Supply chain reconfiguration for new product development through risk management approach

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Abstract. Nowadays, innovation is increasingly growing and the lifetime of products is decreasing. In this situation, New Product Development (NPD) is an advantage that makes it possible to survive in the competitive market. However, risks are unavoidable in NPD in any industry. Therefore, identifying, management, and mitigation of risks are considered of high significance for companies. By taking risk management into account, this study introduces a new multi-objective mathematical model for Supply Chain (SC) configuration in the presence of a new product. The considered SC is multi-echelon, multi-resource, multi-period, and multi-product. In order to manage the risk in this SC, appropriate mitigation strategies were chosen among various risk response strategies considering their cost and effectiveness. Furthermore, influence of each choice on SC was accounted for in the mathematical model. The assumed model explored the optimum tactical and operational Supply Chain Management (SCM) decisions. The ability of the model was assessed by solving a numerical example. The result showed that the choice of various response strategies as well as new product production influenced SC configuration.

1. Introduction

"Supply Chain Management (SCM) aims to integrate plants with their suppliers, customers and other facilities in network so that they can be managed as a single entity, and to coordinate all input/output flows (of materials, information and funds) so that products are produced and distributed in the right quantities, to the right locations, and at the right time" [1]. Today, in a competitive industry, with the aim of gaining more competitive advantages, responsiveness is considered as a factor for differentiation [2]. It is vital for companies to consider the rapid changes in marketing situation as well as wants, likes, and needs of the consumers. There is compulsion for innovation in the market to satisfy the needs of consumers, particularly in the Fast Moving Consumer Goods (FMCG) industry. Many new products encounter challenges as they come into new markets. Studies in 2012 demonstrated that "the rate of New Product Development (NP) success was 56.8% in Europe and 48.6% in Asia" [3].

Reconfiguration of the Supply Chain (SC) is too complex, because a new product lives for a short time and further desire of the consumer is not obvious [4]. This causes some risks that are inevitable in development of new products in any industry or situation. In NPD setting, risk is the likelihood of NPD failure

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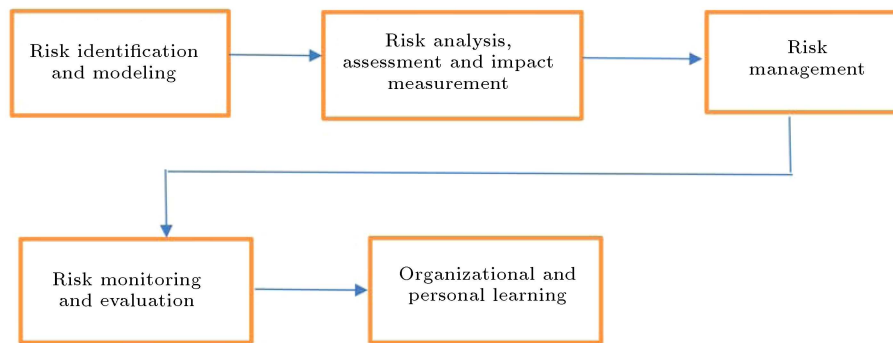
Figure 1. Suply Chain Risk Management (SCRM) activity.

because of some factors like market failure, technology restriction, and organizational obstructing factors that result in the failure of selling the new product [5]. The management of the mentioned factors is called Supply Chain Risk Management (SCRM). Definitions of SCRM basically contain the activities that are shown in Figure 1 [6].

According to Qazi et al. [7], qualitative methodology has received considerable attention in research studies, while quantitative methods have been less developed. Neither have the aspects of design change and NPD been taken into account rightly. Therefore, more studies are required to investigate the quantitative techniques. Also, it will be worthwhile if more research studies consider risks regarding NPD and explore the impact of design changes on SC risks. According to Liu and Sun (2018), when risk management is not complete, the whole construction project and operation processes may face a large number of problems [8].

This study aims to develop an approach for configuring a multi-echelon, multi-product, and multi-period SC for a new product considering economic performance and quantitative risk aspects with the goal of increasing satisfaction level of consumers. Net Present Value (NPV), risk, and consumer satisfaction level have been considered as the three objectives of SC in a deterministic multi-objective optimization model. This study aims to identify the most efficient strategies in order to mitigate the risks. To maintain the efficiency and effectiveness, decisions regarding the selection of the plant that will manufacture the new product, the suppliers, and the distribution centers which will sell it should be made prior to launching a new product.

The rest of the paper is organized as follows. Section 2 provides a review of the literature on the related research topics and methods. Section 3 presents the proposed model of SC configuration. Numerical data and statistics as well as the results of the performance and risk assessment are given in Section 4. The sensitivity of financial parameters is assessed in Section 5.

Finally, the paper ends with a discussion and concluding remarks in Section 6.

2. Literature review

2.1. NPD and SC configuration

Early research on new product and technology diffusion in the marketing literature can be traced back to the 1960s [9]. The need to study this area is essential because, according to Amini and Li [10], successful launch of new products raises the general profit of a company by an average of 31%.

Amini and Li [10] developed an integrated optimization model with the purpose of configuration of SC subject to demand dynamics and other SC parameters. In the integrated model introduced by Li and Amini [11], decisions are made to determine multiple-sourcing and safety stock placement in the line in the new product diffusion processes as demand dynamics over its life cycle. Gaur et al. [12] studied a Closed Loop Supply Chain Configuration (CLSCC) for new product and its reconditioned version. The mixed-integer nonlinear programming model they offered could concurrently determine optimal production/sales plan and configure the whole CLSC. In another study, Nepal et al. [13] enhanced SC efficiency and stability by a model that cooperatively incorporated sourcing, inventory costs, and compatibility decisions in the configuration of the SC.

Jafarion and Bashiri [14] presented a dynamic SC model which accounted for the time of new product launching in the SC and concurrently optimized it with SC configuration. Their model also took production, sales, transportation planning, and their lead times into consideration.

Afrouzy et al. [15] developed an SC model that integrated development of product, production of old and new products, and their impact on SC configuration. In another study, they [16] improved their model by assuming stochastic parameters related to demands and capacities of suppliers.

Brandenburg [17] employed a goal programming

approach considering economic and environmental criteria. The performance of the approach was demonstrated by the case example of an FMCG manufacture. In this study, a scenario approach also modeled the effect of long-term demand uncertainties.

Brandenburg [4] proposed a hybrid approach in order to configure an eco-efficient SC for a new product. This paper utilized a discrete-event simulation to evaluate the financial, operational, and environmental performance of varying SC configuration options while the Value-At-Risk (VAR) concept was adopted to assess the associated SC risks.

Graves and Willems [18] investigated the ways of configuring the SC for a new product that had been designed before. They contended that the suppliers, parts, processes, and transportation modes should be specified at each step in the SC.

Chauhan et al. [19] explored the issue of SC design strategically when the opportunity for a new market production/distribution needed to be launched in an existing SC. A deterministic Mixed-Integer Linear Programming (MILP) model was employed for a multi-echelon SC. Jahani et al. [20] reconfigured an existing supply change network structure in which new products were launched to the market. They also considered correlation between demand and price in the markets. Table 1 shows the related studies to clarify the main contributions of the present study to the formulated structure.

2.2. Supply Chain Risk Management (SCRM)

SCRM has received remarkable attention in recent years, because the risk events that influence an SC have increased [6]. In this section, we refer to some related studies about this area.

Brandenburg [4] accounted for the VAR concept to suggest a green supply chain design and assess the associated SC risks. He proposed a simulation model for two kinds of SC configuration options. The requirement of establishing robust and resilient supply networks was highlighted by Klibi et al. [21]. They stated that cash flow should be reduced during a multi-period planning horizon as a metric, which indicated SC uncertainties.

Kayis et al. [22] suggested a new method in the engineering projects that simultaneously mitigated risk in the process of design and development of new product. First, they prioritized and quantified the risks and then, they used five computational algorithms for mitigating those risks.

More evaluations related to the issue are provided in review articles. We refer to some of them here. Tang and Musa [23] reviewed various quantitative models for managing SC risks. Different SCRM strategies were connected to the actual practices. They found that those quantitative models were primarily designed for managing operational risks rather than disruption ones. Prakash et al. [24] devised a systematic literature review approach. They suggested a change of focus toward establishing and verifying SCRM theories employing techniques like hypothesis testing, simulations, surveys, case studies, etc. The literature arrangement of Peidro et al. [25] centered on a taxonomy in three dimensions: sources of uncertainty, problem type, and modelling approach. Three sources of demand, process/manufacturing, and supply uncertainty were recognized for uncertainty. Khojasteh-Ghamari and Irohara [26], after exploring SCRM papers of three previous years, observed that companies were making effort to manage SC risk while minimizing cost and maximizing profit and NPV. Risk could be on supply side, demand side, or process side. They believed that researchers would be interested in stochastic methods for SCRM over time. Sahling and Kayser [27] paid attention to vendor selection in context for supply network planning to develop a non-linear model approximated by an MILP.

In the model developed by Guillén et al. [28], multi-objective stochastic programming was utilized to specify the optimal retrofit of the existing SC. A robust multi-objective SC design model was proposed and evaluated by a case example from food industry by Azaron et al. [29]. Nickel et al. [30] suggested an MILP model for multi-period network design. The decisions that needed to be made were related to facility location, material flow, and fixed asset investments. By taking efficiency and risk into account, Huang et al. [31] presented a branch-and-reduce algorithm to specify Pareto-optimal robust supply network configurations.

Most studies concerned with SC redesign or configuration only consider financial risks without paying attention to other significant strategic risks, such as operational and sustainability, which were suggested by Heckmann et al. [32] and Fahimnia et al. [33]. Therefore, there is a need to consider different types of risk and the appropriate response strategies against them. Also, the impact of these mitigating strategies on the configuration of SC in the presence of a new product is worthy of attention.

2.3. Research motivation

To improve NPD activities in an SC, this study presents an MILP model that accounts for a multi-echelon, multi-product, multi-period, and multi-source SC with NPD and the risk related to it. The previously conducted research studies are generalized in the following aspects:

- The remarkable risks associated with developing new or old products in an FMCG supply chain as well as different risk response strategies for each risk are considered. The proposed model aims at finding the most efficient response for each risk;

Table 1. New Product Development (NPD) and Supply Chain (SC) configurations.

Author(s)	Product		Echelon		Source		Model type		Formulation					
	Single	Multi	Single	Multi	Single	Multi	Det.[a]	Non-Det[b]	MILP	MINLP	ABM	DES	SD	AHP
Afrouzy et al. (2016) [15]		✓		✓	✓		✓		✓					
Afrouzy et al. (2016) [16]		✓		✓	✓			✓	✓					
Li and Amini (2011) [10]	✓		✓		✓			✓		✓				
Li and Amini (2012) [11]	✓		✓			✓		✓			✓			
Brandenburg and Schilling (2010) [34]	✓			✓	✓			✓				✓		
Brandenburg et al. (2014) [35]	✓			✓	✓			✓				✓		
Brandenburg (2015) [17]	✓			✓	✓			✓	✓					
Brandenburg (2017) [4]	✓			✓	✓			✓				✓		
Butler et al. (2006) [36]		✓		✓	✓			✓	✓					
Chauhan et al. (2004) [19]	✓			✓	✓		✓		✓					
Graves and Willems (2005) [18]	✓			✓	✓		✓		✓					
Gaur et al. (2017) [12]	✓		✓		✓		✓			✓				
Hansen and Grunow (2015) [37]	✓		✓		✓			✓	✓					
Higuchi and Troutt (2004) [38]	✓		✓		✓			✓					✓	
Jafarian and Bashiri (2014) [14]	✓			✓		✓	✓		✓					
Jahani et al. (2017) [20]	✓			✓		✓		✓		✓				
Nepal et al. (2011) [13]	✓			✓	✓			✓		✓				
Pan and Nagi (2010) [39]	✓			✓	✓			✓	✓					
Schilling et al. (2010) [40]	✓			✓	✓			✓				✓		
Farahani et al. (2014) [41]	✓			✓	✓			✓	✓					✓
This study		✓		✓		✓	✓		✓					

[a]Det.: Deterministic; [b]Non-Det.: Non-Deterministic.

- The effects of each risk response strategy on improving the level of demand, final production, and raw material supply capacity are considered in the model.

3. Problem description

Risk factors as well as their probability and effects need to be identified. Identifying potential risks can rest on the knowledge of experts, historical information, and SC structure [5]. The cost of risk response and risk reduction/elimination stand against each other. The higher the commitment to risk reduction gets, the further the cost of response strategies inflates. The proposed framework pays attention to optimizing cost as well as risk and customer satisfaction level. To identify the optimal response strategies for each risk, an optimization model is formulated. Each plant is capable of designing and introducing the new product in the planning horizon. Since risks are capable of being correlated, the model guarantees that mitigating the risk in one part of the SC will not results in increasing the risk in another part. The model gives a quantitative risk analysis to help companies in making decisions on how to allocate limited resources to the risks. To support these decisions, the SC configuration problem is formulated as an MILP optimization model.

Assumptions

- A three-echelon SC model, which consists of several suppliers, manufacturers, and distributors, is considered and several products are produced;

- The new product is manufactured from some new raw materials using the available systems;

- Producers have two kinds of inventories, namely inventory of raw material and inventory of final product. Inventory can decrease idleness, especially in demand fluctuation circumstances during the product life cycle;

- Limitations related to a fixed order quantity and a daily production capacity cause minimum and maximum lot sizes;

- Supplier and production plants are expected to work under a push strategy;

- The SC works undergoing a make-to-stock policy that rests on estimated demands;

- Demand is supposed to be deterministic for three periods;

- Market demands of wholesalers, distributors, and retailers are met right from stock by the distribution centers;

- If the demand cannot be satisfied fully and in time, backorders are not permitted; hence, the sales are lost.

The indices, sets, and parameters that are designed to model the SC network are defined in the following figure. We continue with a brief description of the objective function and constraints of the model.

3.1. Model formulation

The structure of the aforementioned SC is depicted in Figure 2. It includes the following elements:

- A set of suppliers that send raw materials to plants;

- A set of plants that produce products. There are warehouses for storing raw materials in addition to final products before and after production;

- A set of final markets that make products accessible to customers. There are warehouses for final products too.

The overall problem can be formally expressed as follows:

Indexing sets

t	Index of periods
s	Index of suppliers
l	Index of manufacturers (set L)
r	Index of demand regions (set R)
k	Index of raw materials
p	Index of finished products
ϑ	Set of transportation connections
x	Set of plant and demand region locations
i	Set of items k, p
w	Index of risks
q	Index of response strategies
δ_θ	Duration of transport via connection $\theta \in \vartheta$

Scalars

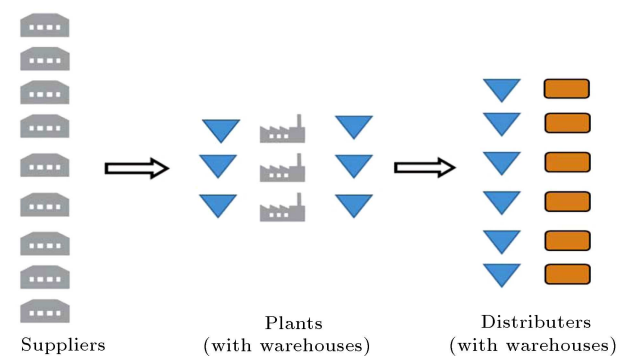|	
B	Dedicated budget to risk response
π^{cap}	Cost of capital

Figure 2. Supply Chain (SC) structure.

Parameters

Parameters related to risk:

R'_{wq} Amount of reduction in risk w after implementing response strategy q

R_w Level of risk w before implementing response strategy

R^*_w Target value of risk w

Prices and costs:

$\pi^{sell}_{p,r}$ Selling price of finished product p in demand region r

$\pi^{store}_{i,x}$ Storage cost per unit of item i at location x

$\pi^{trans}_{s,l}$ Cost of transportation connection from supplier s to plant l

$\pi^{trans}_{l,r}$ Cost of transportation connection from plant l to demand region r

$\pi^{raw}_{k,s}$ Cost of raw material k that is supplied by supplier s

$\pi^{conv}_{p,l}$ Cost of conversion in production p at plant l

c_q Cost of strategy implementation q

Capacities:

$\mu^{raw}_{k,s}$ Minimum order quantity of raw material k from raw supplier s

$cap^{raw}_{k,s}$ Production capacity of raw material k from raw supplier s

$\mu^{conv}_{p,l}$ Minimum production of finished product p at plant l

$cap^{conv}_{p,l}$ Production capacity of finished product p at plant l

Impact of implementing risk response strategies:

$\Delta^{raw}_{q,k,s}$ Deviation of production capacity of raw material k from raw supplier s by using strategy q

$\Delta^{conv}_{q,p,l}$ Deviation of production capacity of finished product p at plant l by using strategy q

$\Delta^{demand}_{q,p,r,t}$ Deviation of demand of finished product p at demand region r in period t by using strategy q

Demand:

$d_{p,r,t}$ Demand of finished product p at demand region r in period t

Transportation connection:

$\theta_{s,l}$ Binary parameter for transportation connection from supplier s to plant l

$\theta_{l,r}$ Binary parameter for transportation connection from plant l to demand region r

Bill of material:

$\varphi_{k,p}$ Quantity of raw material k used for producing finished product p

List of variables

Positive variables:

$xy^{raw}_{q,s,t}$ Auxiliary variable for linearized product of x_q and $y^{raw}_{s,t}$

$xy^{conv}_{q,p,l}$ Auxiliary variable for linearized product of x_q and $y^{conv}_{p,l}$

Cost variables:

cf_t Cash flow in period $t \in T$

ci_t Cash inflow in period $t \in T$

co_t Cash outlay in period $t \in T$

c^{store}_t Total storage cost in period $t \in T$

c^{trans}_t Total transportation cost in period $t \in T$

c^{raw}_t Total cost of raw material in period $t \in T$

c^{conv}_t Total conversion cost in period $t \in T$

c^{risk}_t Total risk cost in period $t \in T$

Decision variables:

$q^{sale}_{p,r,t}$ Sale quantity of finished product p at demand region r in period $t \in T$

$q^{store}_{i,x,t}$ Storage quantity of item $i \in \{k,p\}$ at location $x \in L \cup R$ in period $t \in T$

$q^{trans}_{k,(s,l),t}$ Transportation quantity of raw material k on transportation connection from supplier s to plant l in period $t \in T$

$q^{trans}_{p,(l,r),t}$ Transportation quantity of finished product p on transportation connection from plant l to demand region r in period $t \in T$

$q^{raw}_{k,s,t}$ Raw material quantity of material k supplied by supplier s in period $t \in T$

$q^{conv}_{p,l,t}$ Production quantity of finished product p at plant $l \in L$ in period $t \in T$

$q^{lost}_{p,r,t}$ Quantity of lost order of finished product p in demand region $r \in R$ and period $t \in T$

Binary decision variables:

$$x_q = \begin{cases} 1 & \text{if response strategy } q \text{ is selected} \\ 0 & \text{otherwise} \end{cases},$$

$$y_{s,t}^{raw} = \begin{cases} 1 & \text{if supplier } s \text{ worked at period } t \in T \\ 0 & \text{otherwise} \end{cases},$$

$$y_{p,l}^{conv} = \begin{cases} 1 & \text{if finished product } p \text{ produced by} \\ & \text{plant } l \text{ in period } t \in T \\ 0 & \text{otherwise} \end{cases}.$$

Objective functions

The economic objective of company value is to maximize the *NPV*, i.e. the discounted sum of cash flows from the resulting SC configuration and operation decisions.

$$\max \quad NPV = \sum_{t \in T} \frac{cf_t}{(1 + \pi^{cap})^{t-1}}. \tag{1}$$

The objective function related to customer satisfaction level, given with the minimum Lost Income (LI), is as follows:

$$\min \quad LI = \sum_{p \in P} \sum_{r \in R} \sum_{t \in T} \pi_{p,r}^{sell} q_{p,r,t}^{lost}. \tag{2}$$

Risk objective function maximizes total risk reduction.

$$\max \quad risk \ (reduction) = \sum_{w=1}^{W} \sum_{q=1}^{Q} \left(\frac{R'_{wq} x_q}{R_w} \right). \tag{3}$$

Constraints

Financial constraints

Cash flows caused by SC configuration and operation are taken into account by financial restrictions. The cash flow of period $t \in T$ is calculated by the difference of cash inflow ci_t and cash outlay co_t (Constraint (4)). The amount of total product sales determines cash inflow ci_t for each period $t \in T$ (Constraint (5)). The amount of the entire cost of storage, transportation, raw materials, finished goods production, and risks presents cash outlay for each period (Constraint (6)).

$$cf_t = ci_t - co_t \qquad \forall \ t \in T, \tag{4}$$

$$ci_t = \sum_{p \in P} \sum_{r \in R} \pi_{p,r}^{sell} q_{p,r,t}^{sales} \qquad \forall \ t \in T, \tag{5}$$

$$co_t = c_t^{store} + c_t^{trans} + c_t^{raw} + c_t^{conv} + c_t^{risk} \quad \forall \ t \in T. \tag{6}$$

Cost constraints

By further constraints, the costs of storage (Constraint (7)), transportation (Constraint (8)), raw material (Constraint (9)), conversion of finished goods production (Constraint (10)), and mitigating the risks (Constraint (11)) will be calculated more precisely. The sum of the selected risk response strategies is divided by 365 as we choose it once a year, unlike the other costs that are chosen every day.

$$c_t^{store} = \sum_{i \in \{k.p\}} \sum_{x \in L \cup R} \pi_{i.x}^{store} . q_{i.x.t}^{store} \qquad \forall \ t \in T, \tag{7}$$

$$c_t^{trans} = \sum_{i \in \{k.p\}} \sum_{\theta \in \vartheta} \pi_{\theta}^{trans} q_{i.\theta.t}^{trans} \qquad \forall \ t \in T, \tag{8}$$

$$c_t^{raw} = \sum_{k \in K} \sum_{s \in S} \pi_{k,s}^{raw} q_{k,s,t}^{raw} \qquad \forall \ t \in T, \tag{9}$$

$$c_t^{conv} = \sum_{p \in P} \sum_{l \in L} \pi_{p,l}^{conv} q_{p,l.t}^{conv} \qquad \forall \ t \in T, \tag{10}$$

$$c_t^{risk} = \sum_{q} (x_q c_q)/365 \qquad \forall \ t \in T. \tag{11}$$

Capacity constraints

Minimum lot sizes are represented by operational constraints on the supply side and plant production (Constraint (12) and (14)). It is possible to increase maximum capacities of suppliers and the production factories. This change can occur by selecting risk response strategies associated with capacities, e.g. interplant inventory sharing, on-site supplier hubs, redundant suppliers, etc. (Constraint (13) and (15)). This model is nonlinear due to Constraints (13) and (15).

$$\mu_{k,s}^{raw} . y_{s,t} \leq q_{k,s,t}^{raw} \qquad \forall \ t \in T, \quad s \in S, \quad k \in K, \tag{12}$$

$$q_{k,s,t}^{raw} \leq CAP_{k,s}^{raw} . y_{s,t}^{raw} + \sum_q \Delta_{q,k,s}^{raw} . x_q . y_{s,t}^{raw}$$

$$\forall \ t \in T, \quad s \in S, \quad k \in K, \tag{13}$$

$$\mu_{p,l}^{conv} . y_{p,l}^{conv} \leq q_{p,l.t}^{conv} \quad \forall \ p \in P, \quad l \in L, \quad t \in T, \tag{14}$$

$$q_{p,l.t}^{conv} \leq CAP_{p,l}^{conv} . y_{p,l}^{conv} + \sum_q \Delta_{q,p,l}^{conv} . x_q . y_{p,l}^{conv}$$

$$\forall \ t \in T, \quad l \in L, \quad p \in P. \tag{15}$$

Transportation constraints

Operational constraints for the material flow assure that supplier and production plants utilize a push strategy, i.e. produced quantities are shipped from the supplier (Constraint (16)) or production plant (Constraint (17)) to the receiver of goods after production has finished. In this model, the finished products can also be stored in plants for a period of time. Besides, mass balances are applied to finished goods

(Constraint (18)) and components (Constraint (19)).

$$q_{k,s,t}^{raw} = \sum_{l \in L} \sum_{(s,l) \in \vartheta} q_{k,(s,l),t}^{trans},$$

$$\forall \; k \in K, \quad s \in S, \quad t \in T, \tag{16}$$

$$q_{p,l,t}^{store} = q_{p,l,t-1}^{store} + q_{p,l,t}^{conv} - \sum_{r \in R} \sum_{(l,r) \in \vartheta} q_{p,(l,r),t}^{trans},$$

$$\forall \; l \in L, \quad p \in P, \quad t \in T, \tag{17}$$

$$q_{p,r,t}^{store} = q_{p,r.t-1}^{store} - q_{p,r,t}^{sales} + \sum_{l \in L} \sum_{\theta \in \vartheta} q_{p,\theta,t-\delta_\theta}^{trans}$$

$$\forall \; p \in P, \quad r \in R, \quad t \in T, \tag{18}$$

$$q_{k,l,t}^{store} = q_{k,l,t-1}^{store} - \sum_{p \in P} \varphi_{k,p}.q_{p,l,t}^{conv} + \sum_{s \in S} \sum_{\theta \in \vartheta} q_{k,\theta,t-\delta_\theta}^{trans}$$

$$\forall \; t \in T, \quad l \in L, \quad k \in K. \tag{19}$$

Demand

Backorders are not permitted and demands that are not fully satisfied result in lost sales. Therefore, operational constraints on the demand side indicate sales and lost sales quantities that must match the demands (Constraint (20)). If some risk response strategies that are related to the marketing risk, e.g., proactive market orientation, branding, lean production, etc., are applied, demands can rise. The impact of these strategies is shown in demand constraint.

$$q_{p,r,t}^{sales} + q_{p,r.t}^{lost} = d_{p,r,t} + \sum_q \Delta_{q,p,r,t}^{demand}.x_q$$

$$\forall \; p \in p, \quad r \in R, \quad t \in T. \tag{20}$$

Budget

This constraint ensures that the total cost for mitigating the risk will not be more than the assigned budget.

$$\sum_q x_q c_q \leq B. \tag{21}$$

Target level of the risk

The resulting risk value must be less than or equal to the target level of that risk after implementing the mitigation strategies (Constraint (22)). Constraint (23) shows that the total reduction in the risk level must be greater than or equal to zero:

$$R_w - \sum_{q \in Q} \left(R'_{wq}.x_q \right) \leq R_w^*, \tag{22}$$

$$\sum_{q \in Q} R'_{wq}.x_q \geq 0. \tag{23}$$

Problem simplification

By introducing the auxiliary variables $xy_{(q,s,t)}^{raw}$ and $xy_{(q,p,l)}^{conv}$, Constraints (13) and (15), which

are nonlinear, can be transformed into the following equivalent programming problem.

Constraint (13):

$$q_{k,s,t}^{raw} \leq CAP_{k,s}^{raw}.y_{s,t}^{raw} + \sum_q \Delta_{q,k,s}^{raw}.xy_{q,s,t}^{raw}$$

$$\forall \; t \in T, \quad s \in S, \quad k \in K,$$

is equivalent to:

$$xy_{q,s,t}^{raw} \geq x_q + y_{s,t}^{raw} - 1 \qquad \forall \; q \in Q, \quad s \in S, \quad t \in T, \tag{24}$$

$$xy_{q,s,t}^{raw} \leq x_q \qquad \forall \; q \in Q, \quad s \in S, \quad t \in T, \tag{25}$$

$$xy_{q,s,t}^{raw} \leq y_{s,t}^{raw} \qquad \forall \; q \in Q, \quad s \in S, \quad t \in T. \tag{26}$$

Constraint (15):

$$q_{p,l.t}^{conv} \leq CAP_{p,l}^{conv}.y_{p,l}^{conv} + \sum_q \Delta_{q,p,l}^{conv}.xy_{q,p,l}^{conv}$$

$$\forall \; l \in L, \quad p \in P, \quad t \in T,$$

is equivalent to:

$$xy_{q,p,l}^{conv} \geq x_q + y_{p,l}^{conv} - 1 \qquad \forall \; q \in Q, \quad p \in P, \quad l \in L, \tag{27}$$

$$xy_{q,p,l}^{conv} \leq x_q \qquad \forall \; q \in Q, \quad p \in P, \quad l \in L, \tag{28}$$

$$xy_{q,p,l}^{conv} \leq y_{p,l}^{conv} \qquad \forall \; q \in Q, \quad p \in P, \quad l \in L. \tag{29}$$

4. Solution approach

The optimization model is formulated and solved by employing weighted global criterion method. This method replaces multiple objectives with a single objective by which the distance between each objective and its ideal amount is minimized. Weights (w_{NPD}, w_{risk}, w_{LS}) are used to indicate the three objectives with different degrees of significance. The optimization problem is formulated as follows:

$$\max \quad z = w_{NPD}.\frac{NPV - NPV^{\min}}{NPV^{\max} - NPV^{\min}}$$

$$+ w_{risk}.\frac{risk - risk^{\min}}{risk^{\max} - risk^{\min}}$$

$$+ w_{SL}.\frac{LI^{\max} - LI}{LI^{\max} - LI^{\min}}.$$

$X^{\min}$ and $X^{\max}$, $X \in \{NPV, Risk, LI\}$, represent the minimum and maximum quantities of X in payoff matrix. Payoff matrix is an $n \times n$ matrix in which element (i, j) shows the quantity of objective function j by optimizing the objective function i.

Table 2. Risks and related risk response strategies.

Risk	Risk responds strategies
1. Customers' acceptance	1. Proper understanding of customers' behaviors and needs; 2. Choosing correct marketing strategies (organized marketing channel); 3. Proactive market orientation; 4. Branding; 5. Giving explanation to customers (special explanation about what makes the product different from the previous ones and why they should buy it); 6. Advertising.
2. Competitors	1. Reducing the prime cost of product; 2. Lean manufacturing; 3. Using sales offer.
3. Wrong estimation of sales quantity as well as production cost in future, price elasticity, and price	1. Market research.
4. Problems of electricity distribution	1. Purchasing a power generator.
5. Problems of suppliers	1. Supervising suppliers; 2. Enhancing suppliers' knowledge; 3. Redundant supplier; 4. Interplant inventory sharing.
6. Order cancellation	1. Searching for new customers for each period (for every one percent of order cancellation in each period, one percent new distributor should be found each month).
7. Quality problems	1. APQA; 2. More experiments (proper control of incoming items and suitable structure design in laboratory); 3. ISO.
8. Natural disasters	1. Insurance; 2. Retrofitting the buildings; 3. Adding equipment.

4.1. Experimental study

To show performance efficiency of the proposed model, in this section, a hypothetical numerical example is illustrated. Consider a three-echelon SC operating in the beverage sector including six raw material suppliers, three plants, and nine distribution centers, which produces three products by using four raw materials. A new product will be developed by using existing facilities. First, NPD risks in an SC should be identified, measured, and prioritized. The risk response strategies for each risk should also be identified. The probabilities of the risk events and their impacts as well as the amounts of risk reduction after implementing risk response strategies need to be scored by knowledge of the experts. Some of the risks related to NPD in an FMCG supply chain are listed in Table 2.

It is assumed that demands for products are deterministic and have been made individually for three

Table 3. Parameters and intervals for their random values.

Parameter	$\pi_{s,l}^{trans}, \pi_{l,r}^{trans}$	$\varphi_{k,p}$	$\pi_{i,x}^{raw}$	$\pi_{i,x}^{store}$	$cap_{k,s}^{raw}$	$cap_{p,l}^{conv}$	$\mu_{k,s}^{raw}$
Range of values	(0.1,0.2)	(0,0.9)	(0,3.2)	(0,0.25)	(0,500000)	(15000,150000)	(0,100000)
Parameter	$\mu_{p,l}^{conv}$	$\pi_{p,l}^{sell}$	$\pi_{p,l}^{conv}$	R'_{wq}	R_w	$\Delta_{q,k,s}^{raw}$	$\Delta_{q,p,l}^{conv}$
Range of values	(3000,200000)	(4.45,10.6)	(0.19,2.2)	(0,0.06)	(0.25,0.33)	(0,25000)	(0,1000)

Table 4. Risk-related model input and interest rate.

Input variable	Variable name	value
W	Number of risks	10
Q	Number of response strategies	20
B	Total available budget	$3,000,000
R_w^*	Target value of risk w	0.199
π^{cap}	Cost of capital	0.2

Table 5. Total cost in each period.

	Variable name	t_1	t_2	t_3
cf_t	Cash flow	3096105	3189167	3201297
ci_t	Cash inflow	4378791	4425031	4390388

Table 6. Sales quantity of finished product.

$q_{p,r,t}^{sale}$ Finished product		t_1	t_2	t_3
p_1	r_1	7290.00	7790	6790
	r_2	31350	32350	30350
	r_3	41820	41820	42820.00
	r_4	104250	114250	1042.50
	r_5	20685.00	19685	21685.00
	r_6	52260	50260	53260
p_2	r_1	5220	6220	5720.00
	r_2	6455.333333	9440	10440.00
	r_3	26649.67	11910	0.00
	r_4	0	5000	16610
	r_5	5175	5675	5275
	r_6	0	5255	5455
p_3	r_1	3135.00	2635	3235
	r_2	12450	12450	11950
	r_3	31200.00	31200	31400
	r_4	72900.00	73900	71900
	r_5	5190.00	4690	5290
	r_6	6222	5722	5922
p_4	r_1	1041	891	941
	r_2	5235	4735	5835
	r_3	4170	4270	4370
	r_4	10440	10940	12440
	r_5	2091	1591	1791
	r_6	5235	5735	5335

periods. For parameters, random values are generated in given intervals. Table 3 shows the parameters and their random values.

Parameter $\Delta_{q,p,r,t}^{demand}$ shows the amount of increase in finished products sale caused by employing response strategies. It is assumed that this amount of increase is 10%. Strategies that affect sales are Strategies 1–10 and Strategy 15. Table 4 shows the rest of input data.

4.2. Results
This example has been solved by GAMS software. In Tables 5–15, optimal configurations of the proposed model are depicted for the considered example. Table 5 demonstrates cost variables. Table 6 refers to decision variables on sales quantity of the finished product in the sales centers.

Table 7 shows the appropriate storage quantity of finished product in plants and sale centers. The variable of decision on transportation is illustrated in Table 8.

Optimal raw material transportation quantity from suppliers to plants is given in Table 9. Table 10 presents raw material quantity supplied by each supplier and the optimal production of finished product quantity in each plant.

Table 11 represents the lost sale quantity of the finished product. To make it short, the variables not listed in the table have the value of zero.

4.3. Binary decision variables
After the model was run, all risk response strategies

Table 7. Storage quantity of raw material and products in different place and time.

$q_{i,x,t}^{store}$		t_1	t_2	t_3
Raw material k and finished product p	**Manufacturer l and distributer r**			
k_1	l_1	0	0	86464.3
k_2	l_1	0	0	583.50
k_2	l_2	1570.50	0	970.50
k_2	l_3	1817.2	0	1517.2
k_3	l_2		0	24369.10
k_3	l_3	25830.70	0	0
p_1	r_2	32350	0	0
p_1	r_3	0	0	42820
p_1	r_4	0	0	104250

were selected except for strategies number 4, 6, 7, 9, 15, and 16.

The results show that except for product 2, all the other products are produced in plant 1 and in selecting the suppliers, suppliers 1 and 4 in the first period; suppliers 1 and 5 in the second period; and suppliers 1, 4, and 5 in the third period have not been chosen.

Table 12 presents optimal values of objective functions and their weights.

5. Sensitivity analysis

To show the performance of the proposed model, a sensitivity analysis was executed for the numerical example. We considered changes in two financial parameters and capacity of raw material production.

Twenty percent of change in budget parameter allocated to risk mitigation was taken into account. Table 13 shows these changes.

As it is observed, if we rise the budget, the NPV and Risk reduction objectives would improve, but LI objective has the best amount at \$3,000,000. Figures 3 and 4 demonstrate the amounts of variation in the values of objective functions in relation to the change in the parameter of budget and show the sensitivity of the problem. The sensitivity of the objective functions to change in the budget parameter shows a conflict between the objective functions.

Now, assuming that the allocated budget is \$3,000,000, the sensitivity of the model to the other parameters is measured. Table 13 reveals that the amount of lost sale is high. Investigation of results shows that the amount of LI is related to product 2, because while there are demands for this product, there is no production. If raw material suppliers increase the raw material capacity of product 2, the
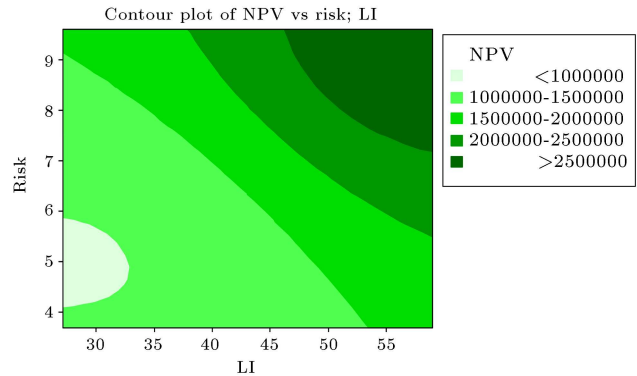
Figure 3. Pareto space contour chart.
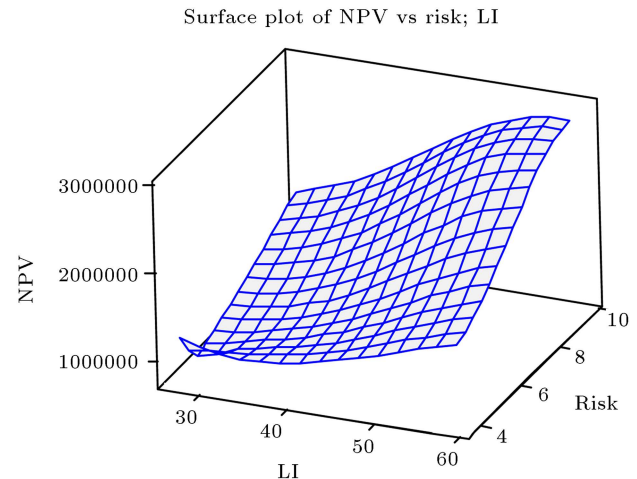
Figure 4. Pareto chart of budget changes.

LI objective function will be reduced. Therefore, in order to improve the LI objective function, capacity of suppliers needs to be increased or contracts with new suppliers must be closed. Table 14 shows these changes.

Table 8. Transportation quantity of finished product p from plant l to demand region r.

$q^{trans}_{p,(l,r),t}$					
Product p	**Manufacturer**	**Distributer**	t_1	t_2	t_3
p_1	l_1	r_1	7.29E+03	7790	6790
p_1	l_1	r_2	0		30350
p_1	l_1	r_3	0	42265.00	0
p_1	l_1	r_4	1.04E+05		0
p_1	l_1	r_5	8460	19685.00	0
p_1	l_1	r_6	0	50260	28260
p_1	l_2	r_3	41820	42375.00	0
p_1	l_2	r_4	0	132625	0
p_1	l_2	r_5	1.22E+04	0	0
p_1	l_2	r_6	5.23E+04	0	25000
p_1	l_3	r_2	63700	0	0
p_1	l_3	r_3	0	0	0
p_1	l_3	r_4	0	85875	0
p_1	l_3	r_5	0	0	21685
p_2	l_1	r_6	0	0	0
p_2	l_2	r_1	5220	6220	5720
p_2	l_2	r_2	6455.333	9440	0
p_2	l_2	r_3	0	11910	0
p_2	l_2	r_4	0	0	16610
p_2	l_2	r_5	5175	5675	5275
p_2	l_2	r_6	0	5255	5455
p_2	l_3	r_1	0	0	0
p_2	l_3	r_2	0	0	10440
p_2	l_3	r_3	26649.67	0	0
p_2	l_3	r_4	0	5000	0
p_3	l_1	r_1	3135	0	0
p_3	l_1	r_2	0	12450	11950
p_3	l_1	r_3	0	0	0
p_3	l_1	r_4	51453	47828	35035
p_3	l_1	r_5	5190	0	0
p_3	l_1	r_6	6222	5722	0
p_3	l_2	r_1	0	2635	3235
p_3	l_2	r_2	12450	0	0
p_3	l_2	r_3	31200	31200	31400
p_3	l_2	r_4	0	0	36865
p_3	l_2	r_5	0	4690	0
p_3	l_3	r_4	21447	26072	0
p_3	l_3	r_5	0	0	5290
p_3	l_3	r_6	0	0	5922
p_4	l_1	r_1	1041	752	
p_4	l_1	r_2	5235	1735	5835
p_4	l_1	r_3	4170		0
p_4	l_1	r_4	4440	10940	0
p_4	l_1	r_5	2091		0

Table 8. Transportation quantity of finished product p from plant l to demand region r (continued).

$q_{p,(l,r),t}^{trans}$					
Product p	Manufacturer	Distributer	t_1	t_2	t_3
p_4	l_1	r_6	0	5735	0
p_4	l_2	r_1	0	139	0
p_4	l_2	r_2	0	0	0
p_4	l_2	r_3	0	4270	4370
p_4	l_2	r_4	6000	0	0
p_4	l_2	r_5	0	1591	0
p_4	l_2	r_6	0	0	5335
p_4	l_3	r_1	0	0	941
p_4	l_3	r_2	0	3000	0
p_4	l_3	r_4	0	0	12440
p_4	l_3	r_5	0	0	1791
p_4	l_3	r_6	5235	0	0

Table 9. Transportation quantity of raw material k on transportation connection from supplier s to plant l.

$q_{k,(s,l),t}^{trans}$					
Raw material	Supplier	Manufacturer	t_1	t_2	t_3
k_1	s_1	l_1	0	0	24632.2
k_1	s_1	l_2	0	237000	152324.5
k_1	s_1	l_3	0	0	60043.3
k_1	s_2	l_1	0	0	0
k_1	s_2	l_2	170000	22175	0
k_1	s_2	l_3	0	113559.5	0
k_1	s_3	l_1	1.89E+05	277710.1	0
k_1	s_3	l_2	0	0	0
k_1	s_3	l_3	123463	0	0
k_2	s_4	l_1	1697.7	0	0
k_2	s_4	l_2	2170.5	0	0
k_2	s_4	l_3	2340.7	0	0
k_2	s_5	l_1	0	2499.7	0
k_3	s_6	l_1	18054.17	0	0
k_3	s_6	l_2	0	69500	0
k_3	s_6	l_3	51445.83	0	0
k_3	s_7	l_1	36941.23	55432.4	35898
k_3	s_7	l_2	41390.57	4384.1	29583.9
k_3	s_7	l_3	0	0	14018.1
k_4	s_8	l_2	0	4900	2812
k_4	s_8	l_3	4900	0	2088
k_4	s_9	l_1	0	0	0
k_4	s_9	l_2	3370.067	2800	3800
k_4	s_9	l_3	429.9333	1000	0

Table 10. Raw material quantity supplied by supplier and production quantity of the finished product.

$q_{k,s,t}^{raw}$					$q_{p,l,t}^{conv}$				
Raw material	Supplier	t_1	t_2	t_3	Product	Manufacturer	t_1	t_2	t_3
k_1	s_1	0	237000	237000	p_1	l_1	105250	32650	103840
k_1	s_2	170000	135734.5	0	p_1	l_2	103165	175000	127135
k_1	s_3	312742.3	277710.1	0	p_1	l_3	70465	42220	30650
k_2	s_4	6208.9	0	0	p_2	l_2	38275	15810	27635
k_2	s_5	0	2499.7	0	p_2	l_3	5225	27690	15865
k_3	s_6	69500	69500	0	p_3	l_1	39905	55357	54457
k_3	s_7	78331.8	59816.5	79500	p_3	l_2	71500	71500	71500
k_4	s_8	4900	4900	4900	p_3	l_3	20952	5000	5000
k_4	s_9	3800	3800	3800	p_4	l_1	7540	12135	5000
					p_4	l_2	25239	6000	22982
					p_4	l_3	3000	3000	3000

Table 11. Quantity of lost order of finished product p in demand region.

$q_{p,r,t}^{lost}$				
Finished product	Distributer	t_1	t_2	t_3
p_2	r_3	15410	15910	9695
p_2	r_4	73600	75600	74600
p_2	r_6	0	0	5515

Table 12. Optimal values of objective functions.

Objective function	Optimum
NPV	7976866.78
Risk	5.974
LI	2666954.4
Weight of objective	$w_{NPD} = 0.8$
	$w_{risk} = 0.048$
	$w_{LI} = 0.472$

Convention cost is changed in order to analyze the impacts of cost efficiency differences between production plants. Table 15 investigates the impact of changes in production costs on products 2 and 4 (new product). The production cost for product 2 is reduced by 20% and, in the next row, the production cost for product 4 in the three plants increases by 20%.

In Table 16, the changes in two parameters of pro-duction cost for product 2 and production capacity of raw material are simultaneously investigated. We aim to concurrently estimate the decrease in the amount of LI with these changes. Production costs drop by 20% and production capacity is doubled for the first and third raw materials and tripled for the fourth raw material.

As it is represented in Table 16, the NPV and LI objective functions have been significantly improved. These changes will result in an increase by 12.9% in NPV, a decrease by 78.8% in the LI objective function, and a decrease by 7.2% in the amount of risk objective function.

The changes of parameters and the observed results prove efficacy of the model and it can be concluded that the model is flexible enough.

5.1. More cases
To test the efficiency and robustness of the optimization procedure, more cases by multiplying some of the parameters are provided. Table 17 shows the results.

As it can be observed, by multiplying the parameters of the problem, the time of solving increases and the model will not be solved within a reasonable time. Meta heuristic algorithms can be used for solving such large-scale problems.

6. Conclusion and future work

New Product Development (NPD) works as a key for companies in different industries like Fast Moving Consumer Goods (FMCG) to succeed in the competitive market. On the other hand, developing a new product poses various risks to companies. The ability

Table 13. Changes in the budget allocated to risk mitigation.

Budget quantity	NPV objective (percentage of changes in NPV objective)	Risk objective	LI objective	Risk response strategies that are not selected (number of risks selected)	Producing finished product p_i in plant L_l (p_4 is new product)
$2,400,000	7,807,999.036 (−%2)	4.91	2,776,186.8	$q_2, q_4, q_6, q_7, q_9, q_{11,}, q_{13}, q_{16}, q_{17}$ (11)	(table) $L_1 L_2 L_3$ / p_1 • • • / p_2 • − • / p_3 • • • / p_4 • • •
$3,000,000	7,976,866.78 (%0)	5.97	2,666,954.4	$q_4, q_6, q_7, q_9, q_{15}, q_{16}$ (14)	(table) $L_1 L_2 L_3$ / p_1 • • • / p_2 − • • / p_3 • • • / p_4 • • •
$3,600,000	7,993,532.23 (+%0.2)	6.73	2,735,622.24	$q_4, q_7, q_{15},$ (17)	(table) $L_1 L_2 L_3$ / p_1 • • • / p_2 − • — / p_3 • • • / p_4 • • •

Table 14. Effect of changes in raw material capacity on the results.

Amount of increase in raw material production capacity	NPV objective (percentage of changes in NPD objective)	Risk objective	LI objective	Producing finished product p_i in plant L_l (p_4 is new product)	Finished product lost sales in six distributers in each period
Production capacity of the raw material for 1, 3, and 4 doubles	8,523,305.015 (+%6.8)	5.97	1,626,847.2	(table) $L_1 L_2 L_3$ / p_1 • • • / p_2 • • • / p_3 • • • / p_4 • • •	(table) t_1 t_2 t_3 / p_1 ⋮ 0 0 0 / p_2 r_4 54010 56510 54810 / p_3 ⋮ 0 0 0 / p_4 ⋮ 0 0 0

to respond to and mitigate those risk events puts a company ahead of its rivals and reduces the expected long-term damage to its business. Given these tips, this paper aimed to identify a new model for a multi-echelon, multi-product, multi-source, and multi-period optimization model for Supply Chain (SC) configuration and NPD with risk management. To determine the adequate SC configuration, three levels of decision

should be made, namely strategic, tactical, and operational, to optimize the expected profit, level of risk, and consumer satisfaction based on the classifications discussed in [20,10,7]. The strategic decisions involved the quantity and place of distribution centers for distributing new products. The tactical decisions were production rate of each selected factory to produce a new product in addition to the old ones and the

Table 15. Changes in conversion cost of final products 2 and 4.

Amount of changes in conversion cost	NPV objective (percentage of changes in NPD objective)	Risk objective	LI objective	Producing finished product p_i in plant L_l (p_4 is new product)	Average of finished product lost sales in six distributers in each period
A 20% reduction in the conversion cost of product 2 in all factories	7,987,297.88 (+%0.13)	5.97	2,669,771.4	(see matrix A1)	(see matrix A2)
An increase by 20% in the conversion cost of product 4 (new) in all factories	7,817,166.49 (−%2)	5.97	2,667,793.08	(see matrix B1)	(see matrix B2)

Matrix A1 (Producing finished product):

	L_1	L_2	L_3
p_1	•	•	•
p_2	•	−	•
p_3	•	•	•
p_4	•	•	•

Matrix A2 (Lost sales):

	t_1	t_2	t_3
p_1	0	0	0
p_2	22252.5	45755	44905
p_3	0	0	0
p_4	0	0	0

Matrix B1 (Producing finished product):

	L_1	L_2	L_3
p_1	•	•	•
p_2	•	−	•
p_3	•	•	•
p_4	•	−	•

Matrix B2 (Lost sales):

	t_1	t_2	t_3
p_1	0	0	0
p_2	44505	45755	22452.5
p_3	0	0	0
p_4	0	0	0

Table 16. Effect of changes in production cost and raw material capacity on the results.

Changes in production capacity and production cost simultaneously	NPV objective (percentage of changes in NPD objective)	Risk objective	LI objective	Producing finished product p_i in plant L_l (p_4 is new product)	Average of finished product lost sales in six distributers in each period
Production capacity for raw materials 1 and 3 is doubled and for the fourth raw material tripled. Production costs drop by 20%.	9,009,291.82 (+%12.9)	5.54	564,292.2	(see matrix C1)	(see matrix C2)

Matrix C1 (Producing finished product):

	L_1	L_2	L_3
p_1	•	•	•
p_2	•	•	•
p_3	•	•	•
p_4	•	•	—

Matrix C2 (Lost sales):

	t_1	t_2	t_3
p_1	0	0	0
p_2	8875	20250	6183.3
p_3	0	0	0
p_4	0	0	0

Table 17. Another case with larger dimensions.

Case	Suppliers	Plants	Distributers	Raw materials	Finished products	NPV ($)	Risk	LI ($)	Goal programming Objective	Time (s)
1	9	3	6	4	4	$1.565*10^6$	10.114	$1.974*10^5$	0.820	5.95
2	36	12	12	4	8	$4.356*10^7$	10.199	$1.141*10^7$	0.851	127.65
3	144	48	24	4	16	$2.604*10^8$	20.167	$3.026*10^8$	0.95	1705.9

appropriate risk response strategies. The operational decisions were the transportation quantity of new and present products in the new network and the essential inventory levels in each factory and distribution center. Tactical as well as operational decisions–i.e. how much to source, produce, and sell–had to be made upon the product-plant allocation and decisions on choosing the best mitigating risk response strategies were made by running the model. The impact of each risk response strategy on capacity of suppliers, factories, and demand was included in the model. It was solved by GAMS software.

Sensitivity analysis showed the impact of some different parameters on the objectives. It showed significant improvement in all objective functions by increasing raw material capacity of suppliers and decreasing production costs. By increasing the budget allocated to risk mitigation, an improvement in NPV and Risk objectives was observed, but the Lost Income (LI) increased. This occurred because when the budget increased, the quantity of mitigation strategies rose from 11 to 17. That is, adopting some risk response strategies related to increase in demand raised LI.

The model is capable to reconfigure an SC in the presence a new product. For future research, taking a solution approach for large-scale instances of the proposed model can be of significance. As another suggestion, the problem can be investigated with stochastic parameters such as demand, cycle times, and price.

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