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Technical Note

Modelling of just-in-time distrubution network under raw material quality and time constraints

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Abstract

Just-in-time (JIT) delivery is one of the key delivery strategies that enable the right quality product to reach the point of demand at the right time without creating unnecessary costs in the supply chain network. The concepts of quality and time are two main factors to be considered in this issue. Particularly because the variability in quality directly affects cost and time, it is very important for JIT delivery. In this study, the effect of raw material quality within the supply chain network which tries to ensure JIT delivery is examined. For this, a multi-stage, multi-period mixed-integer mathematical model is proposed in the study. The model aims to minimize the total supply chain cost by trying to balance the purchasing and quality costs for manufacturers. In addition to standard constraints, the stock balance and time constraints have been developed for JIT delivery. As a result of the model resolved with the GAMS Distribution 21.6 program, 34.5% of the raw material supplied from suppliers is provided from 1st quality raw materials, while 65.5% is provided from 2nd quality raw materials. Despite its low purchasing costs, 3rd quality raw material has not been preferred by the producers in any period because it causes a delay in JIT delivery. Besides, it is seen that deliveries are made very close to the maximum delivery time of distribution centers, depending on the variability in raw material quality. It is understood that raw material quality is an important concept in a JIT supply chain network due to its significant impact on time.

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INTRODUCTION

The supply chain system forms a large system with its supplier, manufacturer, distribution center, retailer, and customers. This system, which enables all processes from supplier to customer to be realized in an integrated way, aims to distribute the products at the right time, in the right

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place, at the right quantity to minimize the cost of the chain while satisfying the customer needs [1]. Strategic decisions are taken to realize this aim constitutes supply chain network design problems. These problems, determine the capacities of the plants in the chain, their locations, the quantities of products distributed between facilities, the quantities of items required for all transactions from supplier to the customer, and the distribution network [2]. The most important factor in supply chain network design problems is the company's aim. [3]. Because the supply chain network created for the companies in line with the determined aims varies. If the determined aim is cost minimization or profit maximization, cost parameters such as transportation, holding, fixed cost are considered; when the aim is customer satisfaction maximization, parameters that are important for the customer such as defective product quantity, lead time, environmental factors are handled. Generally, network design problems, which are handled through cost minimization, include the JIT concept in supply chain network design models and can address the objectives in terms of both cost minimization and customer satisfaction. The JIT concept, created by the Japanese for production systems in the 1950s, aims to increase customer satisfaction by reducing waste and costs in the supply chain as in production. This aim is provided by JIT delivery to the customer. Because, JIT delivery to the customer is very important, both in terms of increasing customer satisfaction and reducing costs [4].

While there are many studies in the literature on supply chain network design problems, there are few studies involving the JIT concept in these problems. Time and quality are also discussed separately from JIT. We can summarize the studies on these subjects as follows:

Memari, Ahmad and Hassan [5] solved a large-scale JIT logistics problem. The aim of the mixed-integer linear programming model developed for this problem is to minimize the total logistics costs while ensuring the JIT delivery. In this article, customer demand and uncertainty in supplier capacities are handled with triangular fuzzy numbers. For the solution of the proposed model, particle swarm optimization and harmony search algorithm are used to compare the methods. Yang, Ho, and Kao [6] have developed a multi-stage JIT inventory model that addresses uncertain delivery time and defective quality constraints. The model developed to minimize the total cost was analyzed by Ant Colony Algorithm and it was found that Ant Colony Algorithm is more effective than Particle Swarm Optimization Algorithm. Ghasimi and Ghodsi [7], offers three new inventory control models for perishable products in the JIT supply chain. The model aims to minimize the total cost of the entire supply chain, including production, transportation, stock, early and late delivery, and the cost of processed goods. Genetic Algorithm (GA) and CPLEX program are used for the solution of these models. Farahani and Elahipanah [4] developed a two-purpose hybrid integer mathematical model for a three-stage supply chain distribution network that distributes JIT. The first objective is to minimize the total supply chain costs, while the second objective is to achieve JIT distribution by minimizing the amount of inventory and backorders in the chain. To solve this model, a non-dominated hybrid classification GA was applied. Wang and Sarker [1] developed a mixed-integer nonlinear programming model for the multi-stage supply chain that deals with JIT logistics activities. The aim of this model is to minimize Kanban number, lot size, lot number, and total supply chain cost. The proposed model was solved with a branch-bound algorithm and developed heuristics. Wang, Fung, and Chai [8] propose a JIT distribution network system under limited supply capacity. The aim of the proposed model is to minimize the penalty for delay in satisfying retailer requirements under limited warehouse capacity, total production, and transport costs. The model can be solved by converting to a linear programming problem using mathematical inference. Ghasimi, Ramli, and Saibani [9] propose a mathematical model for a supply chain network where defective quality products cannot be repaired and sold to customers at a lower price. The proposed model aims to minimize production, distribution, inventory, and return order costs. In the article, JIT logistics is used to determine the economic production quantity (EPQ), the appropriate length of each cycle (ALOEC), and the quantities of defective products, scrap products, and retailers. The proposed model was analyzed by the GA method. Çalık [10] proposes a mixed-integer linear programming model for the closed-loop supply chain, taking the delivery time and environmental factors into account. The proposed model also aims to minimize total costs and delay time. Scenario analyzes were also performed to measure the effect of transport costs, carbon emission costs, and delivery time on the model. The model and each scenario are solved by applying to the GAMS Distribution program. Memari et al [11] propose a multi-cycle, multi-stage, and dual-purpose optimization model that includes carbon emission and environmental factors in addition to the JIT concept. In the proposed model, the first aim is to minimize the total supply chain cost and the second aim is to minimize the allowable carbon quota per period. This study examines the impact of JIT delivery on carbon emissions. In the study, a Non-dominated Sequencing Genetic Algorithm-II (NSGA-II) method was developed for the problem and it was solved with the help of the Taguchi method. Memari, Ahmad and Rahim[12] propose a mixed-integer linear programming model that emphasizes environmental factors while ensuring JIT delivery. The model has two objective functions; the first one is to minimize product delivery time and the second one is to minimize total carbon emissions across the entire supply network. The study examines the environmental impact of reducing the number of deliveries and delivery time. An NSGA-II method was used in the model solution. Yılmaz [13] examined the problems of loading vehicles in cases where picking from multiple suppliers for logistic operations in a JIT production system was carried out multiple times. In this study, a mixed-integer linear programming model is proposed to ensure optimum transportation between customers and suppliers. In the proposed model, it is aimed to prevent the increase of stocks that are formed by early delivery and waiting with late delivery. The model tested with real data was analyzed by using a CPLEX decoder. Lai, Lee, and Ip [14] provide an alternative view to the JIT concept with a system dynamics tool that focuses on the entire system. In the study, JIT and Kanban models were created by using a system dynamic approach which is modeling and simulation. Strategies are handled in the model to improve inventory control, quality, and productivity. The methodology used provides a new paradigm to understand customer and supplier interactions that shape a company's performance by analyzing a company's logistics policies. Alglawe et al [2] propose a nonlinear optimization model on quality costs and quality level analysis in supply chain design. In the proposed model, the aim is to minimize the total costs including operating costs, production costs, fixed costs, and quality costs. How scenario, opportunity, investment, and transportation costs will affect the decision of quality level, quality costs, and plant site selection has been tested. Excel Solver program was used to solve the proposed model and scenario analysis. Vera et al [15] propose a mixed-integer linear programming model that analyzes the effects of capacity, quality, delivery time, and interest rate factors on supply chain profit. In the model, the cost of poor quality was studied for the quality factor and process adequacy indices were used. In the time factor, the delivery time window proposed by Hsu et al [16] was used. The model which aims to maximize the system profit has been analyzed by the GAMS Distribution program. ANOVA analysis was also used to measure the interaction of each factor.

In this study, a multi-stage supply chain network consisting of suppliers, manufacturers, distribution centers, and retailers was established. In this supply chain network, the effects of this raw material quality difference on JIT delivery are examined by taking into account the tradeoff between the purchase and quality costs caused by the differences in the quality of the raw material supplied to the manufacturer. In the proposed model for this study, the inventory balance constraint that prevents early and late product quantity is used to ensure JIT delivery. Time constraints are used to prevent the early and late time of product due to the additional time created by the difference in raw material quality. The aim of the model is to minimize the total cost of the supply chain, including the costs of transportation, production, purchasing, quality, early, and a late penalty. With the determination of the effects of raw material quality and time constraints on the supply chain, the gap in JIT and supply chain network design problems literature is tried to be filled.

PROBLEM DEFINITION

In this study, a four-stage supply chain network consisting of multiple suppliers, multiple manufacturers, multiple distribution centers, and multiple retailers has been established as shown in Figure 1. In this network, raw materials of three different quality levels provided by suppliers are sent to the producers. The raw materials that reach the manufacturer are subjected to additional processing according to their quality. This creates quality cost and additional processing time for the manufacturer. Therefore, the manufacturer is experiencing a tradeoff between increasing purchasing costs in direct proportion to raw material quality and decreasing quality costs in inverse proportion. The additional processing time also affects the early or late delivery of the product to the retailer. After production, the final products reach the distribution center and retailer via direct channels. Capacity is limited in suppliers, manufacturers, distribution centers, and retailers throughout the supply chain. Distribution centers and retailers do not have initial and final stocks. Sales of retailers start with satisfying the first demands and all the demands are satisfied in the planned periods. Demands are deterministic in each period. The locations of suppliers, manufacturers, and retailers are determined. The products are transported in trucks of sufficient capacity with a uniform transport mode. Delivery times, production, and additional processing times between the supplier, the manufacturer, and the distribution center are also deterministic. The aim of the mixed-integer mathematical model for this established supply chain network is to minimize the total supply chain cost.

Since the model is not tested with real-life data and the data used are deterministic, it cannot respond to the uncertainties that occur in real life. To eliminate this limitation, uncertainties that occur in real life can be determined and included in the model.

The Model Formulation

In this section, the notations, parameters, decision variables, objective function, and constraints of the mathematical model are given below.

- **İndices**
  i: Suppliers Index i ε {1, 2…… I}
  j: Manufacturers Index j ε {1, 2…… J}
  k: Distribution Centers Index k ε {1,2…… K}
  l: Retailers Index l ε {1,2…… L}
  q: Raw Material Quality Levels Index q ε {1,2…… Q}
  p: Periods Index p ε {1,2…… P}

- **Decision Variables**
  X_{ijqp}: Amount of q quality raw material transported from supplier i to manufacturer j in period p
  Y_{jkp}: Amount of product transported from manufacturer j to distribution center k in period p

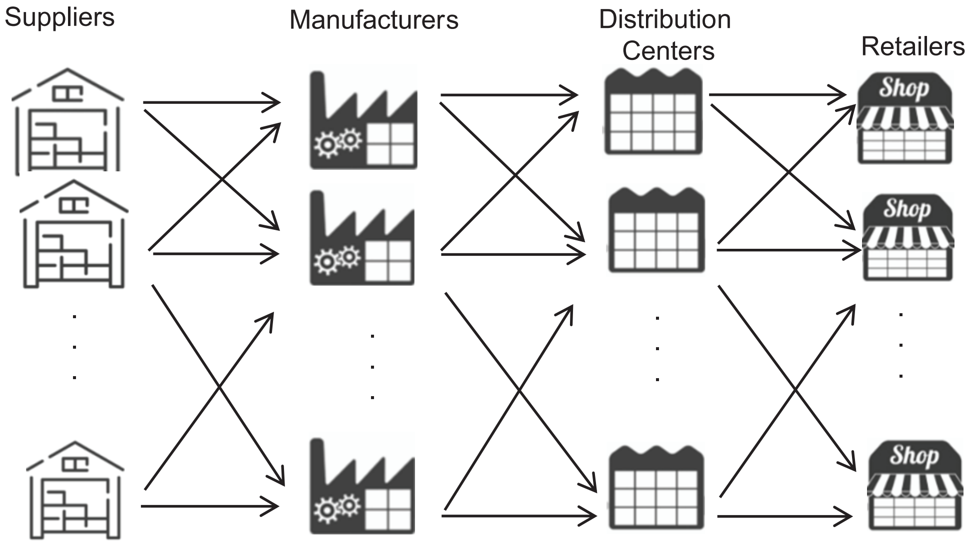

Figure 1. Supply chain network of proposed model.

Z_{klp}: Amount of product transported from distribution center k to retailer l in period p

R_{jqp}: Amount of q quality raw material reprocessed in manufacturer j in period p

S^1_{kp}: Inventory level of distribution center k in period p

S^2_{lp}: Inventory level of retailer l in period p

YM_{lp}: Backorder level of retailer l in period p

TS_{klp}: Delivery lead time of product from distribution center k to retailer l in period p

$$O_{kp}:\left\{\begin{matrix}1,\ \text{if distribution center is opened}\\ 0,\ \text{otherwise}\end{matrix}\right\}$$

$$W_{klp}:\left\{\begin{matrix}1,\ \text{if the distribution center serves the retailer}\\ 0,\ \text{otherwise}\end{matrix}\right\}$$

- **Parameters**

C^1_{ijqp}: Transportation cost of q quality raw material from supplier i to manufacturer j in period p

C^2_{jkp}: Transportation cost of product from manufacturer j to distribution center k in period p

C^3_{klp}: Transportation cost of product from distribution center k to retailer l in period p

K^1_{iqp}: Capacity of supplier i for q quality raw material in period p

K^2_{jp}: Capacity of manufacturer j in period p

K^3_{kp}: Capacity of distribution center k in period p

D_{lp}: Demand of retailer l in period p

P_{iqp}: Purchasing cost of q quality raw material from supplier i in period p

RQ_q: Percentage of total q quality raw material for additional operation

I^1_{kp}: Holding cost of distiribution center k in period p

I^2_{lp}: Holding cost of retailer l in period p

B_{lp}: Penalty cost of backorders for retailer l in period p

- OC_{kp}: Opening cost of distribution center k in period p
- U_{jp}: Production cost of manufacturer j in period p
- F: Number of distribution centers to be opened
- YN_{jqp}: Additional operation cost of q quality raw material at manufacturer j in period p
- T^1_{ijp}: Delivery lead time of raw material from supplier i to manufacturer j in period p
- T^2_{jp}: Production time of manufacturer j in period p
- T^3_{jqp}: Additional processing time of q quality raw material at manufacturer j in period p
- T^4_{jkp}: Delivery lead time of product from manufacturer j to distribution center k in period p
- T^5_{klp}: Maximum delivery lead time of product from distribution center k to retailer l in period p
- T^6_{klp}: Minimum delivery lead time of product from distribution center k to retailer l in period p
- T^7_{lp}: Total lead time of product to retailer l in period p

- **Objective Function**

$$\begin{aligned}\text{Min ZET} = &\sum_i\sum_j\sum_q\sum_p X_{ijqp}C^1_{ijqp} + \sum_j\sum_k\sum_p Y_{jkp}C^2_{jkp}\\ &+\sum_k\sum_l\sum_p Z_{klp}C^3_{klp} + \sum_j\sum_k\sum_p Y_{jkp}U_{jp}\\ &+\sum_j\sum_q\sum_p YN_{jqp}R_{jqp} + \sum_k\sum_p OC_{kp}O_{kp}\\ &+\sum_i\sum_j\sum_q\sum_p X_{ijqp}P_{iqp} + \sum_k\sum_p I^1_{kp}S^1_{kp}\\ &+\sum_l\sum_p I^2_{lp}S^2_{lp} + \sum_l\sum_p B_{lp}YM_{lp}\end{aligned} \tag{1}$$

- **Constraints**

$$\sum_j X_{ijqp} \le K^1_{iqp} \qquad \forall_{i,q,p} \tag{2}$$

$$\sum_k Y_{jkp} \le K_{jp}^2 \qquad \forall_{j,p} \tag{3}$$

$$\sum_l Z_{klp} \le K_{kp}^3 O_{kp} \qquad \forall_{k,p} \tag{4}$$

$$\sum_i \sum_q X_{ijqp} = \sum_k Y_{jkp} \qquad \forall_{j,p} \tag{5}$$

$$\sum_j Y_{jkp} + S_{kp-1}^1 = \sum_l Z_{klp} + S_{kp}^1 \qquad \forall_{k,p} \tag{6}$$

$$\sum_k Z_{klp} + S_{lp-1}^2 = D_{lp} + S_{lp}^2 + YM_{lp-1} + YM_{lp} \qquad \forall_{l,p} \tag{7}$$

$$RQ_q \sum_i X_{ijqp} = R_{jqp} \qquad \forall_{j,q,p} \tag{8}$$

$$\sum_i \sum_j T_{ijp}^1 + \sum_j T_{jp}^2 + \sum_j \sum_q T_{jqp}^3 + \sum_k T_{jkp}^4 + \sum_k TS_{klp} = T_{lp}^7 \quad \forall_{l,p} \tag{9}$$

$$\sum_k O_{kp} \le F \qquad \forall_p \tag{10}$$

$$TS_{klp} \le T_{klp}^5 \, W_{klp} \qquad \forall_{k,l,p} \tag{11}$$

$$TS_{klp} \ge T_{klp}^6 W_{klp} \qquad \forall_{k,l,p} \tag{12}$$

$$W_{klp} \le O_{kp} \qquad \forall_{k,l,p} \tag{13}$$

$$X_{ijqp}, Y_{jkp}, Z_{klp}, R_{jqp}, S_{kp}^1, YM_{lp}, TS_{klp} \ge 0 \;\; \text{integer} \quad \forall_{i,j,k,l,q,p} \tag{14}$$

$$O_{kp}, W_{klp} \in \{0,1\} \tag{15}$$

Equation (1) illustrates the objective function of the model. In this equation, it is aimed to minimize the costs of transportations between stages, purchasing costs, production and quality costs, fixed costs of the opened distribution center, inventory, and backorder costs. Equation (2) ensures that the raw material sent from suppliers cannot exceed the supplier capacity. Equation (3) is the capacity constraint for the manufacturers, while Equation (4) is the capacity constraint for the distribution center. Equation (5) is the balance constraint that ensures that the amount of product incoming to manufacturers is equal to the amount of outgoing product. Equation (6) and equation (7) is the JIT balance constraint that ensures that products arriving at distribution centers and retailers and outgoing products do not arrive early or late. Equation (8) is the constraint that gives the amount of additional processed raw material. Equation (9) is the constraint that determines the time of delivery that takes place from the distribution center to retailers. Equation (10) is the constraint that constitutes the upper limit for the number of distribution centers to be opened at each period. Equation (11) is the constraint that ensures that delivery from the distribution center to the retailer does not exceed the maximum time. Thus, the late arrival of the product to the retailer is also prevented. Equation (12) is the constraint that prevents delivery from the distribution center to the retailer before the minimum time. This prevents the early delivery of the product. Equation (13) is the constraint that allows each retailer to receive service from the open distribution center. Equation (14) is the constraint that allows variables in the model to be positive. Finally, equation (15) is the constraint that allows integer variables to take values of 0 or 1.

NUMERICAL EXAMPLE AND ANALYSIS RESULTS

In this section, a numerical example is presented through hypothetical data to demonstrate the validity of the proposed model. In the proposed problem, a supply chain network consisting of 4 suppliers, 3 manufacturing centers, 5 possible distribution centers, and 20 retailers has been designed. A 3-period distribution is planned for this supply chain network with a maximum of 3 distribution centers. The proposed model was analyzed using GAMS Distribution 21.6 program on a computer with a 2.50 GHz processor and 16 GB RAM.

In the solved model, the total objective function including transportation, production, purchasing, quality, early and late arrival penalty costs has been obtained as 718,716.090 TL and is shown in Table 1 together with the other statistics of the model.

Figure 2 shows the distribution plan for the supply chain network in the 1st period. The total amount of raw material supplied from the 2nd and 4th supplier in the 1st period is 8802 tons. 4790 tons of raw materials are sent to the first manufacturer as 1st quality raw material. Of the remaining 4012 tons are sent as 2nd quality raw materials to the third manufacturer. Accordingly, 54,42% of the total amount of raw material sent in the first period is 1st quality and 45,58% is 2nd quality raw material. In the 1st period first and second distribution centers opened to satisfy the demands of retailers.

Figure 3 shows the distribution plan for the supply chain network in the 2nd period. A total of 3150 tons of 2nd quality raw materials are sent from the fourth supplier to the first and third manufacturer. 5750 tons of 2nd quality raw materials are sent to the second manufacturer from the third supplier. In this period, 100% of raw material

Table 1. Model summary

Objective Value	718,716.090 TL
Resolutions Time	0,015 sn
Number of Continuous Variables	1231
Number of Constraints	1395
Number of Discrete Variables	315
Number of Iterations	625

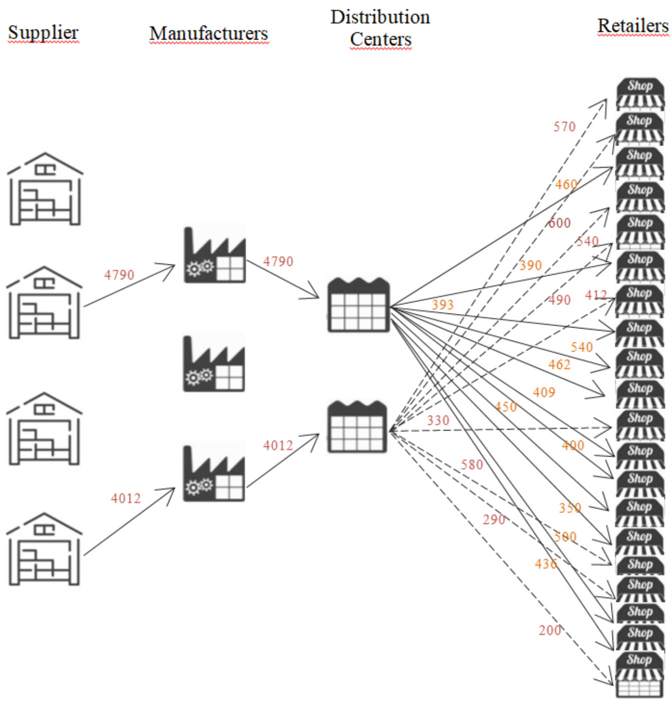

Figure 2. Distribution plan in the 1st period.

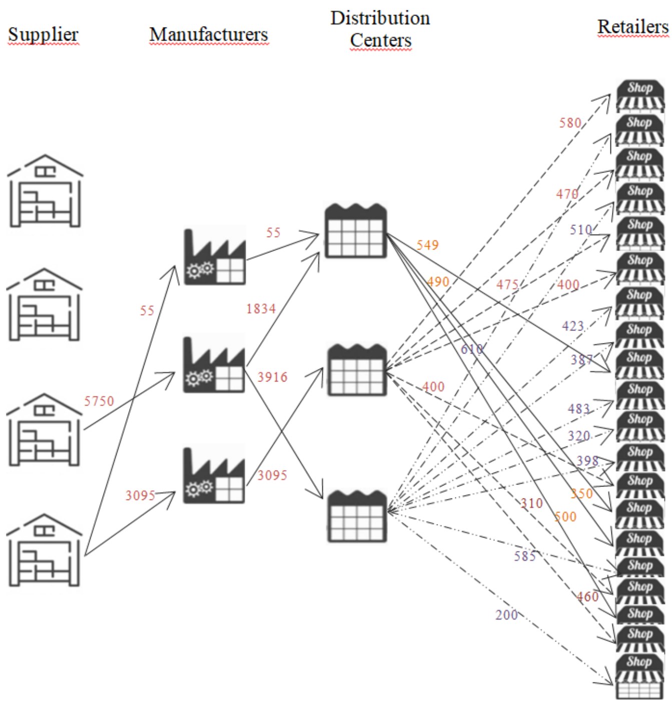

Figure 3. Distribution plan in the 2nd period.

procurement was realized as 2nd quality raw material. In the 2nd period, besides the first and second distribution center, the third distribution center was opened.

Figure 4 shows the distribution plan for the supply chain network in the 3rd period. In this period, the demands of the manufacturer are satisfied from the first and second suppliers. 4654 tons of 1st quality raw materials are sent from the first supplier to the second manufacturer. 4274 tons of 2nd quality raw materials are sent from the second supplier. Accordingly, 52,13% of the raw material supplied is 1st quality raw material and 47,87% is 2nd quality raw material. In the 3rd period, the first,

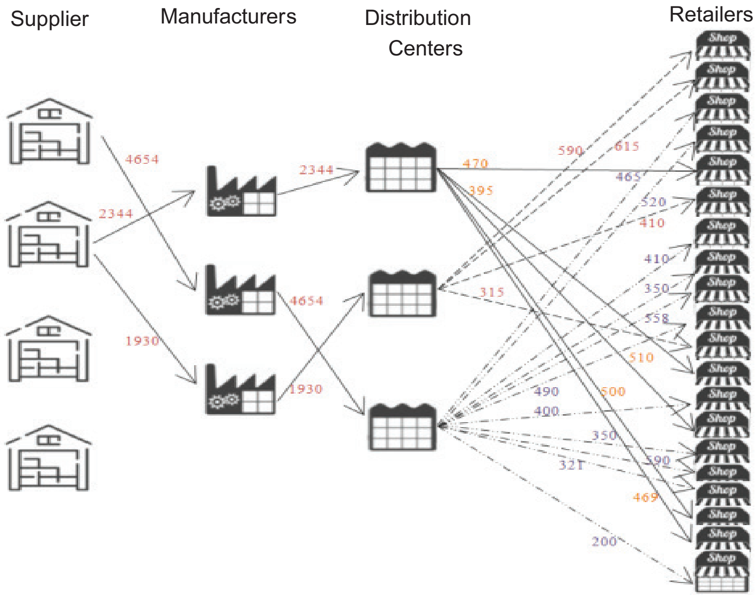

Figure 4. Distribution plan in the 3rd period.

Table 2. Quantity of additional processed raw materials

Quality Level of Raw Material	Period		
	1	2	3
1st Quality	239	0	232,7
2nd Quality	401,2	889,5	427,4
3rd Quality	0	0	0

second, and third distribution centers also satisfy retailer demands.

Table 2 shows the amount of reprocessing in the production centers according to the quality of the raw materials sent from the suppliers. 37,33% of the amount of additional processed raw material in the 1st period is composed of 1st quality raw materials and 62,67% is composed of 2nd quality raw materials. All of the raw materials processed in the second period consist of 2nd quality raw materials. In the third period, 35,25% of the amount of additional processed is composed of 1st quality raw material and 64,75% is second quality raw material. 3rd quality raw material is not preferred by any manufacturer in any period.

Table 3 shows the maximum, minimum and actual delivery lead times for products shipped to retailers. Since the minimum and maximum lead times are the same for all periods. A single value is given in the table. It is seen that the distribution from the distribution center to the retailers takes place just before the delivery time.

CONCLUSION AND FUTURE RESEARCH

A supply chain network is a chain of activities that includes processes from raw material procurement to satisfying customer demands. In this chain, not only the manufacturer's operations but also the operations of the supplier, distribution center, retailer and customers are very important. Because the product, information, and money flows realized in the system affect each other. JIT delivery is one of the most important activities affected by enterprises within the supply chain network. Any delays or early arrivals in production or distribution cause inventory or backorders in the enterprises. Therefore the cost in the supply chain is composed. The excess cost incurred in any enterprise within the chain has reflected the customer and all elements in the supply chain as cost. On the other hand, quality is another important factor to be considered in the supply chain JIT as it affects both the time factor and cost. Because JIT delivery is ensured by delivering the right quality product to customers at the right time without wasting. The factor that affects the delivery at the right time is the provision of the right quality product. Because the quality that cannot be ensured correctly leads to additional costs and processing times and leads to customer dissatisfaction.

In this article, a study on supply chain network design problem has been realized for supply chain system that wants to realize JIT delivery. The effect of the raw material quality on delivery time is investigated. A mixed-integer linear programming model is proposed for this study. The balance and time constraints created in the proposed model ensure delivery on time. Three quality levels have been determined for raw material quality. The higher the quality level, the higher the purchase cost, the lower the additional quality cost and additional processing time. This causes a tradeoff between cost and JIT delivery for manufacturers. To aid resolve this tradeoff, the proposed model is solved on a numerical example. The result shows that the

Table 3. Lead times of retailers

	Retailers	Minimum Lead Time	Maximum Lead Tİme	Actual Lead Time Period		
				1	2	3
1st Distribution Center	3	5	14	14	–	–
	5	3	6	–	–	6
	6	5	15	5	–	6
	8	5	17	16	–	–
	9	3	18	7	18	–
	10	3	3	3	–	–
	12	3	8	8	–	8
	13	4	12	7	–	–
	14	5	10	10	10	10
	15	3	9	3	9	–
	18	7	12	12	11	7
	19	3	8	7	–	8
2nd Distribution Center	1	6	16	13	16	16
	2	5	12	12	–	12
	3	8	19	–	13	–
	4	3	4	3	–	–
	5	9	12	12	12	–
	6	5	24	–	20	5
	7	3	3	3	–	–
	11	3	8	4	–	8
	13	5	17	–	17	–
	16	10	25	18	–	–
	17	5	11	5	5	–
	19	6	15	–	15	–
	20	4	11	6	–	–
3rd Distribution Center	2	6	14	–	6	–
	3	3	3	–	–	3
	4	12	21	–	15	12
	7	10	20	–	17	10
	8	3	7	–	7	7
	9	3	5	–	–	5
	10	8	16	–	16	11
	11	9	18	–	18	–
	12	11	21	–	14	–
	13	3	6	–	–	6
	15	4	18	–	–	18
	16	6	10	–	6	6
	17	7	24	–	–	20
	20	6	12	–	12	12

manufacturer's preference for high-quality raw materials enables lower costs and JIT delivery in the supply chain network.

In future research, the model proposed in the article can be applied to large-scale real data. A variety of heuristic methods can be used to eliminate large calculation times resulting from large data. In the model, two objectives can be created instead of a single objective and can be solved by various methods such as goal programming methods. Also, carbon emissions, the number of vehicles such as the number of trips with green targets can be realized in studies taking into account.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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