A new multi-objective model of agile supply chain network design considering transportation limits

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ABSTRACT
In this research, a triple-objective model with the assumption of multi-material and multi-product in five stage of supply chain network (SCN) is introduced. A five-stage supply chain network includes the following: supplier, manufacturer, retailer and distributor as well as customer zone. The goal is to determine production and supply quantity in each node of supply chain network under stochastic demand of a competitive market. The first objective is minimizing the expenses such as transportation, inventory, shortage and production. The second objective is minimizing the risks in each node as well as route of supply chain network which means considering customer risk in each customer zone and making a connection with supplier zone regarding the SCN routes. The third objective is maximizing flexibility which leads to a restraint model in fluctuation of the market demand. Having the constraints in mind, transportation volume, transportation speed and transportation vehicle are taken into account. The capacity of production is considered with respect to the demands of nodes in the next stage. The inventory and shortage are considered as the constraints of the step. In the final step, a network with different number of nodes is designed which brings about the use of modified NSGA-II regarding the multi-encoding. The results display flexibility effect in supply chain network which dominates the uncertainty situation of the market and a better restraining approach for SCN.

1. Introduction
In recent years, the competitive conditions have led to a number of challenges in companies all over the world in various industries such as production amount and its delivery to ultimate customers. In spite of the very important issues, companies need to consider some other constraints as well. The competitive and dynamic marketplaces have led the companies to design supply chain networks. According to Deloitte Consulting (1999), experts of various large industries in America and Canada comprising automotive, high tech and consumer product industries believe that in the upcoming future, the whole SCs will compete with each other instead of competition among individual firms. To this end, each and every company concerns the local markets and...
the type of industry in competition with other companies. However, a large number of companies might not consider all the stages of supply chain network and just concentrate on the supplier and manufacturer stages.

Rice and Hoppe (2001) believe ‘The conventional wisdom is that competition in the future will not be company vs. company but SC vs. SC’. In fact, all the parts of supply chain network are equally important and the selection in each stage must be considered in detail. The Delphi study on ‘SC vs. SC’ explains the perception of competition in supply chain network. Integrated supply chain management (ISCM) Program at the Massachusetts Institute of Technology (MIT) conducted a Delphi study with more than 30 supply chain experts from industries, academia, and consulting. The study found that 70 percent agreed the supply chain vs. supply chain have accurately characterized the competitive future. They believed that companies will compete as supply chain network, a master channel/ a sub-master channel, or as an individual company based on its supply chain capabilities. The study also found some companies that are vertically integrated such as Zara which competes based on its supply chain network against the master channel (The limited) and also against other retailer like The Gap which are parts of an interconnected supply chain network but the very competition is based on their own supply chain capabilities.

Farahani et al. (2014) introduced the major features of proposed models in both supply chain network design (SCND) and competition structure. According to Zanjirani Farahani, the goal of SCND is to design an efficient network structure for entities of a new chain or reengineering an existing network to increase its total value. In this step, various decisions on the number of chain tires, location, and facilities capacity in each tire as well as the flow of material/product throughout the network are made. The condition of market and business usually determines some of the variables exogenously. The SCND is classified into (1) lean SC, (2) agile/responsive SC, (3) Green SC and (4) sustainable SC. In this paper, an SCND model is introduced by an agile/responsive approach. On the one hand, the flexibility parameter was introduced as nodes ability to modify the level of products in supply chain network and on the other hand, reconfiguration was made by exchanging products between partners in each stage.

The other aspect of supply chain network which was considered in the model is agile manufacturing approach. According to Gosling, Purvisa, and Naima (2010), agile manufacturing has been introduced as a concept to satisfy demands for low-volume and high variety products. By integrating computer systems, hardware and information flows, automated manufacturing systems provide agile manufactures with flexibility and reconfigure ability, in which flexibility is a manufacturing ability to adjust customers’ preferences and reconfigure ability is the ability to meet the changing demands by reconfiguring the structure of the system.

Wilson (2007) has investigated the effects of transportation disruption on supply chain performance using dynamic solution. The results have shown that the transportation between suppliers and manufacturer warehouse is the biggest problem in supply chain. Gedik, Medal, Rainwater, Pohl, and Mason (2014) studied the impact of transportation on supply chain network. The study has shown that the number of disruption has almost no impact on transportation cost if several good alternative routes in the supply chain network could be used. Regarding the study conducted by Gedik et al. (2014), the idea of which rout is better than the other is used. Moreover to the
assumption of using different vehicles for forwarding shipments. This was intended to reduce transportation disorder in SCN, transportation volume, and speed are considered as constraints in this study.

Sarkar, Ganguly, Sarkar, and Pareek (2016) studied the effect of variable transportation in a three-echelon supply chain model. A three-supply chain model by which the supplier can make semi-finished products as spare or extra for the final product and transport them to the manufacturer for using in finished products. The aim of the study was to reduce costs of supply chain by considering variable transportation. In order to improve the presented model by Sarkar et al. (2016) on one hand, three aspects of transportation were introduced to minimize the costs in the total supply chain and to avoid disorders in transportation simultaneously. On the other hand, multi-products with different volume were considered which must be sent by three types of vehicles with different capacity of transportation. As an example, a truck can accommodate 50 m$^3$ of goods. The very limits of transportation affect supply chain delivery time, risk, and flexibility directly.

In this paper, a supply chain network is introduced with the consideration of agile manufacturing approach. The model is consisted of five echelons: supplier, manufacturer, distributor, retailer, and customer zone. In each stage, three relations among partners are to be considered: straight, jumping, and sharing. In this model, production capacity, transportation capacity, number of transportation, speed of transportation between nodes, inventory capacity, inventory level, shortage level, network connection (connection between stages), and risk and material limitation are considered. The model is designed for multi-products and three main objectives of the model are as follows: minimizing cost, risk simultaneity, and maximizing flexibility.

The aims of companies to reach to a better position in market when sanction is severe and also to avoid demand fluctuation lead them to finding a solution to conquer this matters. We presented our model to help small firms in supply chain networks to see the big picture and help other identical firms in their stage or other stages of SCN. On the other hand, big companies must understand that the supply chain network nodes are not islands in the ocean; nevertheless, they are a part of the main companies and as a part of family they must have the same goal. However, many companies know these facts but the real work begins after knowing. How can they sell their products when the market collapses? The main answer in our research to this question is we must divide our customer zone and make a decision based on each one of the customer zone and implementing this task comes from integrated SCN which is introduced in our paper with respect of new relation in each stage of SCN.

2. Literature review

2.1. Supply chain network

Jang, Jeng, Chang, and Park (2002) proposed an optimized supply network design model and a planning scheme of production and distribution activities that are modeled as three decomposed mathematical formulation. However, the complete procedure appears complex and needs a genetic algorithm procedure to generate the final integrated production distribution plan. In another study, Talluri and Baker (2002)
considered a three-phase approach to design an MSC. Nevertheless, the network design procedure does not consider the transportation connections among the stages in the network design and the routing material is analyzed in the third phase only.

Zanjirani Farahani and Elahipanah (2008) introduced a bi-objective model for distribution network of a three-echelon supply chain, with two objective functions: minimizing costs and minimizing the sum of backorders and surpluses of products in all periods. Delivery lead times and capacity constraints are also considered in a multi-period, multi-products and multi-channel network. A hybrid non-dominated sorting genetic algorithm is applied to solve real-size problem of this mixed-integer linear programming model. In the same vein, Elhedhli and Goffin (2005) addressed a production–distribution system design problem involving three echelons including plants, distribution centers (DCs) and customer zones. An integrated model was developed accepting a single-sourcing policy to minimize distribution, production, handling and transportation costs as well as the fixed costs of opening DCs. The major novelty of the paper was a two-level Lagrangian relaxation approach.

Costantino, Dotoli, Falagario, Fanti, and Mangini (2012) presented a technique for strategic management of the chain addressing supply planning and allowing the improvement of the MSC agility in terms of ability in reconfiguration to meet performance. A digraph modeling and integer linear programming were enhanced to optimally design the MSC. The original approach avoids supply chain disruption and stock out and at the same time can manage spare parts distribution. It was considered that MSC contains different stages: typical stages are, for instance, suppliers, manufacturers, distributors, retailers and final customers. In the model, partners of different MSC stages are connected by two types of links: direct links and jump links. The important constrains of the presented model include production capacity, transportation capacity and connection between nodes, in which manufacturer can provide a certain quantity of materials (or component) to each partner in next stage or final customer, but no providing material and products from partners were considered in each stage.

In another study, Pan and Nagi (2013) assume that manufacturing sequence is fixed, materials are processed through a series of echelons and there is only one operation in each echelon. The main objective of the model was the selection of companies in each echelon to form the supply chain network. Note that a company can be qualified to perform multiple operations with corresponding production capacity and cost. Formulation of the problem integrating all decisions was done in order to minimize the total operational costs including fixed alliance costs between two companies’ production, raw material holding, finished products holding, as well as transportation costs under production and transportation capacity limits. A Lagrangian heuristic is proposed and used to solve the model.

Yu and Goh (2014) specifically considered the context of selection of supplier which has to strategically meet a triple objective of cost, risk and visibility for the downstream of supply chain. A planned budget for all suppliers, minimum amount of visibility for each part, fulfillment of the demand quantity, capacity constraint for each supplier, maximum allowable supply risk for each supplied part by supplier, and minimum order quantity were taken into account and the integrality on the decision variables was maintained. The model had three main objectives: supply chain visibility (SCV) maximization, supply chain risk (SCR) minimization and cost minimization.
Accordingly, Sarrafha, Seyed Habib, Rahmati, Niaki, and Talab (2014) developed a multi-periodic structure for SCND involving suppliers, factories, DCs, and retailers. The nature of the logistic decisions is tactical that encompasses procurement of raw materials from suppliers, production of finished product at factories, distribution of finished product to retailers via DCs, and storage of raw material and end product at factories and DCs. The two objectives are minimizing the total SC costs as well as minimizing the average tardiness of product to DCs. The obtain model is a bi-objective mixed-integer non-linear programming (MINLP). The model was solved by a novel algorithm, called multi-objective biogeography-based optimization (MOBBO) to find a close optimum solution. The study has shown three-echelon supply chain networks that are NP-Hard class of optimization problems; therefore; NSGA-II was used in order to solve five-echelon supply chain network in this paper.

Pasandideh, Niaki, and Asadi (2014) introduced a model that is bi-objective optimization of multi-product, multi-period, three-echelon supply chain network consisting of manufacturing plants, DCs each with uncertain services, and customer nodes. The two objectives are minimization of total cost while maximizing the average number of products dispatched to customers. The decision variables are as follows: (1) the number and the locations of reliable DCs in the network, (2) the optimum number of item produced by plants, (3) optimum quantity of transported products, (4) the optimum inventory of products at DCs and plants, and (5) the optimum shortage quantity of the customer nodes. The problem was formulated into the framework of a constrained bi-objective mixed-integer linear programming model, and then it was solved using the GAMS software. In another study, Reza Pasandideh, Akhavan Niaki, and Asadi (2014) introduced a bi-objective optimization of a multi-product, three-echelon supply chain network problem. To make the problem more vivid in reality, the majority of the parameters in the network, including fixed and variable costs, customer demand, available production time, set-up production times, are considered stochastic. A non-dominated sorting genetic algorithm (NSGA-II) is used to solve the complicated problem.

Bandyopadhyay and Bhattacharyya (2013) proposed the modification of an existing multi-objective evolutionary algorithm (MOEA) known as non-dominated sorting genetic algorithm- II (NSGA-II). The proposed algorithm was applied on a tri-objective problem for a two-echelon serial supply chain. The considered objectives are as follows: (1) minimization of the total cost of a two-echelon serial supply chain, (2) minimization of the variance of order quantity and (3) minimization of the total inventory.

Quddus, Chowdhury, Marufuzzaman, Fei, and Bian (2017) studied about the stochastic programming model in supplier chain network in which multi-model facility was represented due to uncertainties situation. Furthermore, Chatzikontidou, Longinidis, Tsiakis, and Georgiadis, Michael (2017) introduced a flexible supply chain network model that uses generalized production/warehouse nodes instead of individual production plants and warehouses while conquer with demand uncertainty using a scenario-based approach and tactical levels (facility location, production rate..) which in our research we add the vehicle routing problem to this model and also we changed basically the levels and how supply chain should response to market demands.
3. Model description and formulation

3.1. Assumptions

In this paper, a five-echelon SCN was designed, as shown in Figure 1. This network consisted of suppliers (first stage), manufacturers (second stage), distributors (third stage), retailers (forth stage) and customer zone (fifth stage). The main assumptions involved in this problem are as follows:

(0) Raw material was considered in supplier stage.
(1) The chain has multi-products structure
(2) The supplier stage supplies materials with respect to each product for each manufacturer
(3) Each node in supply chain network could be connected to other nodes in current stage or next stage
(4) The demands of nodes are stochastic
(5) The manufacturing plants production and storage area are limited
(6) The shortage is allowable in each nodes of network.
(7) The customer zone is considered as echelon.

Figure 1. Supply chain network example.
3.2. Model diagram

The supply chain network structure is represented by \( E = (N, A) \), where \( N \), the set of nodes, represents suppliers, manufacturers … and \( A \), the set of arcs, refers to the possible connections between some nodes. In this paper, connection between nodes is classified as three kinds of relation: (1) straight relation, (2) jumping relation and (3) internal relation or sharing relation. The internal relation in each stage means that partners can share their products to satisfy the demands of themselves. As can be seen in Figure 1, the raw material goes to a manufacturer from suppliers with straight relation. In manufacturer stage, raw material will be altered to products, meaning that the production process will have been conducted in this stage. Furthermore, the products go into the DC in each part of the supply market. In the next step, the products will be forwarding from distributor (Node 10) to retailers and, respectively, to final customers (Node 17) in which there is a jumping relation between nodes. The distributions in real world are complicated; for example, retailer 1 (Node 14) supplies retailer 2 (Node 13) by sharing relation in order to avoid shortage. The main objective of sharing relation is to imply that retailers could be in role of distributors and could use emergency protocol for avoiding losing customers.

The interaction between Nodes 13 and 14 is the example of internal relation in retailer stage. The connection between Nodes 1 and 4 is example of straight relation, and in the end the relation between Node 10 (in distributor’s stage) and Node 17 (in final customer’s stage) is the example of jumping relationship.

Customer zone stage is the last stage but not the least important one in SCN. Customer zone is considered as an independent part because of its effects on total productivity in network. Customers can be divide into different zones due to their taste, choice and regions. For instance, Asus laptops have much more sale in Iran rather than HP laptops, but the result in another country like Italy is different. Considering customer zone as a stage would help companies to increase their sale rate with respect to customer desire.

3.3. Formulation

A triple-objective mixed-integer non-linear mathematical formulation of the problem is proposed for supply chain network. The model introduced in this part uses the following notations including indices, parameters, and decision variables.

**Set of indices:**

- \( P \) The set of indices \{\( p = 1, 2 \ldots P \)\} for products.
- \( I \) The set of indices \{\( I = 1, 2 \ldots I \)\} for initial nodes in arcs.
- \( J \) The set of indices \{\( j = 1, 2 \ldots J \)\} for end nodes in arcs.
- \( M \) The set of indices \{\( m = 1, 2 \ldots, M \)\} for raw material.
- \( N \) The set of indices \{\( n = 1, 2 \ldots, N \)\} for number of nodes.
- \( T \) The set of indices \{\( t = 1, 2 \ldots, T \)\} for number of transportation vehicles.
Parameters:

\( C_p^n \)  Unit production cost of product by manufacturer (in manufacturing node) or cost of sales (in distributor and retailer node)

\( F_m^p \)  Factor making of product p from raw materials

\( T_{rij} \)  Unit transportation cost of volume of products from node i to node j

\( V_c^j_t \)  Cost of vehicle t in transportation form node i to node j

\( P_r_c_i^p_m \)  Capacity of manufacturer n to produce product p, manufacturer nodes

\( D_{rij} \)  Distance between node i and node j

\( I_{cn} \)  Inventory cost of product p in node n

\( I_{cm}^m \)  Inventory cost of material m in node n

\( V_p \)  Volume of product p

\( V_m \)  Volume of material m

\( I_{pcn} \)  Inventory planet cost in node n. (fix cost of using warehouse)

\( I_{vc}^n \)  Inventory volume of warehouse w in node n

\( S_{chc}^n_p \)  Shortage cost of product p in node n

\( S_{chm}^n_m \)  Shortage cost of material m in node n

\( V_{esij} \)  Vehicle speed of transportation product p from node i to node j

\( R_p^n \)  Risk product p in node n

\( B_p^n \)  Benefits of producing (distributing) product p to catch share of market in node n

\( W_{D_{ij}} \)  Weight of demand product p from node i to node j

Decision variables:

\( x_p^n \)  Quantity of product p produce in node n (n \( \notin \) supplier)

\( x_m^n \)  Quantity of material m in node n (n \( \in \) supplier or manufacturer)

\( x_{ij}^p \)  Quantity of product p transport from node i to node j

\( n_{Ve}^t_i \)  Number of vehicle t in node n

\( n_{I_{pcn}} \)  Number of inventory planet in node n

\( n_{sh_p}^n \)  Quantity of shortage product p in node n

\( n_{sh_m}^n \)  Quantity of shortage material m in node n

\( Y_{ij} \)  the past between nodes

Formulation:

\[
\text{Min } z_1 = \sum_{n=1}^{N} \sum_{p=1}^{P} C_p^n \times x_p^n + \sum_{n=1}^{N} \sum_{p=1}^{P} V_p^n \times I_{cn}^p \times x_p^n + \sum_{n=1}^{N} \sum_{m=1}^{M} V_m^m \times I_{cm}^m \times x_m^n \\
+ \sum_{n=1}^{N} I_{pcn} \times n_{I_{pcn}} + \sum_{n=1}^{N} \sum_{p=1}^{P} S_{chc}^n_p \times n_{sh_p}^n + \sum_{n=1}^{N} \sum_{m=1}^{M} S_{chm}^n_m \times n_{sh_m}^n \\
+ \sum_{i=1}^{I} \sum_{j=1}^{J} \left( \sum_{p=1}^{P} x_p^n \times V_p^n \times V_c^{ij} \right) + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{p=1}^{P} T_{rij} \times V_p^n \times x_{ij}^p \times \text{dis}_{ij} \times Y_{ij} \\
+ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} V_c^{ij} \times n_{Ve}^t_i \\
(1)
\]
\[
\text{Max } z_2 = \sum_{n=1}^{N} \sum_{p=1}^{P} B_n^p \times x_n^p
\]

(2)

\[
\text{Min } z_3 = \sum_{n=1}^{N} \sum_{p=1}^{P} R_n^p \times x_n^p + \sum_{n=1}^{N} \sum_{m=1}^{M} r_n^m \times x_n^m
\]

(3)

\[x_n^m \leq \sum_{p=1}^{P} x_n^p \times Fr_n^p \quad \forall \text{ each node}(n)
\]

(4)

\[\sum_{n \in \text{manufacturer}} \sum_{p=1}^{P} x_n^p \times Fr_n^p \leq \sum_{i} \sum_{j} \sum_{m=1}^{M} \text{Cas}_{ij}^m \quad \{j \in n \in \text{manufacturer} \quad i \in \text{ suppliers}
\]

(5)

\[x_n^p \leq \text{Prc}_n^p \quad \forall p, n \in \text{manufacturer}
\]

(6)

\[
\sum_{i=1}^{I} \sum_{j=1}^{I} \sum_{p=1}^{P} x_{ij}^p \times WD_{ij}^p \leq \sum_{i=1}^{I} \sum_{j=1}^{I} \sum_{p=1}^{P} mD_{ij}^p + \text{varD}_{ij}^p,
\]

(7)

\[
\begin{cases}
\sum_{i=1}^{I} \sum_{j=1}^{I} \sum_{p=1}^{P} V^p \times x_{ij}^p + \sum_{i=1}^{I} \sum_{j=1}^{I} \sum_{m=1}^{M} V^m \times x_{ij}^m \leq \text{Tr}_{t} \times nV_{ij}^t \quad \forall t, \text{for each } ij \\
\text{Tr}_{t} \leq \sum_{i=1}^{I} \sum_{j=1}^{I} \sum_{p=1}^{P} V^p \times x_{ij}^p + \sum_{i=1}^{I} \sum_{j=1}^{I} \sum_{m=1}^{M} V^m \times x_{ij}^m \leq \text{Tr}_{t+1} \times nV_{ij}^t \\
\text{...}
\end{cases}
\]

(8)

\[
\begin{cases}
\sum_{p=1}^{P} V^p \times x_{ij}^p \leq IV_{w}^n \\
IV_{w}^n \leq \sum_{p=1}^{P} V^p \times x_{ij}^p \leq IV_{w+1}^n \\
\text{...}
\end{cases}
\]

(9)

\[X^p_{ij} \leq M \times Y_{ij}
\]

(10)

\[
\begin{cases}
Y_{ij} = 1 \\
Y_{ij} = 0
\end{cases}
\]

\[
\begin{cases}
\text{if } i \in \text{supplier stage and } j \in \text{manufacturer} \\
\text{if } i \in \text{manufacturer stage and } j \in \text{manufacturer or distributer} \\
\text{if } i \in \text{distributer stage and } j \in \text{distributer or retailer} \\
\text{if } i \in \text{retailer stage and } j \in \text{final customer} \\
\text{other wise}
\end{cases}
\]

(11)
\[ X_n^p + nsh_n^p = \sum_{i=1}^{I=I=n} \sum_{j=n}^{mD_{ij}^p + \text{var}D_{ij}^p} \quad \forall \text{ for each } n, p \quad (12) \]

Equation (1) represents the first objective function of our problem that minimizes cost. This objective minimizes cost of production, holding inventory, volume of inventory (warehouse capacity), shortage, transportation vehicle, transportation cost (regarding distance), and vehicle speed (considering speed of transportation with respect to distance).

Equation (2) represents the second objective function that maximizes the production of different products and their delivery to customers; in other words, it indicates flexibility of SCN to meet customer demands and maximizing reconfiguration in the same way.

Equation (3) represents the risk objective function that minimizes the risk of each node of supply chain according to quantity and type of products.

Constraint (4): it refers to the quantity of raw material for producing products.

Constraint (5): it shows the number of materials used to produce products in manufacturer nodes and qualifies supply materials. “Fm p” parameter shows the contents of each product which is made with raw materials.

Constraint (6): it is known as step-by-step constraint that is a chain limitation just as the last one, which controls the inventory of products in each node due to storage capacity.

Constraint (7): it defines quantity of products in each nodes of supply chain network and satisfaction of product demand in nodes from manufacturer stage to final customer stage.

Constraint (8): it refers to a series of constraints that are related to each other. If the volume of transportation was less than the first vehicle, the first vehicle would be used for transportation; otherwise the next vehicle with more accommodation will be used. The optimized combination of transportation will be chosen in this part.

Constraint (9): it refers to a series of constraints that are related to each other. This constraint is known as step-by-step constraints. If one of them is not satisfied with the answers, it would go to the next constraint until satisfaction will be completed. This constraint is used for inventory of warehouses.

Constraint (10): it represents possible network relationship in supply chain network and insures possible path between nodes.

Constraint (11): it represents the shape of five-stage supply chain network.

Constraint (12): it has mean demand and variance of demand in each node; it refers to the shortage of each product in each node of supply chain network.

Constraint (13): it implies the shortage of each raw material in initial nodes (supplier or manufacturer) with respect to mean and variance demand.

Constraint (14): it shows the relation of each node from the first stage to second stage, and indicates an amount of product in each node that is transmitted by the related nodes.

Constraint (15): it refers to all decision variables that must be non-negative.

\[ X_n^m + nsh_n^m = \sum_{i=1}^{I=I=n} \sum_{j=n}^{mD_{ij}^m + \text{var}D_{ij}^m} \quad \forall \text{ for each } n, m \quad (13) \]

\[ X_{ij} \times Y_{ij} \leq X_n^p \quad \forall \text{ for each } n, p \quad , j = n \quad (14) \]
4. Solving approach

The nature of the problem is a triple-objective mixed-integer non-linear mathematical model which has several constraints. GAMS software could not solve it in large scale and in a recent research by Keyvan Sarrafha (Elhedhli & Goffin, 2005), it has shown that the three-echelon supply chain network belongs to NP-Hard problems, so NSGA-II is used. Due to the nature of the problem with two different encodings in which the first one belongs to raw material and the other one is related to products. The NSGA-II was developed to work with multi-encoding solution and alter in each stage because of the dimension of the problem in each stage. In fact, the solution dimension changes due to the number of nodes in current stage and the next one. The multi-encoding NSGA-II was introduced as a solution to dominate multi-encoding problem.

4.1. NSGA-II

NSGA-II was first introduced by Deb, Pratap, Agerwal, and Meyarivan (2002), which is one of the most applicable and propounded algorithms based on GA to solve multi-objective optimization problem. NSGA-II starts generating a random parent population of size nPop. During several consecutive generations, the objective values of a population are evaluated by using an evaluation function. Then, population is ranked based on the non-domination sorting procedure to create Pareto fronts. Each individual of the population under evaluation obtains a rank equal to its non-domination level (1 is the best level, 2 is the next best level, and so on), where the first front contains individuals with smallest rank, the second front corresponds to individuals with the second rank, and so on.

4.2. Multi-encoding

The proposed model has two important decision variables that all the responses depend on them: quantity of raw material and quantity of each product. The raw materials are transported from supplier stage to manufacturer stage and then changed into final products. Because of the very action, a new encoding must be added to the network, so a new approach was introduced to change one encoding into another. The example of this action is shown in Tables 1 and 2. Table 1 indicates the material from supplier stage which is received from two manufacturers and in the manufacturer section it was changed into products. Production in manufacturer will be done with respect to FM parameters. FM parameters are the amount of each material which is needed to produce goods:

\[
X_i^p, X_p^m, X_j^p, nVe'_{ij}, nIp_n, nsh^p_n, nsh^m_n \geq 0
\]

(15)

| Mat01 | Mat02 | Mat03 | Mat04 | Mat05 |
|-------|-------|-------|-------|-------|
| 208   | 419   | 2026  | 4407  | 998   |
| 193   | 497   | 3519  | 2433  | 1061  |

Table 1. Raw material in manufacturer.
\[ FM^1 = [0 \ 0 \ 1 \ 2 \ 3], \quad FM^2 = [0 \ 1 \ 2 \ 1 \ 0], \quad FM^3 = [1 \ 2 \ 0 \ 1 \ 0], \quad FM^4 = [0 \ 0 \ 1 \ 2 \ 3], \quad FM^5 = [1 \ 0 \ 2 \ 1 \ 0]. \quad Mat01 \times FM^1, \ldots = Pr01, \ldots \]

Example: Number of supplier = 3, Number of manufacturers: 2, Number of raw material = 5, Number of products = 5.

Another kind of encoding change in the presented method is in transportation from one stage to the next one. This action alters the dimension of encoding. For example, the transportation of products from manufacture to distributors. The dimension of encoding changes with respect to the number of distributors and it will be done until the end of supply chain. Figure 2 shows the approach of changing encoding from the beginning of supply chain network.

![Figure 2. Supply chain network encoding.](image-url)
4.3. Selecting crossover and mutation

The complexity of encoding in the problem brings about the idea of a new way for crossover and mutation. Taking each and every stage into account, [0 1] is divided in this approach. The supply chain network has five stages (n) and then [0 1] is divided into four parts (n – 1) (with the notice that the 0–1 period is divided into four parts). A random number between [0 1] will be produced, and taking the random number into consideration, the crossover and the mutation will be done in that stage. The changes from the selected stage come to the other stage as whip move until changes are done in the entire supply chain network. Figure 3 shows the selecting crossover and mutation approach.

4.4. Modified NSGA-II

The modified multi-encoding NSGA-II (MENSGA) is introduced to solve the problem with modification of multi-encoding and selecting crossover and mutation. MENSGA starts generating random parent with respect to initial population size. The initial population is evaluated by none sorting function. The new generation will be produced from the old generation regarding none sorting function. The stage will be selected with a random number, then crossover and mutation are used in order to produce new generation. Moreover, non-dominate sorting will be used again for ranking solutions. This procedure will be repeated until the stop condition is reached (Figure 4). Multi-encoding NSGA-II.

Step1: Generating random parent. (Multi-Encoding).

Step2: Evaluate initial population with non-dominate sorting for three main objectives.

Step3: Selecting stage to implement crossover and mutation.

Step4: Evaluate new generation with non-dominate sorting.

Step5: Repeat the loop until the satisfaction of stop condition.

5. Numeric example

5.1. Examples

The numeric example of supply chain network is consisted of three suppliers, two manufacturers, six distributors, ten retailers and four final customer nodes. The entire supply chain network contains 25 nodes which have relation with each other to satisfy the demands of final customer’s regions. The model is solved with Modified NSGA-II which is represented in Section 4.4. In order for solving problem, MATLAB 2016 was used, solving time with respect to the size of problem is 6 min and 05 s, with 5 iterations in main loop and 50 iterations in Pareto function (subsidiary loop). The assumptions of numeric example are as follows:

- The assumption of demand parameters is changing between 1000 and 10,000 for each product and with different variance with respect to each node (Table 3).
- Distance parameters between nodes are assumed to be between 100 and 1000 km (Table 4).
- Pareto size number is 50.
- Risk parameters (Tables 5–8).
### Figure 3. Selecting crossover and mutation approach.
Evaluate initial population with non-dominant sorting for three main objectives

Selecting stage for implementing crossover and mutation

Evaluate new generation with non-dominant sorting

Stop condition

Yes

Final solution

No

Figure 4. Multi-encoding NSGA-II.

Table 3. Demand of each products respects to manufacturer.

| Demand | Pro 1 | Pro 2 | Pro 3 | Pro 4 | Pro 5 |
|--------|-------|-------|-------|-------|-------|
| Manu 1 | 2786  | 3053  | 3975  | 3532  | 4976  |
| Manu 2 | 3215  | 4327  | 4553  | 3248  | 3392  |
Risk parameters in Table 5 represent the manufacturer's risk. This risk is consisted of production flexibilities, maintenance and other criteria which influence production. Tables 6 and 7 show the distribution risk in retailer and distributor nodes. Distribution risk could contain risk of sales, holding consumables products. Table 8 represents important risk in supply chain network, which could affect all nodes. The important feedback which comes from customer are utility satisfaction or after sales service satisfaction. All of the risk parameters can be obtained from MCDM tools regarding related criteria for each echelon. In this paper, DEMATEL approach is used in order to obtain the risk parameters. For more details, see appendix.

The final solutions of the model concerning the assumption are simply shown in Table 9. As can be seen the solutions have been sorted according to non-dominant sorting function regarding three main objectives: cost, flexibility and reconfiguration, and risk. As the results indicate ranking depends on the measurement of solution and dominations. The best 10 solutions of the model with five iterations in main loop are presented in Table 9. Each solution refers to three numbers. The cost fitness represents entire expenditure of supply chain while as the risk measurements indicates the cumulative risk of production which depends on the route of supply chain and type of products. The risk index of supply chain is attained from the fitness, and the last objective is flexibility which normally changes

| Dist 1 | Dist 2 | Dist 3 | Dist 4 | Dist 5 | Dist 6 |
|--------|--------|--------|--------|--------|--------|
| 672    | 446    | 421    | 339    | 356    | 613    |
| 454    | 566    | 893    | 320    | 862    | 797    |

Table 5. Risk of production different products in manufacturers.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Manu 1 | 0.92681153602213 | 0.0134880105760211 | 0.152264256885604 | 0.1552717272482812 | 0.135949656832800 |
| Manu 2 | 0.397180718011987 | 0.804377418062707 | 0.749281190584437 | 0.467715064868957 | 0.255664752619623 |

Table 6. Risk of distributing different products in distributors.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Distributer 1 | 0.31493192575 | 0.148566683149 | 0.537378111422 | 0.47164115428 | 0.49949388645 |
| Distributer 2 | 0.1231469391 | 0.630918790 | 0.53871014150 | 0.420155713707 | 0.11528901879 |
| Distributer 3 | 0.6651889924 | 0.0843332969 | 0.96727072815 | 0.92541569426 | 0.93957780704 |
| Distributer 4 | 0.3149319257 | 0.1485666831 | 0.53737811142 | 0.47164115428 | 0.49949388645 |
| Distributer 5 | 0.1231469391 | 0.6309187900 | 0.53871014150 | 0.420155713707 | 0.11528901879 |

Table 7. Risk of distributing different products in retailers.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Retailer 1 | 0.1243081150900 | 0.0120934813307825 | 0.304500708227568 | 0.820596762844057 | 0.608486754890215 |
| Retailer 2 | 0.868290346909 | 0.476324266464176 | 0.477910177414684 | 0.586249115875316 | 0.63220066354652 |
| Retailer 3 | 0.570499725848 | 0.897557844055082 | 0.266314281316768 | 0.247739047547807 | 0.780365541764735 |
| Retailer 4 | 0.1672066750560 | 0.53400422490554 | 0.111663853005986 | 0.362403399615399 | 0.0524680118627607 |
| Retailer 5 | 0.570499725848 | 0.897557844055082 | 0.266314281316768 | 0.247739047547807 | 0.780365541764735 |
| Retailer 6 | 0.1243081150900 | 0.0120934813307825 | 0.304500708227568 | 0.820596762844057 | 0.608486754890215 |
| Retailer 7 | 0.868290346909 | 0.476324266464176 | 0.477910177414684 | 0.586249115875316 | 0.63220066354652 |
| Retailer 8 | 0.570499725848 | 0.897557844055082 | 0.266314281316768 | 0.247739047547807 | 0.780365541764735 |
| Retailer 9 | 0.1672066750560 | 0.53400422490554 | 0.111663853005986 | 0.362403399615399 | 0.0524680118627607 |
| Retailer 10 | 0.570499725848 | 0.897557844055082 | 0.266314281316768 | 0.247739047547807 | 0.780365541764735 |
between 50 and 200. Considering the model, the maximum stage of flexibility means how many products changing in demand could be dominated by SCN. For example, the solution with 55 means that 55 products could be supplied by supply chain with respect to the changes in customers' demands and orders. These features could be attained by experts which was introduced as BP\textsubscript{N} parameters in each node. The BP\textsubscript{N} parameter was introduced to define the node capability in reconfiguration and flexibility by noticing the concerns (Gosling et al., 2010).

Furthermore, the fluctuation of reaching the best answer is shown in Figure 5 where it seems that the model goes from one zone of answers to another.

Figure 5 shows the searching algorithm in order to find the best solution of the problem considering three fitnesses, as fitnesses one and two can be compared to each other, the searching concentrates on domination process.

In order to manifest the efficiency of the model, it is solved with 100 iterations. Solving time was 10 min and 33 s. Using internal functions and also implementing modified NSGAII accelerate reaching the best solution.

Figure 6 simply shows the rend of reaching pick of the feasible area. Moreover, Table 10 indicates the best 10 solutions after 100 iterations are different from 5 iterations and the algorithm landed in a better feasible area, which means with more iteration it would gain better solutions. Figure 6 shows the 100 iterations of modified-NSGA-II. In 100 iterations, 1000 solutions have been reviewed.

5.2. Sensitivity analysis

Sensitivity analysis regarding the risk parameters is done for the presented model. New risk parameters are obtained from different experts in supply chain with DEMATEL approach. The model was solved according to the experts’ opinion. Tables 11–14 indicate the risk parameters. As can be seen in Table 15, the final solutions of the

| Risk     | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|----------|-----------|-----------|-----------|-----------|-----------|
| Customer 1 | 0.5136587945624 | 0.673731545505282 | 0.251156949197241 | 0.579718156137102 | 0.469999980757697 |
| Customer 2 | 0.5183652633433 | 0.859632827829061 | 0.921387630223229 | 0.408362234882364 | 0.401700487156446 |
| Customer 3 | 0.7989096110891 | 0.485352621804607 | 0.705248149693083 | 0.239665766012993 | 0.575615478685094 |
| Customer 4 | 0.5183652633433 | 0.859632827829061 | 0.921387630223229 | 0.408362234882364 | 0.401700487156446 |

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Table 9. Best solution of problem which obtained from algorithm (five iterations in main loop).

| Fitness/solution | - Fitness 1 (cost) | + Fitness 2 (flexibility) | - Fitness 3 (risk) |
|------------------|--------------------|---------------------------|--------------------|
| Solution 1       | 38,332,409.782.920 | 125.966666666667         | 3485.80993563896   |
| Solution 2       | 35,827,307.2090   | 125.050000000000         | 5401.4640370645    |
| Solution 3       | 38,076,653.2680   | 132.616666666667         | 3692.30193716710   |
| Solution 4       | 34,986,187.681.3067 | 120.3333333333334 | 6254.4650138512    |
| Solution 5       | 38,490,276.522.5256 | 89.65000000000000 | 2774.38795213421   |
| Solution 6       | 35,493,722.516.3004 | 115.63333333333333 | 5665.85343554297   |
| Solution 7       | 39,143,024.710.7105 | 55.316666666666667 | 1676.1951098427    |
| Solution 8       | 35,870,898.269.631 | 109.966666666666667 | 5174.1987462067    |
| Solution 9       | 37,864,151.994.6949 | 160.116666666666667 | 4322.29563488613   |
| Solution 10      | 35,682,174.399.7561 | 106.93333333333333 | 5618.1683169935    |
problem have meaningful change in risk fitness. The risk parameters also altered the flexibility objective as well as risk objective; however, the entire new solutions are not too far from the previous ones. To sum up, considering the aspects of industry it is better to use efficient approach to asset risk parameters.

At last but not least, Figure 7 shows the changes in three objectives, respectively, with different risk parameters, meaning that the method of determining the risk parameters

| Fitness/solution | - Fitness 1 (cost) | + Fitness 2 (flexibility) | - Fitness 3 (risk) |
|------------------|-------------------|---------------------------|-------------------|
| Solution 1       | 37,468,347,061.9478 | 182.2000000000000000000  | 5244.82144789427   |
| Solution 2       | 34,848,273,613.2735 | 164.1000000000000000000  | 6851.5132175521    |
| Solution 3       | 37,667,884,797.0171 | 145.0833333333333333333 | 4476.40038502431   |
| Solution 4       | 35,339,576,374.9429 | 153.0500000000000000000  | 6097.64366314583    |
| Solution 5       | 38,538,072,723.1800 | 92.6333333333333333333  | 2984.61875209331    |
| Solution 6       | 37,980,787,418.0097 | 54.06666666666667        | 2558.97386581879    |
| Solution 7       | 37,659,180,432.5626 | 170.7833333333333333333 | 4550.16494054687    |
| Solution 8       | 35,294,373,432.5626 | 155.5000000000000000000  | 6098.25735467508    |
| Solution 9       | 37,828,115,720.8396 | 125.4000000000000000000  | 4092.08110890466    |
| Solution 10      | 35,903,823,229.5665 | 106.4833333333333333333 | 4824.18890310952    |
Table 11. Risk of production different products in manufacturers.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Manu 1 | 0.926811553602213 | 0.0134880105760211 | 0.152264256885604 | 0.594721727248212 | 0.135949656832800 |
| Manu 2 | 0.397180718011987 | 0.804377418062707 | 0.749281190584437 | 0.467715064868957 | 0.255664752619623 |

Table 12. Risk of distributing different products in distributors.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Distributor 1 | 0.31493192575 | 0.14856683149 | 0.537378111422 | 0.47164115428 | 0.4994388645 |
| Distributor 2 | 0.1231469391 | 0.6330918790 | 0.53871014150 | 0.420155713707 | 0.11528901879 |
| Distributor 3 | 0.6651889924 | 0.0843332969 | 0.96727072815 | 0.92541569427 | 0.93957780704 |
| Distributor 4 | 0.3149319257 | 0.1485668314 | 0.5373781114 | 0.47164115428 | 0.4994388645 |
| Distributor 5 | 0.1231469391 | 0.6330918790 | 0.53871014150 | 0.420155713707 | 0.11528901879 |

Table 13. Risk of distributing different products in retailers.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Retailer 1 | 0.1243081150900 | 0.0120934813307825 | 0.304500709227568 | 0.820596762844057 | 0.60846758450215 |
| Retailer 2 | 0.862890346909 | 0.47632466464176 | 0.477910177414684 | 0.586249115875316 | 0.63220066354652 |
| Retailer 3 | 0.575049972584 | 0.897557840450508 | 0.286314281316768 | 0.247739047547807 | 0.780365541764735 |
| Retailer 4 | 0.1672066750560 | 0.534304422490554 | 0.111663853005986 | 0.362403399615399 | 0.0524680118627607 |
| Retailer 5 | 0.575049972584 | 0.897557840450508 | 0.286314281316768 | 0.247739047547807 | 0.780365541764735 |
| Retailer 6 | 0.1243081150900 | 0.0120934813307825 | 0.304500709227568 | 0.820596762844057 | 0.60846758450215 |
| Retailer 7 | 0.8628903469092 | 0.47632466464176 | 0.477910177414684 | 0.586249115875316 | 0.63220066354652 |
| Retailer 8 | 0.575049972584 | 0.897557840450508 | 0.286314281316768 | 0.247739047547807 | 0.780365541764735 |
| Retailer 9 | 0.1672066750560 | 0.534304422490554 | 0.111663853005986 | 0.362403399615399 | 0.0524680118627607 |
| Retailer 10 | 0.575049972584 | 0.897557840450508 | 0.286314281316768 | 0.247739047547807 | 0.780365541764735 |

Table 14. Risk of customer satisfaction.

| Risk | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|------|-----------|-----------|-----------|-----------|-----------|
| Customer 1 | 0.5136587945624 | 0.673731545505282 | 0.251156949197241 | 0.57918156137102 | 0.469999980757697 |
| Customer 2 | 0.5183652633433 | 0.859632827829061 | 0.921387630223229 | 0.408362234882364 | 0.401700487156446 |
| Customer 3 | 0.7989096110891 | 0.485352621804607 | 0.705248149693083 | 0.239665766012993 | 0.575615478685094 |
| Customer 4 | 0.5183652633433 | 0.859632827829061 | 0.921387630223229 | 0.408362234882364 | 0.401700487156446 |

Table 15. The best solution of problem which obtained from algorithm. (100 iteration in main loop) with new risk parameters.

| Fitness/solution | - Fitness 1(cost) | + Fitness 2 (benefits of production) | - Fitness 3 (risk) |
|------------------|-------------------|-------------------------------------|-------------------|
| Solution 1 | 37,468,347,061.9478 | 84.00000000000000 | 2527.85394496386 |
| Solution 2 | 34,848,273,613.2735 | 105.633333333333 | 5564.03926527707 |
| Solution 3 | 37,667,884,797.0171 | 130.983333333333 | 5007.26873525553 |
| Solution 4 | 35,339,576,374.9249 | 130.583333333333 | 4987.16328163527 |
| Solution 5 | 38,538,072,723.1800 | 129.900000000000 | 4252.4346801946 |
| Solution 6 | 37,980,787,418.0097 | 90.133333333333 | 4294.45843969196 |
| Solution 7 | 37,659,180,432.6187 | 141.900000000000 | 4678.45087998359 |
| Solution 8 | 35,294,373,432.5626 | 90.083333333333 | 3975.24435037464 |
| Solution 9 | 37,828,115,720.8396 | 100.933333333333 | 4057.2693221510 |
| Solution 10 | 35,903,823,229.5665 | 133.650000000000 | 6875.97786759124 |

is crucial to our research and could alter the results significantly. Moreover, we used DEMATEL approach as an intermediate method which could improve by fuzzy method or grey theory method as well.
6. Conclusions

The suggested model was introduced to control uncertainties in the market which is more fluctuated in our country and many firms cannot keep up with these uncertainties such as Demand alteration, Customer Desire, Demand deviation, Customer purchasing power and other economic issues that directly affect production such as material cost, transportation cost, inventory control, shortage cost. Avoiding these matters with notice to sanctions is demanding task for private sectors because they do not have complete support from authorities, with deployment of supply chain design model such as our model companies have significant chance to avoid these severe instabilities in the market, as we could saw its benefits in appliance companies. The important issue here is to see the big picture of supply chain network as one body and distinguish the related limitations to each industry. This model could not help to overcome to uncertainties completely but it could control uncertainties in SC which is crucial subject for companies.

Finally, the result of our research could give better sight of what was our objective in this paper. Risk assessing is one of sophisticated fields in science and many methods were introduced to determining risk. As a result, in our paper, comparing the final solution of two different risk parameters reveals the significance of determining risk parameters in which DEMATEL approach is used. It is suggested using fuzzy-TOPSIS or fuzzy TODIM to evaluate risks in supply chain network to attain more reliable risk parameters and avoid uncertainties.

Moreover, the importance of the presented model was considering transportation in three modes: capacity of vehicle, speed and type of vehicle which helps companies to solve some of the vehicle rout problem (VRP) and simultaneously solves the model difficulties which are inventory, shortage and uncertainties in customer desire and demand. In addition, maximizing flexibility and reconfiguration ability in supply chain were other main objectives which were obtained. Furthermore, using three types of connection helped the model to approach toward the real world condition in SCN, while the multi-encoding and multi-material and product led to problem solving with MENSGAII which was firstly introduced in the research. The main objective of the research was designing a model approximate to the world condition in order to avoid uncertainties and solve the amount of production problem as well as VRP.
For future studies, it is proposed to use multi-encoding in other problems and also for widening the supply chain network in customer zone. The customer zone could be developed as a customer chain network that clarifies the sell problem in market and a leading flag in customer satisfaction; it can use multiple fuzzy approaches to get feedback from customer and utilize that data for alternation and improvement of supply chain network.

**Disclosure statement**

No potential conflict of interest was reported by the author.

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