable and several constraints are integrated in the proposed model. Thus, the nonlinear terms are replaced with the auxiliary variable $Coeb_{it} = Cob_{it}{}^{*}ET_{it}$.

The new constraints are as follows:

$$Coeb_{it} \geq Cob_{it} - M(1 - ET_{it}) \qquad \forall t, i \tag{3.22}$$

$$Coeb_{it} \leq Cob_{it} + M(1 - ET_{it}) \qquad \forall t, i \tag{3.23}$$

$$Coeb_{it} \leq M \times ET_{it} \qquad \forall t, i \tag{3.24}$$

$$Coeb_{it} \geq 0, \quad \text{and integer} \qquad \forall t, i. \tag{3.25}$$

4. Robust model

In many mathematical programming models, it is assumed that the input parameters are known and deterministic, and the impact of uncertainty on the efficiency and fairness of the model is ignored. However, the uncertainty in the parameters of the supply chain is an important factor that must be considered in constructing a good model. One of the main roots of uncertainty in supply chains stems from demand forecasting. Competition, the price of products, technology development, advertising, and customer relationship are among the factors that influence the demand forecast. In this paper, the robust optimization method is used to model the demand uncertainty.

One of the approaches developed in recent years to deal with uncertainty of the data is robust optimization. This approach seeks near-optimal solutions that are justified with a high probability. In the early 1970's, Soyster presented a linear optimization model that capable of resulting the most justifiable answers for all input data. In their model, each input parameter may take any value in a certain range. This approach has a tendency to find solutions which are very conservative. In other words, to ensure the acceptability of the answer in this approach, nominal efficiency is compromised. Bertsimas and Sim [7] provided an approach focusing on the interaction between efficiency and robustness. The advantage of this method is the linearity of their model. In addition, this model can be applied to discrete problems. In this section, the model proposed by Bertsimas and Sim [7] is explained. Consider the following optimization problem:

$$\text{Max } C'x \tag{4.1}$$

subject to

$$Ax \leq b$$
$$l \leq x \leq u.$$

Assume that the ith constraint of the nominal problem is represented by $a_i' x \leq b_i$. Let J_i be the uncertain coefficient set index and $\widehat{a}_{ij}, j \in J_i$ take numerical values based on a uniform distribution with the average value of a_{ij}. Obviously, we have $\widehat{a}_{ij} \in [a_{ij} - a\tilde{a}_{ij}, a_{ij} + \tilde{a}_{ij}]$ for some positive real number $\tilde{a}_{ij}$. In addition, let Γ_i be a parameter within the range of $[0, |\, J_i|]$ whose role is to adjust the robustness of the model against its conservativeness. The purpose is to make the model robust against the situations that may arise under all scenarios in which the changes are greater than Γ_i while a_{it} coefficients change into $(\Gamma_i - \lfloor \Gamma_i \rfloor) \times \widehat{a}_{it_i}$. In other words, a subset of coefficients change and affect the solution. In the presented approach, if the changes are restricted to magnitude of $\lfloor \Gamma_i \rfloor$, the solution would definitely be feasible and if the changes are greater than $\lfloor \Gamma_i \rfloor$, the solution would probably be feasible while the feasibility depends on the magnitude of the change.

Consider the following non-linear model:

Max $C'x$.

Subject to

$$\sum_j a_{ij} x_j + \underset{\{\, S_i \cup \{t_i\} | S_i \subseteq J_i, |S_i| = \lfloor \Gamma_i \rfloor, t_i \in J_i \setminus S_i\}}{\text{Max}} \left\{ \sum_{j \in S_i} \hat{a}_{ij} y_j + (\Gamma_i - \lfloor \Gamma_i \rfloor) \hat{a}_{it_i} y_t \right\} \leq b_i \qquad \forall\ i \tag{4.2}$$

$$-y_j \leq x_j \leq y_j$$

$$l \leq x \leq u$$

$$y \geq 0.$$

If Γ_i is considered to be an integer, the ith constraint is can be expressed by the following formula

$$B_i(x, \Gamma_i) = \underset{\{S_i | S_i \subseteq J_i, |S| = \Gamma_i\}}{\text{Max}} \left\{ \sum_{j \in S_i} \hat{a}_{ij} \left| x_j \right| \right\}.$$

Note that if $\lfloor \Gamma_i \rfloor = 0$ and $B_i\ (X, \Gamma_i) = 0$, the constraint is the same as the original problem constraint. On the other hand, if $\Gamma_i = |J_i|$, the Soyster's model will hold. Hence, by changing the value of $\Gamma_i \in [0, |J_i|]$ a flexible robust adjustment can be achieved. To reformulate the model (27) into a linear optimization model, the following changes are required.

To reformulate the model (27) into a linear optimization model, the following changes are required.

Proposition 4.1. *Consider vector x^*, the conservative function for ith constraint,*

$$B_i(x^*, \Gamma_i) = \underset{\{S_i \cup \{t_i\} | S_i \subseteq J_i, |S_i| = \lfloor \Gamma_i \rfloor, t_i \in J_i \setminus S\}}{\text{Max}} \left\{ \sum_{j \in S_i} \hat{a}_{ij} \left| x_j^* \right| + (\Gamma_i - \lfloor \Gamma_i \rfloor \hat{a}_{it_i} \left| x_j^* \right| \right\}, \tag{4.3}$$

is equivalent to the following optimization model:

$$B_i(x^*, \Gamma_i) = \text{Max} \left\{ \sum_{j \in J_i} \hat{a}_{ij} \left| x_j^* \right| Z_{ij} \right\}. \tag{4.4}$$

Subject to

$$\sum_{j \in J_i} Z_{ij} \leq \Gamma_i$$

$$0 \leq Z_{ij} \leq 1.$$

Proof. It is evident that the problem's optimal solution includes a variable of value $\lfloor \Gamma_i \rfloor$ and a variable of value $\Gamma_i - \lfloor \Gamma_i \rfloor$.

This translates to selecting the subset $\{ S_i \cup \{t_i\} |\, S_i \in J_i, |S_i| = \lfloor \Gamma_i \rfloor, t_i \in J_i \backslash S_i\}$, with regard to the cost function $\left\{ \sum_{j\in S_i} \hat{a}_{ij} \left|x_j^*\right| + (\Gamma_i - \lfloor \Gamma_i \rfloor \hat{a}_{it_i} \left|x_j^*\right| \right\}$ [8]. The model (27) can now be rewritten as a linear model.

$$\text{Max } C'x. \tag{4.5}$$

Subject to

$$\begin{aligned}
&\sum_j a_{ij}x_j + Z_i\Gamma_i + \sum_{j\in J_i} P_{ij} \le b_i && \forall i\\
&Z_i + p_{ij} \ge \hat{a}_{ij}y_j && \forall i, j \in J_i\\
&- y_j \le x_j \le y_j && \forall j \in J_i\\
&l_j \le x_j \le u_j && \forall j \in J_i\\
&p_{ij} \ge 0 && \forall i, j \in J_i\\
&y_j \ge 0 && \forall j \in J_i\\
&Z_i \ge 0 && \forall i.
\end{aligned}$$

It should be noted that the added variables in the corresponding robust model, *i.e.*, z_i, y_j, p_{ij}, are to adjust the robustness of the solution and apply different conservatism levels in the model. □

In this paper, for the modeling of the uncertainty in the demand parameter, the approach used by Thiele [40] and Zokaee *et al.* [43] is utilized. It should be mentioned that the parameter $\widehat{DF}_{git}$ has uniform symmetrical and independent distribution within the range of $[DF_{git} - \widetilde{DF}_{git}, DF_{git} + \widetilde{DF}_{git}]$. To minimize the shortage in distribution centers the auxiliary variable is used and constraint (12) is rewritten as follows:

$$\sum_d Y_{dgit} - \widehat{DF}_{git} \le DF^-_{git} \qquad \forall g, i, t. \tag{4.6}$$

The parameter DF^-_{git} is added to the objective function to minimize the maximum shortage value. In order to consider the uncertainty in the demand parameter, we follow [40] who used an budget of uncertainty, shared by all customers for each product in every period, called Γ_{git}.

The conservatism degree of Γ_{git} takes values between zero and the number of customers in each period. By the argument expressed above the robust constraint (3.12) is obtained as follows:

$$\sum_d Y_{dgit} - DF_{git} - \frac{\Gamma_{git}}{g}\widetilde{DF}_{git} \le DF^-_{git} \qquad \forall g, i, t. \tag{4.7}$$

Considering χ_i^* as the robust solution to the model, the probabilistic guarantee of the robust solution feasibility corresponding to the ith constraint is determined by Zokaee [43]:

$$P\left(\sum \hat{a}_{ij}x_j^* > b_i\right) \le 1 - \varphi\left(\frac{\Gamma_i - 1}{\sqrt{|J_i|}}\right) \tag{4.8}$$

where $\Phi(\theta)$ is the cumulative distribution function of a standard normal random variable. Equation (4.8) is also called the violation probability of constraint (4.1). The same steps can be followed to apply this robust formulation to the objective function coefficients.

5. Solution approach

5.1. Improved multi-choice goal programming

Different methods for solving multi-objective optimization problem have been developed. The goal programming method and its variations are one of the well-known categories. Goal programming is one of the most widely used techniques for the models in which the decision-maker intends to achieve several goals simultaneously. Considering various goals simultaneously provides flexibility in the decision-making process and is usually arranged on the basis of minimizing the deviation from the objectives. This method was first proposed by Charnes and Cooper in 1961. In Charnes' original method, only one primary conservative aspiration level is determined by the decision maker, therefore [10,11] proposed an improved method of multi-choice goal programming in which several aspiration levels were considered for each goal. Jadidi *et al.* [19] proposed a model which is a combination of revised goal programming method and the goal programming with regard to the utility function considering a range of goals instead of only one goal. They believed that in some cases the value of the objective function might go beyond our expectations which are not considered in previous models. This creates a penalty for the model. Therefore, the improved multi-choice goal programming (IMCGP) approach is formulated as follows:

$$\text{Max} \sum_{k=1}^{3} (w_k^a a_k - w_k^b \beta_k) \tag{5.1}$$

$$\begin{aligned}
&\text{s.t. } h_i(X) = (\le \ or \ \ge)\ 0 && i = 1, 2, \ldots, n \\
&f_k(X) = \alpha_k g_k^+ + (1-\alpha_k) g_{k,\min} + \beta_k (g_k^- - g_{k,\min}) && k = 1, 2 \\
&f_k(X) = \alpha_k g_{k,\min} + (1-\alpha_k) g_{k,\max} + \beta_k (g_k^- - g_{k,\max}) && k = 3 \\
&\alpha_k \le y_k \le 1 + \alpha_k && k = 1, 2, 3 \\
&\beta_k + y_k \le 1 && k = 1, 2, 3 \\
&y_k \in \{0, 1\} && k = 1, 2, 3 \\
&0 \le \alpha_k, \beta_k \le 1 && k = 1, 2, 3.
\end{aligned}$$

In the above model, α_k denotes a continuous coefficient between zero and one and represents the normalized distance of the obtained objective function from g_k^+. g_k^- denotes the value of the kth objective function when increasing the value of the function is undesirable. $[g_{k,\min}, g_{k,\max}]$ represents the aspiration level determined by the decision-maker. In the model proposed by Jadidi *et al.* [19], it is assumed that the upper limit of the aspiration level for the kth goal, *i.e.* $g_{k,\max}$, equals g_k^+ which is the value of the kth objective function when increasing the value of the function is desirable; while the lower limit of the aspiration level, *i.e.* $g_{k,\min}$, can be greater than or equal to g_k^- . The range $[g_k^-, g_k^-]$ is devided into two sub-ranges: a more desirable range (MDR) $[g_{k,\min}, g_{k,\max}]$, and a less desirable range (LDR) $[g_k^-, g_{k,\min}]$.

Here, β_k denotes the distance of the normalized kth objective function from . When the value of the obtained kth objective function is greater than $g_{k,\min}$, then a penalty is added to the model that takes a value between zero and one. This is depicted in Figure 2.

5.2. The proposed model formulated by IMCGP

The proposed model considers three objective functions simultaneously. The objectives are maximizing the profit (the difference between revenue and cost of production, purchase, transportation and transfers, and maintenance), maximizing the manufacturing of new and developed products, and maximizing the customer satisfaction. The model obtained through IMCGP method is as follows.

$$\text{Max}\, Z^* = W_1^\alpha \alpha_1 + W_2^\alpha \alpha_2 + W_3^\alpha \alpha_3 - W_1^\beta \beta_1 - W_2^\beta \beta_2 - W_3^\beta \beta_3. \tag{5.2}$$

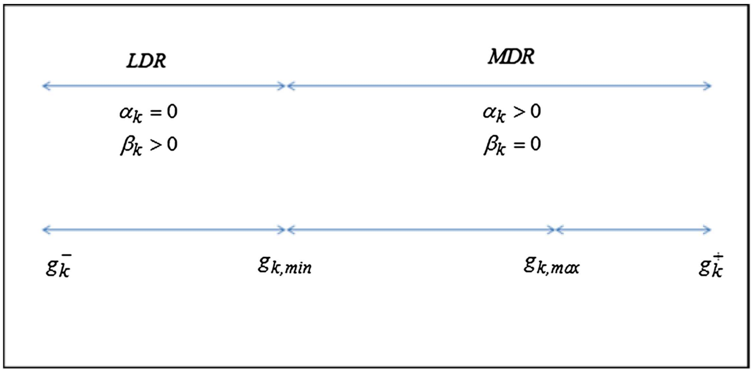

Figure 2. Relationships among the IMCGP parameters.

Subject to:

Constraints (3.4)–(3.11), (3.13)–(3.21), (3.22)–(3.25), (4.6)–(5.1) and

$$f_k(X) = \alpha_k g_k^+ + (1-\alpha_k) g_{k,\min} + \beta_k (g_k^- - g_{k,\min}) \qquad k = 1,2,3 \tag{5.3}$$

$$\alpha_k \le y_k \le 1 + \alpha_k \qquad k = 1,2,3 \tag{5.4}$$

$$\beta_k + y_k \le 1 \qquad k = 1,2,3 \tag{5.5}$$

$$y_k \in \{0,1\} \qquad k = 1,2,3 \tag{5.6}$$

$$0 \le \alpha_k, \beta_k \le 1 \qquad k = 1,2,3. \tag{5.7}$$

6. Case study

In this section, a case of Khazar Gas Company (KGC) is studied. In this article, a field study is conducted to obtain related data for the case study and the corresponding supply chain network design. KGC was established in 1971 with the aim of household appliances production in an area measured 1000 m^2 in the city of Amol in Iran. The company became operational producing rice cooker and tabletop gas stove. KGC is the exemplary production unit selected by the Ministry of Cooperatives in 1992 and also is recognized as the distinguished unit selected by the Bureau of Standards and Industrial Research in 1994. After gaining years of experience and technical knowledge, managers launched the production of oven gas stove and the oven scheme production line. This company produces a variety of desktop gas and stove ovens, and is seeking to improve its position in a competitive market by manufacturing newer and more diverse products. Five following products have been considered in this study:

1) *Four-flame desktop gas stove* that is the first product which is produced until the last planning period if there is a demand for it.
2) *Four-flame Oven with a cabinet* that is the second product of the study which is supposed to become developed to a better and newer product.
3) *Four-flame gas stove with cabinet and lighter* is the third product of study which is assumed to enter in the production line and replace the second product.
4) *Four-flame plate and glass gas stove* are the fourth product group which is considered to be the new products that enters in the production line and is to be produced in a factory starting from the period such that benefits the organization.
5) *Kitchen Hood* is the fifth product and enters as a new product in a production line similar to the fourth product.

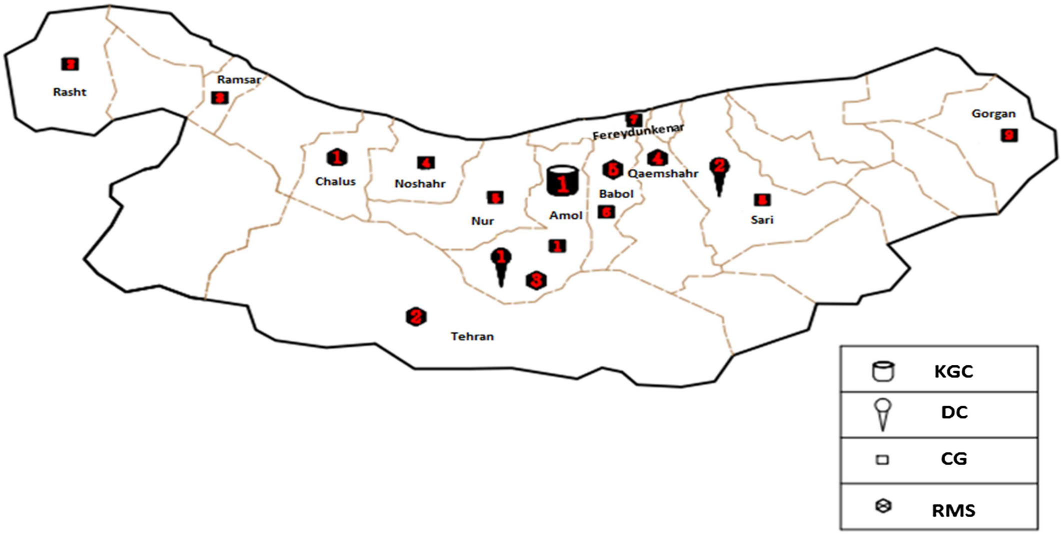

FIGURE 3. Study area.

TABLE 1. Capacity of the plant in each period (CF_{ft}).

Period									
1	2	3	4	5	6	7	8	9	10
550	650	750	850	950	1050	1150	1250	1350	1450

The case study includes the plant (KGC), distribution centers, suppliers and customers for which the required parameters are given in what follows.

6.1. Input parameters

According to Figure 3, there are 5 raw material suppliers (RMS), 2 distribution centers (DC), 9 customer groups (CG) and one plant (KGC). In this article, 5 kinds of products are considered and product 1 is constantly produced without any changes. Product 2 is to be advanced to product 3 and products 4 and 5 are introduced to the market as new products by the relevant company.

The planning time unit is a month. The research was conducted over ten periods and each season is consisted a period. The unit of cost is considered to be thousand *Rials*. In addition, the production capacity of KGC is shown in Table 1.

The manufacturing process of each of the products is associated with two types of cost: the fixed manufacturing cost, and the variable cost calculated per product unit. The production costs are presented in Table 2. Moreover, the production of each product requires a certain amount of time presented in Table 3. Corresponding products sale prices are tabulated in Table 4.

Different raw material types, used in the manufacturing of products, are provided from 5 suppliers and delivered to KGC. Table 5 shows the bill of material or the products and the units of raw materials required to produce each product.

Tables 6–8 present the unit cost of transporting each unit of each raw material type from suppliers to the plant, the shipping cost per each product from KGC to the distribution centers, and from the distribution centers to the customers, respectively.

TABLE 2. Cost of the production.

	Product				
	1	2	3	4	5
C_{fi}	20	32	35	50	40
FC_{fi}	120	150	190	250	200

TABLE 3. Time needed to produce one unit of the product (TP_{fi}).

	Product				
Plant	1	2	3	4	5
1	2	3	3	4	5

TABLE 4. Sale price of the product (PD_i).

	Product				
Plant	1	2	3	4	5
1	265	310	340	400	200

TABLE 5. Bill of material matrix (B_{ir}).

	Raw material															
Product	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	6	4	4	0	1	4	4	0	0	0	0	0	0	0	0	0
2	15	4	4	0	1	4	4	0	0	2	0	0	0	0	0	0
3	15	4	4	0	1	4	4	0	0	2	0	1	0	1	4	0
4	6	4	4	0	1	4	0	4	0	0	1	1	0	1	4	1
5	10	0	0	1	0	0	0	0	1	0	2	0	1	0	0	0

TABLE 6. Shipping cost between suppliers and the plant (TCR_{sf}).

Supplier				
1	2	3	4	5
0.4	0.01	0.02	0.025	0.03

TABLE 7. Shipping cost between plant and distribution centers (TCF_{fd}).

Distribution center	
1	2
0.5	1.5

TABLE 8. Shipping cost between distribution centers and customer groups (TCD_{dg}).

	Customer group								
Distribution center	1	2	3	4	5	6	7	8	9
1	1	5	3	1.5	2	5.5	1.5	3	7
2	2	6	2.5	1.6	1	4	2.5	4	8

TABLE 9. Holding cost for raw materials in the plant (HR_{fr}).

Raw material															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.1	0.001	0.01	0.02	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

TABLE 10. Holding cost for products in the plant (HF_{fi}).

Product				
1	2	3	4	5
2	3	3.5	4	3

TABLE 11. Holding cost for products in distribution centers (HD_{di}).

	Product				
Distribution center	1	2	3	4	5
1	2.5	3	4.1	5	3.6
2	2.5	3.2	4	5	3.6

TABLE 12. Initial inventory of raw materials in the KGC (IIR_{fr}).

Raw material															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10	5	8	2	4	3	3	0	0	3	0	0	0	0	0	0

Procurement and holding of raw materials and final products in different stages of supply chain impose costs. The holding cost per unit of raw material and product in different facilities are given in Tables 9–11.

The inventories of raw materials at KGC are not zero prior to the beginning of the planning horizon. The initial inventory levels of raw materials are provided in Table 12. Moreover, each distribution center has an initial inventory. The information concerning each distributor's initial inventory is provided in Table 13.

Furthermore, duration and cost of designing new and improved products are given in Table 14.

CRM is one of the main strategies to focus on key customers. It is after the initial attraction of customers and encouraging them to be more involved and turning them into loyal customers that the organization can reach more profitability. Four warranty period durations, namely 6, 9, 12 and 15 months, are considered to provide the possibility of selecting the best duration to bring more profitability while increasing customer satisfaction.

TABLE 13. Initial inventory of products in distribution centers (IID_{di}).

	Product				
Distribution center	1	2	3	4	5
1	100	200	0	0	0
2	150	180	0	0	0

TABLE 14. Cost and time to develop and design new products.

Product	dl_i	NP_i
3	2	2000
4	2	12 000
5	3	10 000

TABLE 15. Impact factor of each warranty on products (O_{iv}).

	Warranty			
Product	1(6 month)	2(9 month)	3(12 month)	4(18 month)
1	0.1	0.3	0.4	0.2
2	0.4	0.2	0.1	0.3
3	0.1	0.2	0.3	0.4
4	0.2	0.1	0.4	0.3
5	0.2	0.1	0.4	0.3

TABLE 16. Impact factor of each advertising on products (W_i).

Product	1	2	3	4	5
W_i	0.1	0.17	0.18	0.25	0.30

TABLE 17. Cost of each warranty for advertising of products(Cod_v).

Warranty			
1 (6 month)	2(9 month)	3(12 month)	4(18 month)
10	12	14	15

In addition, the maximum available advertisement budget is 60 000 thousand *Rials*. Furthermore, the impacts of each warranty option and advertising on various products are provided in Tables 15 and 16.

6.2. Solution procedure

In this section, the proposed multi-objective model is solved following the IMCGP approach using Lingo software and the results are presented. Based on the case study, IMCGP parameters are obtained as $g_1^+ = 329997.4, g_2^+ = 4250, g_3^+ = 18002.8, g_1^- = 0, g_2^- = 0, g_3^- = 6$, and g_k^+. is obtained by solving max $f_k\ (X)$ and g_k^-

TABLE 18. Assigned weight corresponding to each objective function.

	$k = 1$	$k = 2$	$k = 3$
W_k^α	0.45	0.30	0.25
W_k^β	0.25	0.30	0.45

TABLE 19. Production plan for the planning horizon (PR_{fit}).

	Period									
Product	1	2	3	4	5	6	7	8	9	10
1	107	58	26	50	25	62	50	60	55	40
2	143	216	120	107	0	0	0	0	0	0
3	0	0	0	0	0	139	200	270	91	147
4	0	0	0	90	99	107	207	95	98	174
5	0	0	0	0	0	110	105	113	146	150

is obtained by solving min $f_k(x)$. Here, $g_{k,\max}$ and $g_{k,\min}$ represent the kth expected goal which are determined by the company's experts' opinions as follows:

$g_{1,\max} = 320\,000$, $g_{2,\max} = 4000$, $g_{3,\max} = 18\,000$

$g_{1,\min} = 250\,000$, $g_{2,\min} = 3500$, $g_{3,\min} = 15\,000$

Here, it is assumed that there are three conditions which the decision-maker plan to consider in her/his decisions:

Condition 1: $g_{\mathrm{k\ min}} > g_k^-$ and $g_{k,\min} < g_k^+$, having that each objective function has a critical point ($g_{k,\min} \forall K$) and two ranges (MDR and LDR).

Condition 2: The first objective is more important than the second one and $f_1(x)$ should be more preferable in MDR.

Condition 3: The third objective, while being less important than the first and the second objective should not significantly exceed $g_{3,\min}$.

In order to apply the IMCGP, first, the sets $g_{k,\min}$ and $g_{k,\max}$ are defined under condition 1. To consider the second condition, $W_1^\alpha \gg W_2^\alpha$ must hold and therefore, α_1 should increase and $f_1(x)$ approaches $g_{2,\max}$. The assigned weight corresponding to each objective function is given in Table 18.

The results obtained by solving the model of the case study are as follows:

$f_1(x) = 243$, $g_{1,\max} = 7\,153\,000$ which is within the MDR with $\alpha_1 = 0.89$

$f_2(x) = 2331$ that lies between $g_{2,\max}$ and g_2^+ with $\alpha_2 = 0.74$

$f_3(x) = 1801$ that lies between $g_{3,\min}$ and $g_{3,\max}$ with $\alpha_3 = 1$

Based on the results, the third goal is fully satisfied since $\alpha_3 = 1$; however, the first and second goals have not been fully satisfied and somewhat deviate from their expected values while they are within the MDR range.

The produced amounts of products in each period is obtained through solving the multi-objective model for which the information is provided in Table 19. In this case, planner should be interested to determine the appropriate time to introduce the new and improved products. Addressing this concern, time period for development and introduction of the new product are specified in Figure 4.

In a practical sense, Figure 4 shows that the first product is planned to be produced throughout all the periods, the second product is planned to be produced until the end of the fourth period when its production is seized and it is replaced by the developed third product. The design of the third product is initiated at the end of the third period which lasts until the end of the fifth period when it is produced and introduced to the market. The design of the fourth product is initiated at beginning of the second period according to market

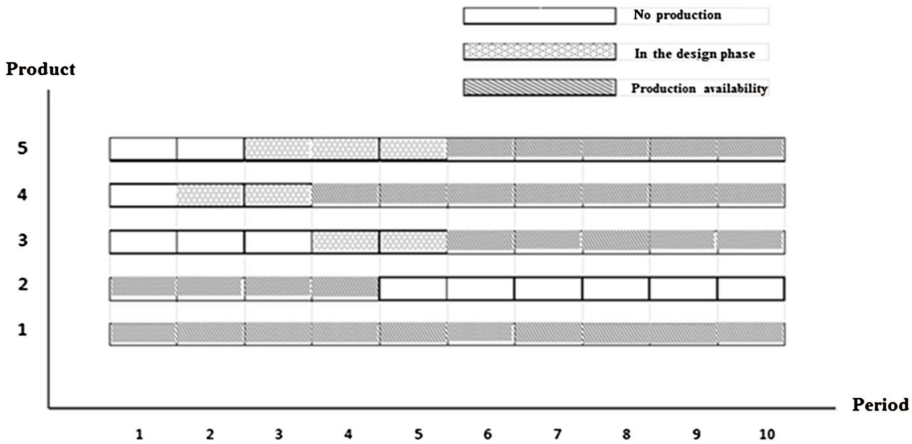

FIGURE 4. Rollover time for products.

TABLE 20. Selected warranty for the product (Od_{iv}).

	Warranty			
Product	1 (6 month)	2(9 month)	3(12 month)	4(18 month)
1	0	1	0	0
2	1	0	0	0
3	0	0	1	0
4	0	0	0	1
5	0	0	1	0

demand and its production and sale begin in the fourth period. The design of the fifth product starts in the third period and lasts until the fifth period and it is produced in the sixth period.

Note once again that, the third objective function is to maximize attracting the customers to profit the organization. The warranty durations for products are the important variables of the problem. Table 20 provides the best warranty durations for the products.

6.3. Uncertainty of data in the case study

This section shows the effect of different values for the uncertain parameter and the objective function's degree of robustness. Robustness has been achieved at a certain "robust cost". Here, it is shown how the different values of the degree of conservatism and parameter uncertainty changes influence the objective function. Correspondingly, Figure 5 shows the constraints violation probability at different levels of conservatism. By observing the diagram in Figure 5, the worst objective function value occurs when the budget of uncertainty (Γ_{git}) has the highest amount of uncertainty. In other words, the demand parameter has a direct impact on the results and the value of the objective function. Another point that can be found by comparing the changes in data is that a 20 percent increase over the range of demand has the greatest effect on the variability of the objective function value. The highest percentage of the variation in the objective function for a 5% change is 1.9 which occurs for the budget of uncertainty being at 7.

If the uncertain conditions of demand are not controlled, there would be a 13% probability that the objective function value deviates from optimality. However, by increasing the budget of uncertainty, the probability of optimality deviation is reduced. This probability is not related to the fluctuation value and volume of the

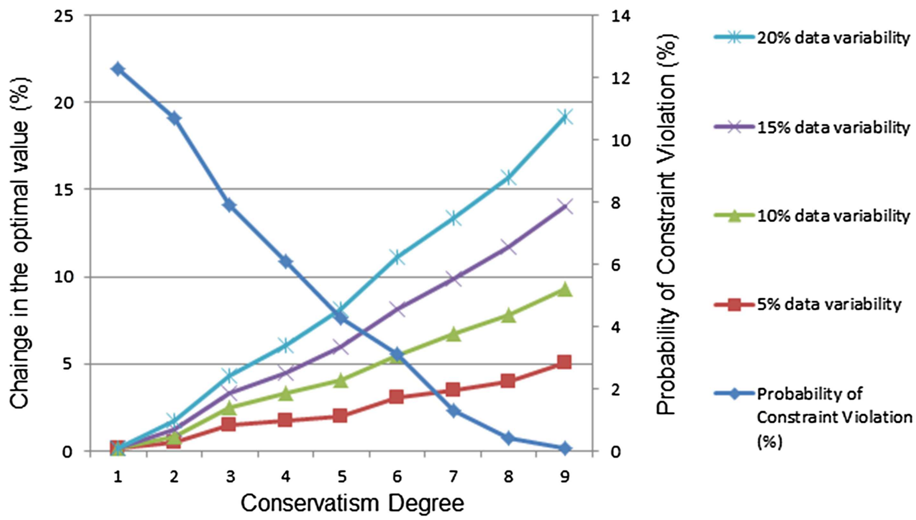

Figure 5. Sensitivity analysis of the proposed model in relation to changes in demand value.

Table 21. Different possible constraint violations of the different budget of uncertainties.

Budget of uncertainty (Γ_{git})	3	4	6	8
Constraints violation probability	%7	%6	%3.2	%0.3

uncertain parameters which are related to budget of uncertainty and the total number of uncertain parameters. One must take into account the fact that the probability of constraint violation is reduced when the budget increases. The slope of the constraints violation probability diagram is initially high and by passing the budget of uncertainty 7 falls below 5% and is not substantial. If a 95% confidence is desired, then Γ_{git} should be set to 6. These values are given in Table 21.

Overall, it can be concluded that by increasing the budget of uncertainty, while the probability of constraint violation is lowered, the profit objective function is also reduced. It should be noted that the probability of deviation from optimality is not related to the fluctuation value and volume of the uncertain parameters is related to budget of uncertainty and the total number of uncertain parameters. The mentioned discussion helps the decision-maker to find a better understanding of the conditions.

Table 22 shows the production plan under uncertain conditions for 0.05 change in data with budget of uncertainty 10. According to Table 22, product 2 is produced up to the fourth period till it is replaced by product 3. Product 4 is in the design phase at the third and fourth periods and enters the production line at the fifth period, and the product 5 is in design phase during the first, second and third periods and its production process begins at the fourth period. Similarly, the best warranty option for each product under uncertainty conditions is provided in Table 23.

7. Conclusion

Identifying the customers' needs and satisfying them is a crucial condition for surviving in a competitive market. Due to the changing nature of customer needs, addressing the supply chain network design along with new product development and customer relationship management would be essential to succeed in a competitive market. The new products which can meet the needs and demands of the customers and retain and

TABLE 22. Production plan in the planning horizon for budget of uncertainty 10 (PR_{fit}).

	Period									
Product	1	2	3	4	5	6	7	8	9	10
1	1123	100	0	0	132	0	24	0	148	0
2	112	124	83	132	0	0	0	0	0	0
3	0	0	0	0	121	200	134	157	0	312
4	0	0	0	0	102	118	112	100	143	221
5	0	0	0	103	102	90	0	121	135	142

TABLE 23. Selected warranty of the product for budget of uncertainty 10 (O_{div})

	Warranty			
Product	1 (6 month)	2(9 month)	3(12 month)	4(18 month)
1	0	1	0	0
2	1	0	0	0
3	0	0	1	0
4	0	0	1	0
5	0	0	0	1

satisfy customers are key factors in maintaining and improving a competitive advantage. Configuring proper network chains and considering customer satisfaction leads to improvement of such aspects to control the time, cost, and quality and help to take advantage of future opportunities. Implementing the concept of CRM in the supply chain enables the chain to provide superior services to the customer and profit the entire chain. Moreover, in the real situations, the nature of many production parameters such as demand is uncertain and must be taken into account. This paper presented a multi-objective mathematical model involving customer relationship management and a supply chain network design when a new product is going to be manufactured in the uncertain environment. Further, the proposed model ensures that different schemes and objectives are deliberated.

The model results provide information to help practitioners to have a better vision regarding their future production plan.

REFERENCES

[1] A.Z. Afrouzy, S.H. Nasseri, I. Mahdavi and M.M. Paydar, A fuzzy stochastic multi-objective optimization model to configure a supply chain considering new product development. *Appl. Math. Model.* **40** (2016) 7545–7570.

[2] F. Altiparmak, M. Gen, L. Lin and I. Karaoglan, A steady-state genetic algorithm for multi-product supply chain network design. *Comput. Ind. Eng.* **56** (2009) 521–537.

[3] M. Amini and H. Li, Supply chain configuration for diffusion of new products: an integrated optimization approach. *Omega* **39** (2011) 313–322.

[4] S. Anderson, "Sanity check." Destination CRM, Viewpoint, available at: www.destinationcrm.com (2006).

[5] T. Aouam and N. Brahimi, Integrated production planning and order acceptance under uncertainty: A robust optimization approach. *Eur. J. Oper. Res.* **228** (2013) 504–515.

[6] A. Ben-Tal and A. Nemirovski, Robust convex optimization. *Math. Oper. Res.* **23** (1998) 769–805.

[7] D. Bertsimas and M. Sim, Robust discrete optimization and network flows. *Math. Program.* **98** (2003) 49–71.

[8] D. Bertsimas and M. Sim, The price of robustness. *Oper. Res.* **52** (2004) 35–53.

[9] C. Billington, H.L. Lee and C.S. Tang, Product rollover: process, strategies and opportunities. *Sloan Manage. Rev.* **39** (1998) 23–30.

[10] C.T. Chang, Multi-choice goal programming. *Omega* **35** (2007) 389–96.

[11] C.T. Chang, Revised multi-choice goal programming. *Appl. Math. Model.* **32** (2008) 2587–2595.

[12] C.T. Chang, Multi-choice goal programming with utility functions. *Eur. J. Oper. Res.* **215** (2011) 439–445.

[13] A. Charnes and W.W. Cooper, Management Models and Industrial Applications of Linear Programming. New York, Wiley (1961).

[14] L. El Ghaoui and H. Lebret, Robust solutions to least-squares problems with uncertain data. *SIAM J. Matrix Anal. Appl.* **18** (1997) 1035–1064.

[15] C. Forza, F. Salvador and M. Rungtusanatham, Coordinating product design, process design, and supply chain design decisions: Part B. Coordinating approaches, tradeoffs, and future research directions. *J. Oper. Manage.* **23** (2005) 319–324.

[16] D. Francas and S. Minner, Manufacturing network configuration in supply chains with product recovery. *Omega* **37** (2009) 757–769.

[17] A.C. Garavelli, Flexibility configurations for the supply chain management. *Int. J. Prod. Econ.* **85** (2003) 141–153.

[18] N. Gholamian, I. Mahdavi, R. Tavakkoli-Moghaddam and N. Mahdavi-Amiri, Comprehensive fuzzy multi-objective multi-product multi-site aggregate production planning decisions in a supply chain under uncertainty. *Appl. Soft Comput.* **37** (2015) 585–607.

[19] O. Jadidi, S. Cavalieri and S. Zolfaghari, An improved multi-choice goal programming approach for supplier selection problems. *Appl. Math. Model.* **39** (2015) 4213–4222.

[20] M. Jafarian and M. Bashiri, Supply chain dynamic configuration as a result of new product development. *Appl. Math. Model.* **38** (2014) 1133–1146.

[21] J. Jouzdani, M. Fathian, A. Makui and M. Heydari, Robust design and planning for a multi-mode multi-product supply network: A dairy industry case study. *Oper. Res.* (2018) 1–30. https://doi.org/10.1007/s12351-018-0395-0

[22] B. Karakostas, D. Kardaras and E. Papathanassiou, The state of CRM adoption by the financial services in the UK: An empirical investigation. *Inf. Manage.* **42** (2005) 853–863.

[23] J. Kettunen, Y. Grushka-Cockayne, Z. Degraeve and B. De Reyck, New product development flexibility in a competitive environment. *Eur. J. Oper. Res.* **244** (2015) 892–904.

[24] M.S. Kisomi, M. Solimanpur and A. Doniavi, An integrated supply chain configuration model and procurement management under uncertainty. A set-based robust optimization methodology. *Appl. Math. Model.* **40** (2016) 7928–7947.

[25] E. Koyuncu and R. Erol, PSO based approach for scheduling NPD projects including overlapping process. *Comput. Ind. Eng.* **85** (2015) 316–327.

[26] H. Li and K. Womer, Modeling the supply chain configuration problem with resource constraints. *Int. J. Project Manage.* **26** (2008) 646–654.

[27] J.J. Liou, A novel decision rules approach for customer relationship management of the airline market. *Expert Syst. Appl.* **36** (2009) 4374–4381.

[28] S.M.J. Mirzapour Al-E-Hashem, H. Malekly and M.B. Aryanezhad, A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty. *Int. J. Prod. Econ.* **134** (2011) 28–42.

[29] J.M. Mulvey, R.J. Vanderbei and S.A. Zenios, Robust optimization of large-scale systems. *Oper. Res.* **43** (1995) 264–281.

[30] P.K. Naraharisetti and I.A. Karimi, Supply chain redesign and new process introduction in multipurpose plants. *Chem. Eng. Sci.* **65** (2010) 2596–2607.

[31] B. Nepal, L. Monplaisir and O. Famuyiwa, A multi-objective supply chain configuration model for new products. *Int. J. Prod. Res.* **49** (2011) 7107–7134.

[32] S. Oh, K. Ryu and M. Jung, Reconfiguration framework of a supply network based on flexibility strategies. *Comput. Ind. Eng.* **65** (2013) 156–165.

[33] M.M. Paydar, V. Babaveisi and A.S. Safaei, An engine oil closed-loop supply chain design considering collection risk. *Comput. Chem. Eng.* **104** (2017) 38–55.

[34] K.J. Petersen, R.B. Handfield and G.L. Ragatz, Supplier integration into new product development: coordinating product, process and supply chain design. *J. Oper. Manage.* **23** (2005) 371–388.

[35] I.J. Petrick and A.E. Echols, Technology road mapping in review: A tool for making sustainable new product development decisions." *Technol. Forecast. Soc. Change* **71** (2004) 81–100.

[36] M.S. Pishvaee, M. Rabbani and S.A. Torabi, A robust optimization approach to closed-loop supply chain network design under uncertainty. *Appl. Math. Model.* **35** (2011) 637–649.

[37] N.C. Romano, Jr. and J. Fjermestad, Electronic commerce customer relationship management: A research agenda. *Inf. Technol. Manage.* **4** (2003) 233–258.

[38] A.L. Soyster, Technical note–convex programming with set-inclusive constraints and applications to inexact linear programming. *Oper. Res.* **21** (1973) 1154–1157.

[39] M. Tracey and R. Neuhaus, Purchasing's role in global new product-process development projects. *J. Purchas. Supply Manage.* **19** (2013) 98–105.

[40] A. Thiele, A robust optimization approach to supply chains and revenue management. (Doctoral dissertation, Massachusetts Institute of Technology) (2004).

[41] E. Van Kleef, H.C. Van Trijp and P. Luning, Consumer research in the early stages of new product development: a critical review of methods and techniques. *Food Qual. Prefer.* **16** (2005) 181–201.

[42] J. Wang and Y.F. Shu, A possibilistic decision model for new product supply chain design. *Eur. J. Oper. Res.* **177** (2007) 1044–1061.

[43] S. Zokaee, A. Jabbarzadeh, B. Fahimnia and S.J. Sadjadi, Robust supply chain network design: An optimization model with real world application. *Ann. Oper. Res.* **257** (2014) 15–44.