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Multi-Objective Model of Supply Chain with the Preservation of Balance between Product Quality and Cost Evaluation

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Abstract:
In the global competition of the current age, high-quality products should be supplied according to demand of customer in the shortest time possible. Accordingly, Supply Chain Management (SCM) is an important issue, since meeting needs and interests of customers would not only have done by the last entity attached to customer that is final product, but also by upstream suppliers. At the present study, a three-level planning is developed, which is aimed in optimizing two contradictory goals and has problem conflicts including 1- minimization of costs and 2- maximization of total value production that is considered as the qualitative target function in proposed model and means maximization of quality. Problem formulation is done to present a more realistic model. For this purpose, in this study, quality is depended not only on raw materials, but also on experience and efficiency of operator.

Keywords: *Supply chain, quality, multi-objective optimization, cost*

1. Introduction

Over the not too distant years, competition has been existed among organizations; although the competition has been replaced over the years by competition in supply chain. In the worldwide competitions of the current age, high-quality products should be supplied according to demand of customer and in the shortest time possible. Desire of customer for high quality and fast servicing has enhanced pressures that have not been existed before. As a result, organizations are unable to meet needs of customers by themselves. At the current competitive market, economic and manufacturing firms need management and supervision on relevant resources and elements out of the organization in addition to considering in-organization resources. The reason for this issue is in fact achievement to competitive advantage or advantages with the purpose of gaining more share of market. Accordingly, activities such as supply and demand planning, procurement of materials, manufacturing and product planning, product maintenance, inventory control, distribution, supply and serve the customer that were previously done in firm level are transferred now to supply chain. Effectiveness and inspiration of manufacturers, suppliers and customers on each other and outcomes of these effects appeared in costs, quality, production and delivery time have made supply chain to be appeared as an integrated and correlated system [1]. The issue of supply chain at the current world is considered as a main competitive advantage in way of decreasing final price. Supply chain includes purchasing and supply, logistics and shipping, marketing, organizational behavior, networking, strategic management, management information systems and operations management [2]. However, decision making in different steps of the process and matching with these steps is the main challenge of supply chain. According to intense competition among suppliers, if each ring of this chain acts weakly, whole system would be failed and would not act in expected level. Therefore, effective management of the chain in industry is a main management challenge. Over the years, companies and organizations of industrial and developed countries of the world have paid specific attention to supply chain management and have achieved considerable successes through this. The evidence for this issue is high volume of commercial transactions and profitability and income of successful and efficient supply chain, which has been able to overtake of competitors at the current highly competitive markets [3].

2. Literature Review

Supply chain network design provides an optimum scheme to manage the supply chain. Operation management is an important factor in supply chain management. Distribution network design is another strategic issue in supply chain management that has received a great deal of attention over recent years. Previous studies are reviewed in the following paragraph.
Integration and coordination of purchase-production-distribution complex systems have been the subject of many supply chain-related studies in recent years. et al. [28], [29], [30], et al. [31], et al. [32] and et al. [33] presented full reviews on production and distribution models. [34] published a fundamental article about an integrated production-inventory-distribution system that included a two-step procedure with manufacturer of a final product and navigation of products so that demands of retailers are met. Several models regarding coordination of supply chain developed by [35], [36], [37], [38], [39], [40], [41], [42] and [43].

Mirzapour et al. studied aggregate production in a multi-product, multi-site supply chain by a new model with multi-objective optimization. The presented model was solved as a mixed planning of single-objective integers by means of LP-metric method [44].
[45] developed a stable optimization model for aggregate-probability production planning. [46] proposed a new method for modeling of planning problems regarding aggregate multi-product planning with fuzzy demand and production capacity. The aim function of problem was to minimize the overall production costs (a quadratic function) and function of inventory maintenance costs (a linear function)
[47] developed an integrated (constant) genetic algorithm consisting a new encrypting structure to design a single-source, multi-product and multi-site supply chain network. In order to investigate the algorithm efficiency, it was put into comparison with cplex Software, innovational Lagrangian algorithm, genetic compound algorithm and simulated annealing algorithm. Besides, they proposed a model to minimize overall costs and maximize service level and capacity use matrix of distribution centers. The proposed model was solved via a genetic algorithm to achieve Pareto answer sets.
Today, systematic approach and issues of supply chain are being considered as known subjects in industrial engineering. High volume and variety of studies in field of supply chain management indicate importance and interestingness of this issue.
Handfield and Nichols [4] believe that 3 main factors have made companies follow issue of supply chain seriously as follows:

1- Information revolution
2- Increase in expectations of customers while purchasing products
3- Necessity of creating a new structure in inter-organization relations.

In this study,the problem of integrated planning of Purchase-production-customer in supply chain is modeled and solved. As it is obvious in figure 1, assumed supply chain has 3 levels and in levels 1 to 3, suppliers, manufacturers and customers are respectively placed. Two contradictory goals of this issue include 1- cost minimization and 2- maximization of total value of production that is considered as qualitative target function in pro [posed model and means maximization of quality.

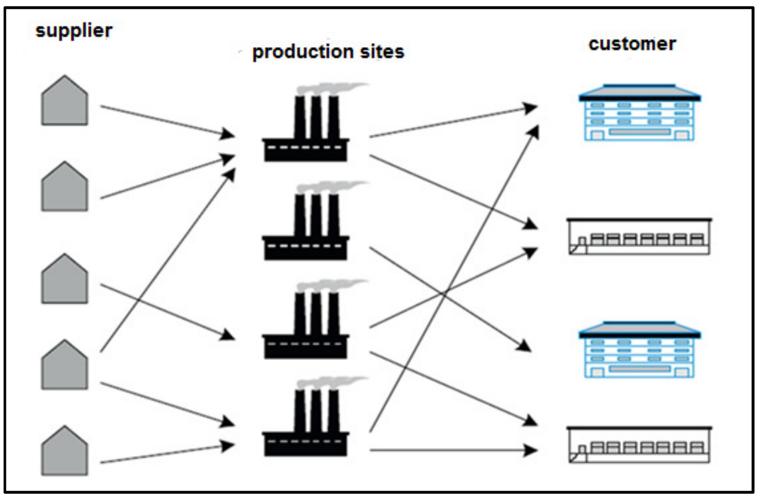

Figure 1:a network of three-stage supply chain

During each period, different levels of human resources are available. It should be noted that to what extent each of them should be used and this can affect maximization of quality. On the other hand, as each of them has its specific costs and the first target function is cost minimization, the contradiction should be solved in form of a multi-objective planning.
Both raw materials and human resources are classified in terms of quality. For this purpose, raw materials with quality level of 1 have the least amount of impurities and raw materials with quality level of L have highest amount of impurities. Human resources are also classified based on their work experience and human resources of level 1 are professional and human resources of level K are trainees. The problem solving should specify that how much raw materials from which supplier should be received in each period; in which production unit and with what level of human resource would be involved to produce finally a product with a qualitative index to minimize supply chain costs and maximize quality to gain customer satisfaction?

3. Methodology

Conditions of the problem:

- The problem is asingle-product, multi-period and three-layer model.
- Place and number of suppliers, manufacturers, distribution centers and retail centers are specified.
- The flow of materials can be provided just between two sequential levels of network layers.
- Capacity of each facility (supplier) and access time of each level of human resource is specified.
- Parameters have been considered definitely.

In way of designing the network, 2-objective and 3-layer supply chain is formed as a result of outputs including:

- Selecting suppliers

- Selecting manufacturers
- Optimal purchase of types of raw materials and optimal use of labor involved in each period and to determine optimal type of production, determine optimal method of shipping of raw materials to the factory and transiting products and delivering them to customers
- An optimization approach with the goal of minimization of supply chain costs and maximization of production value that means maximization of quality.

As it is clear from nature of considered goals, two considered goals are in contradiction. Hence, improvement of one of them may lead to weakness of another one and it is almost impossible to find an answer to optimize two target functions at the same time. As a result, balanced solutions to goals should be found. One of the methods to obtain Pareto solutions is using multi-objective meta-heuristic methods, which produce more Pareto solutions in reasonable time compared to classic algorithms. Hence,Non-dominated Sorting Genetic Algorithm-II (NSGA-II) is designed and implemented to obtain set of optimized Pareto solutions to the proposed model.

3.1. Presenting Mathematical Model

In order to present mathematical model of the problem, firstly hypotheses are remembered:

- The problem is a single-product, multi-period and three-layer model.
- Place and number of suppliers, manufacturers and customers are specified.
- Level of equipment in manufacturing centers is considered same.
- Products are divided to two groups in terms of quality (q). Product with qualitative level of 1 is a first class product and has the best quality and product with quality level of q is the product with lowers quality.
- Raw materials of quality level of 1 have lowest impurity and materials with quality of L level have the highest impurity rate.
- Human resources with skill of level 1 are professional resources and human resources in K level are trainees.
- It has been specified by experts and based on previous experiences that product of q degree could be produced with what extent of human resource and with what level of materials.

3.2. Sets

S: set of suppliers	s=1,2,…,S
L: quality level of raw materials	l= 1,2,…,L
K: skill level of human resources	K= 1,2,…,K
q: quality level of final product	q= 1,2,…,q
C: set of customers/retailors	C= 1,2,…,C
J: set of manufacturers	j=1,2,…,J
T: time period	t=1,2,…,T

3.3. Parameters

- D_{ct} : customer demand during t period
- $\boldsymbol{C_s^l}$: purchase cost of a unit of raw materials from s supplier with qualitative level of l
- $\boldsymbol{C_j^q}$:Production cost of a unit of final product with quality level of q in j factory
- $\boldsymbol{Tc_{sj}}$: shipping cost of raw materials from supplier s to manufacturer j per unit
- $\mathbf{Tc_{jc}}$: shipping cost of product from manufacturer j to customer c per unit
- $\boldsymbol{Mw_{kjt}}$: cost of operator with k level skill during t period in j factory
- $\boldsymbol{Fw_{kjt}}$: cost of firing K level operator from j factory during t period
- $\mathrm{Hw_{kjt}}$: cost for employment of operator with k skill level in j factory during t period
- $\mathbf{Tw_{kk'jt}}$: training cost of operator from k skill level to K' skill level in j factory during t period
- $\boldsymbol{Tp_{kk'}}$: $\begin{cases} 1: if training is possible from k skill level to k' skill level \\ 0: otherwise \end{cases}$
- $\boldsymbol{A_{kjt}}$:time of access to j factory for operator of k level during t period
- $\boldsymbol{a_{jt}^{kl}}$: number of required labor of k level in case of working on materials of l level to produce product in j factory during t period
- $\boldsymbol{ic_j}$: maintenance cost of a unit of product in j factory
- $\boldsymbol{Cap_{st}^l}$: maximum capacity of providing raw materials of type l supplied by s supplier during t period
- M: large number
- : $\boldsymbol{b_{jlk}}$: production time of a unit of product in j factory by operator of k level and law materials of l level

3.4. Variables

- $\boldsymbol{Q_{jt}^q}$: amount of production in j factory during t period with quality level of q

- X_{sjt}^{L} : amount of raw materials with l level quality transferred from s supplier to j manufacturer during t period
- X_{jt}^{lk} : amount of product produced with skill level of k and raw materials of l level in j factory during t period
- Y_{jct}^{q} : amount of product transferred from manufacturer j to c customer during t period with quality level of q
- I_{jt}^{q} : amount of inventory of product in j factory during t period with quality of q level
- L_{kjt} : number of required human resources from k skill level in j factory during t period
- Fl_{kjt} : number of human resource with skill level of k in j factory during t period, who are fired
- Hl_{kjt} : number of human resources with k skill level in j factory during t period, who are employed
- $Tl_{kk'jt}$: number of human resources with k skill level to K' level trained in j factory during t period

Target functions of problem

- First target function

Minimization of costs= Raw materials purchase cost + Raw materials shipping costs + production cost + shipping product to the customer + inventory costs + labor costs + cost of hiring human resources +cost of firing human resources + cost of human resource training

$$Min\ Z_1 =$$
$$\sum_s \sum_j \sum_l \sum_t X_{sjt}^{l} C_s^{l} + \sum_s \sum_j \sum_l \sum_t Tc_{sj} X_{sjt}^{l} + \sum_j \sum_q \sum_t C_j^{q} Q_{jt}^{q} + \sum_j \sum_c \sum_q \sum_t Tc_{jc} Y_{jct}^{q} + \sum_j \sum_q \sum_t ic_j\ I_{jt}^{q} + \sum_k \sum_j \sum_t Mw_{kj} L_{kjt} + \sum_k \sum_j \sum_t Fw_{kj} Fl_{kjt} + \sum_k \sum_j \sum_t Hw_{kj} Hl_{kjt} + \sum_k \sum_{k'} \sum_j \sum_t Tw_{kj} Tl_{kk'jt} (1)$$

- Second target function

Maximization of total production value that is equal to maximization of quality.

$MaxZ2 = \sum_j \sum_t \sum_q w_q\ Q_{jt}^{q} (2)$

3.5. Model Limitations

$$I_{jt}^{q} = I_{j(t-1)}^{q} + Q_{jt}^{q} - \sum_C Y_{jct}^{q} \forall q, j, t \quad (3)$$

$$L_{kjt} = L_{kj(t-1)} + Hl_{kjt} - Fl_{kjt} + \sum_{k'} Tl_{k'kjt} - \sum_{k'} Tl_{kk'jt}\ \forall k, j, t \quad (4)$$

$$\sum_L a_{jt}^{kl} x_{jt}^{kl} \le L_{kjt} \forall k, j, t (5)$$

$$\sum_k A_{tkj} L_{tkj} \ge \sum_k \sum_L b_{jlk} X_{jt}^{LK}\ \forall j, t\ (6)$$

$$Q_{jt}^{q} \ge \sum_C Y_{jct}^{q} \forall q, j, t \quad (7)$$

$$\sum_j X_{sjt}^{L} \le Cap_{st}^{L} \forall L, s, t \quad (8)$$

$$\sum_k X_{jt}^{kL} = \sum_s X_{sjt}^{L} \forall L, j, t \quad (9)$$

$$FL_{kjt} + \sum_{k'} TL_{kk'jt} \le L_{kj(t-1)} \forall k, j, t \quad (10)$$

$$D_{ct} = \sum_j \sum_q Y_{jct}^{q} \qquad \forall c, t \quad (11)$$

$$\sum_{k'} TL_{kk'jt} FL_{kjt} = 0 \qquad \forall k, j, t \quad (12)$$

$$Tl_{k'kjt} \le M\ Tp_{kk'} \qquad \forall k, k', j, t \quad (13)$$

$$\sum_k (FL_{kjt} + HL_{kjt}) \le \alpha_{(t-1)} \sum_k L_{kj(t-1)} \qquad \forall j, t \quad (14)$$

$$\begin{cases} x_{11jt} + x_{12jt} = Q_{jt}^{1} \\ x_{21jt} + x_{22jt} = Q_{jt}^{2} \qquad \forall\ j, t \quad (15) \\ x_{31jt} + x_{32jt} + x_{33jt} + x_{23jt} + x_{13jt} = Q_{jt}^{3} \\ Q_{jt}^{q}, X_{sjt}^{L}, X_{jt}^{lk}, Y_{jct}^{q}, I_{jt}^{q}, L_{kjt}, Fl_{kjt}, Hl_{kjt}, Tl_{kk'jt} \ge 0 \quad (16) \end{cases}$$

Limitation 3: indicates inventory of each period, which is determined according to inventory of previous period and production and delivered products; limitation 4: indicates number of labors with k skill in each factory and during each period; limitation 5 guarantees number of required labor per each period due to production of product with different qualitative levels. Limitation 6 guarantees considering time of accessibility of each labor. Limitation 7 indicates the balance between production and shipping to customer. Limitation 8 guarantees that per each period, amount of semi-cast product received from suppliers should not be more than capacity of supplier. Limitation 9 indicates the balance between production and raw materials. Limitation 10indicates that firing and training should not be more than in access human resources. Limitation 11 guarantees that all demands for product in each period should be provided. Limitation 12 guarantees that an operator trained in a period should not be fired by the same period. Limitation 13 indicates possibility or impossibility of training per each period. Limitation 14 indicates that in each period, human resources can be changed to certain level. Limitation 15 indicates possibility of production of each product of each qualitative level with different operator and raw materials. Limitation 16 indicates nonnegative limitations of decision variables.

3.6. Linearization of Nonlinear Function

As in limitation 12, multiplication of 2 decision variables is possible, the presented model is nonlinear. In order to linearize the model, new variable that is 0 and 1 should be considered as follows:

$$\sum_{k'} TL_{kk'jt} \le M\, Y_{kjt}$$
$$FL_{kjt} \le M\,(1 - Y_{kjt})$$
$$Y_{kjt} \in \{0,1\} \qquad (17)$$

The limitation should be added to the model. In the equation, real number is large.

Accordingly, Integer linear programming (ILP) model is obtained as follows:

$$Min \quad Z_l = \sum_s \sum_j \sum_l \sum_t X^l_{sjt} C^l_s + \sum_s \sum_j \sum_l \sum_t Tc_{sj} X^l_{sjt} + \sum_j \sum_q \sum_t C^q_j Q^q_{jt} + \sum_j \sum_c \sum_q \sum_t Tc_{jc} Y^q_{jct} + \sum_j \sum_q \sum_t ic_j I^q_{jt} + \sum_k \sum_j \sum_t Mw_{kj} L_{kjt} + \sum_k \sum_j \sum_t Fw_{kj} Fl_{kjt} + \sum_k \sum_j \sum_t Hw_{kj} Hl_{kjt} + \sum_k \sum_{k'} \sum_j \sum_t Tw_{kj} Tl_{kk'jt} \quad (18)$$

$$Max\ Z_2 = \sum_j \sum_t \sum_q W_q Q^q_{jt} \qquad (19)$$

$$I^q_{jt} = I^q_{j(t-1)} + Q^q_{jt} - \sum_C Y^q_{jct} \qquad \forall q, j, t \qquad (20)$$

$$L_{kjt} = L_{kj(t-1)} + Hl_{kjt} - Fl_{kjt} + \sum_{k'} Tl_{k'kjt} - \sum_{k'} Tl_{kk'jt} \quad \forall k, j, t \qquad (21)$$

$$\sum_L a^{kl}_{jt} x^{kl}_{jt} \le L_{kjt} \qquad \forall k, j, t \qquad (22)$$

$$\sum_k A_{tkj} L_{tkj} \ge \sum_k \sum_L b_{jlk} X^{LK}_{jt} \qquad \forall j, t \ (23)$$

$$Q^q_{jt} \ge \sum_C Y^q_{jct} \qquad \forall q, j, t \qquad (24)$$

$$\sum_j X^L_{sjt} \le Cap^L_{st} \qquad \forall L, s, t \qquad (25)$$

$$\sum_k X^{kL}_{jt} = \sum_s X^L_{sjt} \qquad \forall L, j, t \qquad (26)$$

$$FL_{kjt} + \sum_{k'} TL_{kk'jt} \le L_{kj(t-1)} \qquad \forall k, j, t \qquad (27)$$

$$\sum_{k'} TL_{kk'jt} \le M\, Y_{kjt} \qquad (28)$$

$$(29)$$
$$FL_{kjt} \le M\,(1 - Y_{kjt})$$
$$Y_{kjt} \in \{0,1\}$$

$$D_{ct} = \sum_j \sum_q Y^q_{jct} \qquad \forall c, t \qquad (30)$$

$$Tl_{k'kjt} \le M\, Tp_{kk'} \qquad \forall k, k', j, t \qquad (31)$$

$$\sum_k \left(FL_{kjt} + HL_{kjt}\right) \le \alpha_{(t-1)} \sum_k L_{kj(t-1)} \forall j, t \qquad (32)$$

$$\begin{cases} x_{11jt} + x_{21jt} = Q^1_{jt} \\ x_{12jt} + x_{22jt} = Q^2_{jt} \qquad \forall\, j, t \\ x_{31jt} + x_{32jt} + x_{33jt} + x_{23jt} + x_{13jt} = Q^3_{jt} \end{cases} \qquad (33)$$

$$Q^q_{jt}, X^L_{sjt}, X^{lk}_{jt}, Y^q_{jct}, I^q_{jt}, L_{kjt}, Fl_{kjt}, Hl_{kjt}, Tl_{kk'jt} \ge 0 \qquad (34)$$

Model solving

The method to solve the 2-objective problem used in this paper is Fuzzy goal programming method. The method has presented a concept named membership function or utility function for each function and then has maximized it for each goal to close up each goal to its optimized value. Membership function for maximization problem is as follows:

$$\mu_i(x) = \frac{f_i(x) - F_i^{Max}}{F_i^{Max} - F_i^{min}} \qquad (35)$$

Where; F_i^{min} and F_i^{Max} are respectively minimum and maximum values of target function $f_i(x)$. Membership function for a minimization problem would be calculated as follows:

$$\mu_i(x) = \frac{F_i^{Max} - f_i(x)}{F_i^{Max} - F_i^{min}} \qquad (36)$$

Mathematical model of fuzzy goal programming that tends to maximize different membership functions would be obtained as follows:

Max λ

Subject to: (38)

$$\mu_i(x) \geq \lambda$$

x∊X

$$\lambda \geq 0$$

After solving the model using Lingo Software, λ is obtained to 0.7566, which is acceptable according to contradiction between target functions.

J=1	T_1	T_2
q_1	56	55
q_2	29	31
q_3	35	36

Table 1: amount of high quality products

L=1	J_1	J_2
S_1	69	0
S_2	0	53
L=2		
S_1	0	0
S_2	39	9
L=3		
S_1	0	0
S_2	12	25

Table 2: amount of raw materials shipped with L quality during first period

L=1	J_1	J_2
S_1	87	5
S_2	0	75
L=2		
S_1	0	52
S_2	32	18
L=3		
S_1	0	0
S_2	3	13

Table 3: amount of shipped raw materials with L level quality in second period

J=1	L_1	L_2	L_3
K_1	37	25	10
K_2	19	4	1
K_3	13	10	1
J=2			
K_1	42	3	19
K_2	9	5	5
K_3	2	1	1

Table 4: amount of product produced by K skill level operator and raw materials of L level in second period

J=1	L_1	L_2	L_3
K_1	28	8	0
K_2	27	23	3
K_3	32	1	0
J=2			
K_1	57	46	10
K_2	11	15	2
K_3	12	9	1

Table 5: amount of products produces with k level operator and raw materials of L level in second period

q=1	C_1	C_2	C_3
J_1	56	0	0
J_2	0	8	43
q=2			
J_1	29	0	0
J_2	0	8	0
q=3			
J_1	2	33	0
J_2	0	22	0

Table 6: amount of shipped products to customer in first period

q=1	C_1	C_2	C_3
J_1	36	0	0
J_2	0	0	68
q=2			
J_1	50	0	0
J_2	12	23	26
q =3			
J_1	0	33	0
J_2	0	34	0

Table 7: amount of shipped product to customer in second period

	Level k	Site j	Period t	
			1	2
L	1	1	5	2
		2	3	5
	2	1	3	4
		2	1	5
	3	1	2	3
		2	3	2
Firing labor	1	1	5	3
		2	2	0
	2	1	6	0
		2	6	0
	3	1	6	0
		2	9	0
Hiring labor	1	1	0	0
		2	0	1
	2	1	0	1
		2	0	4
	3	1	0	1
		2	0	0
Upgrading labor		2		1

Table 8: human resource program obtained from model solving

4. Conclusion

In this study, for the problem of integrated programming of purchase-production-customer in a supply chain network, a certain and multi-objective model is developed with two contradictory goals including 1- minimization of costs and 2- maximization of total value production that is considered as the qualitative target function in proposed model and means maximization of quality. Moreover, the proposed model has linked product quality not only to last ring attached to customer that is manufacturer, but also it has linked it to raw materials shipped to manufacturer and involvement of labors with different skills with the materials. The presented model was firstly a nonlinear model that is changed into a linear programming method using research techniques during the operations and has been validated with a problem in small dimensions using Lingo Software. To solve the problem, fuzzy goal programming method is applied.

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