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RESEARCH PAPER

Optimization in Supply Chain Design of Assembled Products: A Case Study of HEPCO Company

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Abstract
HEPCO is an Iranian corporation that manufactures construction equipment and holds a supply chain with a traditional, non-integrated approach. The materials come from four different sources, including an engineering and parts company, domestic vendors, international vendors, and the company itself supplying the materials and components needed for assembling of products and delivering to customers. Having a non-integrated supply chain has led to an increase in total cost. Therefore, in order to reduce supply chain cost in this company, a three-level model including suppliers, manufacturers, and customers was used. Different ways also were applied to minimize chain cost, including purchase cost, transportation cost, inventory cost, assembly cost, and shortage cost, based on an integer linear mathematical model. It also considered such constraints as balance inventory, assembly capacity, storage capacity, amount of safety stock, and shortage, which were solved by MATLAB software. The results of proposed model were compared with the actual amount of variables in the study period, which indicated a significant reduction in the cost of proposed model comapred to the conventional methods.

Keywords: supply chain management, supply chain costs, mathematical model.

1. Introduction

More than seventy percent of a company's cost is due to supply chain activities, which shows the importance of supply chain management in the overall improvement of financial performance (Elgazzar et al., 2012). In today's challenging conditions, almost all organizations try to meet clients' demands and expectations in order to survive in the ever growing competitive environment. Hence, Supply Chain Management (SCM) has become an important concept amongst researchers and industrial experts (Ramezani et al., 2014).

Managers should be aware of how their operational actions can impact supply chain performance. SCM is a business term that emerged in the last few years and is gaining popularity. It seems to be replacing more of the traditional terms used to describe the management of material and service flows. These include physical distribution, materials management, production scheduling, logistics, channel management, industrial logistics, and distribution. One of the challenging research trends in SCM is increasing the total profit through the improvement of various activities and components (Esmaeeli & Aleahmad, 2021).

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In most of Iranian manufacturing companies, a traditional viewpoint of supply, production, and distribution planning is still extensively used. Each of these components is designed to operate independently, which increases the total cost in many cases.

Heavy Equipment Production Company (HEPCO) is the biggest manufacturer of road and mining machinery in the Middle East, which was established in 1975. The immediate purpose of this company was producing and assembling such products as dozers, loaders, rollers, excavators, and motor graders. Since 1990, when HEPCO created the SCM section, the company has simultaneously appointed professional engineering teams in supply and production segments to set and keep strategic cooperation with well-known brands around the world (Hamta et al., 2021).

The establishment of SCM section has resulted in an advantageous competition and qualified products that are delivered to the market on time. HEPCO actions can be outlined as below:

- To identify suppliers.
- To supply necessary items from foreign brands through business with main suppliers,
- To supply items from the local market through business deals with manufacturers and suppliers.
- To have technical cooperation with main foreign and local suppliers to maximize compatibility between orders and items received in HEPCO.
- To set a system for registering parts ordering on due time and take into account the capacity of the supplier based on MRP and JIT approaches.

This company has 1,500 employees with an annual production capacity of 4,800 units. It provides the materials and parts from four sources to assemble final products and deliver to customers (Ehsanifar & Ehtesham Rasi, 2017). According to the related studies that were carried out in the area of supply chain management, this problem has raised the question of how a mathematical model can be developed for this company that simultaneously considers physical aspects in a supply chain planning problem such as balance inventory, assembly capacity, storage capacity, amount of safety stock, and shortage amount.

In this study, in order to minimize the total supply chain costs including purchase cost, transportation cost, holding cost, assembly cost, and shortage cost, we present a mathematical model that simultaneously considers physical constraints in a supply chain planning problem.

The main steps of this study can be outlined as follows:

- Addressing the planning problem in a multi-period, multi-supplier, multi-echelon, and multi-production supply chain.
- Developing an Integer Linear Programming (ILP) model.
- Testing the applicability and efficiency of the proposed model through a real case study from HEPCO company.
- Comparing the results that were obtained by the proposed model with the actual amount of variables in the study period to show its applicability and advantages.

The rest of the paper is organized as follows. In Section 2, we briefly review the related modeling efforts in the existing literature. In Section 3, the problem statement and mathematical formulation are described in detail. Section 4 describes the proposed solution method. The results of the proposed model are compared to current method in the Section 5 and then in the last section, we summarize our results and give in directions for future research.

2. Literature Review

Sawik (2009) provided a mixed-integer programming model for the assembly scheduling problem for a supply chain with a long planning horizon. Sadeghi Moghaddam et al. (2009) suggested the integrated planning model for the supply, production, and distribution of supply chain using the genetic algorithm in Kachiran Company for minimizing supply chain costs. Nagurney (2010) offered a framework for designing the supply chain and re-designing it in order to determine the optimal levels of capacity and product flow between production, warehousing, and distribution (three levels) in order to minimize costs. Bilgen (2010) presented an integrated mathematical planning model that addressed production-distribution planning in a multi-level supply chain with several production lines, several factories, and several distribution centers.

Yeung et al. (2011) studied a two-echelon supply chain scheduling problem in which a manufacturer acquires supplies from an upstream supplier and processes orders from downstream retailers. The supply chain sells a single short-life product in a single season. They developed two practically relevant and robust methods for supply chain to achieve optimal profit-making performance through channel coordination. Paksoy et al. (2012) considered a problem to optimize a supply chain by balancing the assembly line and finally minimize the transportation and assembly costs. Schulze et al. (2012) developed a conceptual framework for costing based on chain activity. Cagri Koc (2017) suggested an integrated three-echelon model including suppliers, assemblers, and customers to balance assembly line and minimize transportation costs as well as the fixed costs of assembly stations. Özceylan and Paksoy (2013) presented a non-linear mixed-integer programming model which simultaneously determines optimal distribution between facilities with minimum cost, the number of disassembly work stations that will be opened with minimum cost, the cycle time in each disassembly center, and optimal assignment of tasks to work stations. The aim of their study was to optimize a reverse supply chain (RSC) – involving customers and collection/disassembly centers and plants – that minimizes transportation cost while balancing disassembly lines. A numerical example is given to illustrate the applicability of the proposed model.

Hamta et al. (2015) addressed the optimization of strategic and tactical decisions in the supply chain network design (SCND) under a demand uncertainty. In this respect, a two-stage stochastic programming model was developed in which strategic location decisions were made in the first stage, while the second stage contained SCND problem and the assembly line balancing as a tactical decision. In the solution scheme, the combination of sample average approximation and Latin hypercube sampling methods was utilized to solve the developed two-stage mixed-integer stochastic programming model. Yi et al. (2016) designed a closed loop supply chain network for remanufacturing construction machinery. They developed a mixed integer linear programming model and implemented an improved hybrid genetic algorithm. Finally, in order to demonstrate the applicability of the model, they evaluated a firm in Japan. Heydari et al. (2018) provided a mathematical framework for modeling manufacturing cell configuration and raw material supplier selection in a two-level supply chain network. Taheri and Beheshtian (2019) focused on minimizing total tardiness and earliness of orders in an integrated production and transportation scheduling problem in a two-stage supply chain. Moradi et al. (2019) developed an integrated process planning and scheduling learnable genetic algorithm architecture (IPPLEGA). Their goal was to optimize machine assignments and operational sequences and find a schedule so that the makespan is minimized.

Azadegan et al. (2019) extended the body of supply chain disruption management to the concept of near-misses and explained how institutional context plays a major role in learning supply chain disruption responses. Esmaeeli and Aleahmad (2019) focused on detecting bottlenecks by high-level petri nets in the job-shop production system. Their results showed the performance of high-level petri nets for detecting the bottlenecks and modeling the concurrent systems like job shop production systems. Rezaei et al. (2020) developed a supply chain network to manage customer relationships in a multi-objective model. They solved it by the improved multi-choice goal programming method. Azadegan et al. (2020) assessed the effectiveness of business continuity management and of supply chain involvement in BCM (SCiBCM) on reputational and operational damage containment in the face of supply chain disruptions. Tirkolaee et al. (2020) considered three aspects of sustainability to help companies obtain their targets. The goal programming and fuzzy methods were used to solve the problem. Yolmeh and Saif (2020) investigated a closed-loop supply chain network designing problem which was integrated with assembly and disassembly line balancing under demand and return uncertainty. The proposed network contains manufacturers, remanufacturers, assembly centers, intermediate centers (where disassembly lines are located), and customer centers. A new mixed integer non-linear programming model was developed for the proposed problem. Furthermore, an enhanced decomposition approach was developed to solve the proposed model.

Budak (2020) developed a sustainable reverse logistics network with an integration of disassembly line balancing to examine decisions in view of Triple Bottom Line. Andalib Ardakani et al. (2020) presented a multi-period, multi-product, multi-supplier, multi-objective sustainable supply chain in a ceramic tile industry in order to minimize costs and adverse environmental effects and increase social benefits. Moreover, a multi-period, multi-product, multi-supplier, multi-objective supply chain was designed. The quality issue with different technologies and capacity limitations for plants, warehouses, and distribution centers were considered. The problem was mathematically formulated by a mixed integer non-linear programming model and solved using a fuzzy goal programming approach. Ramezanian and Khalesi (2021) proposed a mixed integer nonlinear programming model to formulate the multi-product supply chain network, and solved it using GAMS. Finally, Imperialist Competitive Algorithm (ICA) and Genetic Algorithm (GA), as two well-known meta-heuristic algorithms, were applied to solve the model in larger dimensions. Abdolazimi et al. (2021) presented a mathematical model to classify inventory items, taking into account significant profit and cost reduction indices. Their model had an objective function to maximize the net profit of items in stock. The mathematical model was solved by Benders decomposition and Lagrange relaxation algorithms. Then, the results of the two solutions were compared. TOPSIS technique and statistical tests were used to evaluate and compare the proposed solutions with one another and choose the best one. A summary of previous works and the proposed model is provided in Table 1.

Table 1. Summary of Related Previous Works and the Proposed Model

Article	Network	Model	Objective function	Problem definition
Karimi et al. (2015)	CL	LP	SO	Multi-production, multi-supplier, multi-plant, multi-transportation
Validi et al. (2015)	OL	ILP	MO	Multi-transportation and environmental design
Kisomi et al. (2016)	CL	ILP	SO	Multi-plant and multi-transportation
Özceylan et al. (2017)	CL	ILP	MO	Environmental design
Nurjanni et al. (2017)	CL	ILP	MO	Environmental design
Ghaithan et al. (2017)	OL	ILP	MO	Multi-plant
Kadziński et al. (2017)	OL	ILP	MO	Multi-transportation, environmental design
Mota et al. (2018)	CL	ILP	MO	Multi-production, multi-transportation, multi-plant, environmental design
Liu & Papageorgiou (2018)	OL	ILP	SO	Multi-production, multi-transportation, multi-plant, environmental design
Emamian et al. (2018)	CL	INLP	MO	Multi-production, multi-supplier, multi-plant
Guo et al. (2019)	OL	MILP	MO	Multi-production, multi-transportation, multi-supplier, multi-plant, environmental design
Mogale et al. (2020)	OL	MILP	SO	Supply chain network costs and determining number and location of procurement centers
Yolmeh & Saif (2020)	CL	MINLP	SO	Mode selection
Biglar et al. (2022)	OL	MINLP	SO	Multi-product, Multi-echelon supply chain network
Proposal model	OL	ILP	SO	Multi-period, Multi-supplier, Multi-echelon, Multi-production

Note: OL= Open loop; CL= Close loop; INLP= Integer nonlinear programming; ILP= Integer linear programming; MO=Multi-objective; SO= Single objective

Based on the above-mentioned works, this study presents a mathematical model that simultaneously considers physical aspects in a supply chain planning problem such as balance inventory, assembly capacity, storage capacity, amount of safety stock, and shortage amount. We develop a deterministic integer linear programming (ILP) model to specify the quantities of parts to be produced or purchased from suppliers, stored and transported in order to meet the customers' demands and to minimize the total chain costs including purchase cost, transportation cost, holding cost, assembly cost, and shortage cost.

3. Problem Definition and Formulation

This paper is based on modeling the material flow in the supply chain of HEPCO company with a tensile production system. Hence, the movement direction is as downstream to upstream of the chain. Figure 1 shows the components flow for supply chain of this company with a three-level supply chain including suppliers, manufacturers, and customers.

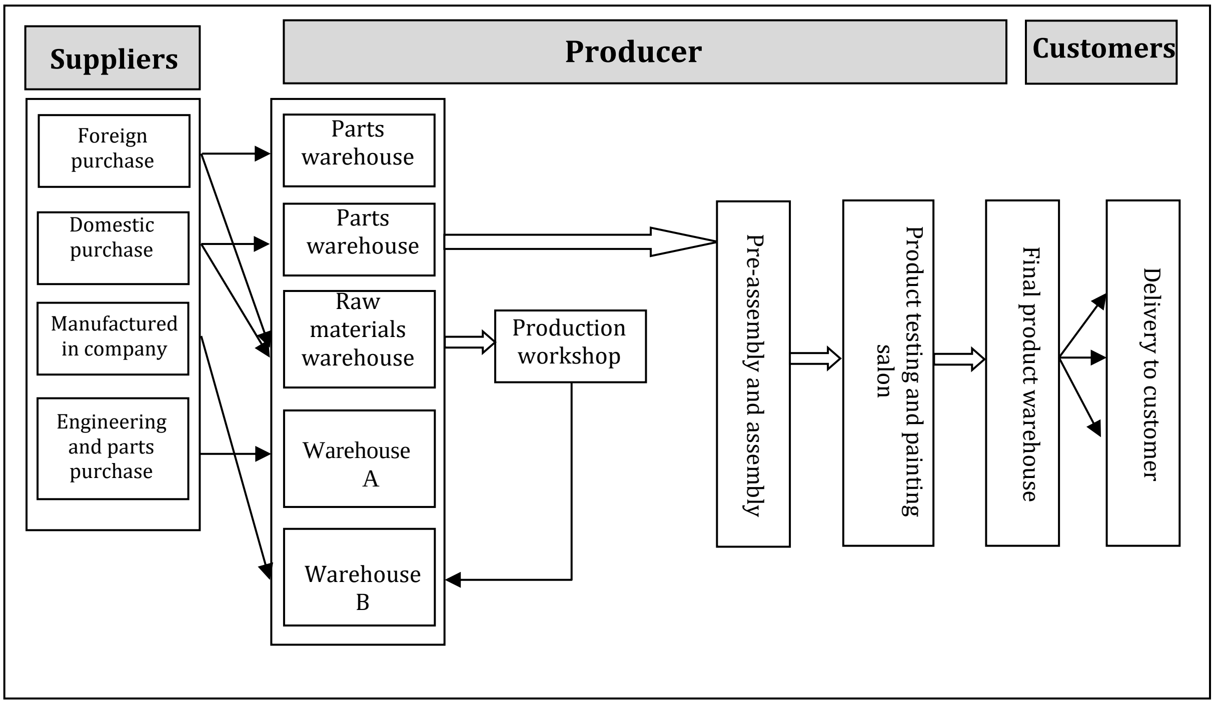

Figure 1. Schematic Diagram of HEPCO Supply Chain

This three-level supply chain includes four suppliers, one producer and customers. It is aimed to reduce the supply chain costs (costs of purchase, transportation, shortage, production, storage, and assembly). Finally, the assembly program for 7 types of products in 2019 is reported in Table 2.

The sample parts were selected using ABC analysis. This method is an inventory management technique that determines the value of inventory items based on their importance to business. Applying the ABC method, managers can categorize inventory items into several classes based on their demand, cost, risk, etc. In this study, using the ABC method and based on experts' opinion, 478 out of 4579 types of parts were chosen for planning. In Table 3, the number of selected samples of each product has been specified based on suppliers.

Table 2. Annual Ordering Data for Products

Assembly program of products in 2019													
Product name	**Program number**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
HEPCO grader	66		5	9		4	14	4		10	10	10	
Straight vibration roller	161	20	30	20	10	20	5	10	5	11	10	10	10
Asphalt roller	23		8		5			5				5	
Static roller	70	10		20		10			10	10		5	5
Sanco loader	70			20	20		20		10				
HEPCO loader	89	10	9		15	10		5		10		20	10
Hydraulic excavator	40		10		10			10				10	
Total	519	40	62	69	60	44	39	34	25	41	20	60	25

Table 3. Data for Selected Samples of Products

Statistical samples chosen from each product according to suppliers					
Product name	**Foreign purchase**	**Domestic purchase**	**Engineering and parts company**	**Manufactured in company**	**Total number of parts**
HEPCO grader	31	8	30	28	97
Straight vibration roller	15	6	13	17	51
Asphalt roller	12	6	29	18	65
Static roller	10	4	19	19	52
Sandco loader	9	3	29	10	51
HEPCO loader	14	6	27	30	77
Hydraulic excavator	25	5	28	27	85
Total	116	38	175	149	478

Therefore, the problem is an integer linear programming with fixed demands, and the assumptions, parameters, and variables are as follows:

Assumptions

- Demand is deterministic and dynamic in each period.
- The capacity of suppliers is limited.
- The capacity of assembly line is limited, and it is programmed based on the number of devices charged to assembly line.
- The capacity of warehouses is limited.
- The assembly line is designed for a unique model of a single product.
- The process time is defined for each work station on the assembly line and production hall.
- A task cannot be divided between two or more work stations and all tasks must be processed.

Model Parameters

t: time period ($t = 0,1,2,\ldots,T$)
i: purchased part ($i = 0,1,2,\ldots,I$)
r: produced part in the workshop ($r = 0,1,2,\ldots,R$)
k: parts required for assembly ($k = 0,1,2,\ldots,K$)
s: number of suppliers ($s = 0,1,2,\ldots,S$)
j: the product made in assembly workshop ($j = 0,1,2,\ldots,J$)

p: number of warehouses (p = 0,1,2,…,P)
e: working station (e = 0,1,2,…,E)
D_{jt}: demand for product j in period t
n_{ij}: number of part i used to make product j
n_{rj}: number of part r used to make product j
cc_{it}: purchasing cost of part i in period t
cp_{rt}: production cost of part r in period t
cd_{jt}: production cost of product j in period t
h_{ipt}: cost of maintaining a unit part i in warehouse p in period t
ΠS_{it}: cost of facing the shortage of a unit part i in period t
ΠL_{rt}: cost of facing the lack of a unit part r in period t
ΠP_{jt}: cost of facing the lack of a unit product j in period t
ma_{ke}: processing time of a unit part k at assembly station e
mm_{re}: processing time of a unit part r at manufacturing station e
mp_j: processing time for a unit product j at final assembly station
CP_{et}: time capacity of production at assembly station e in period t
CCP_{et}: time capacity of production at manufacturing station e in period t
$CCPF_t$: time capacity of production at final assembly station in period t
TC_{is}: transportation cost per a unit part i from supplier s
TC_r: transportation cost per a unit part i
TCP_{jc}: cost of transportation for a unit product j to customer c
SS_{ipt}: amount of precautionary storage of part i in period t in warehouse p
SSP_{jtp}: amount of precautionary storage of product j in period t in warehouse p
CS_{ipt}: storage capacity of part i in period t in warehouse p
CSP_{jtp}: storage capacity of product j in period t in warehouse p

Model Variables

XS_{ist}: value of part i purchased from supplier s in period t
XR_{rt}: value of produced part r required in period t
XA_{ket}: value of part k required at assembly station e in period t
XP_{jt}: value of product j that is produced in period t
XD_{jct}: value of product j that is sent to customer c in period t
I_{ipt}: value of part i stored in warehouse p at the end of period t
IM_{jpt}: value of product inventory j maintained in warehouse p at the end of period t
L_{it}: value of part i deficiency at the end of period t
LD_{jt}: value of deficiency due to non-coverage of product j demand at the end of period t

Mathematical Model

$$\min \quad Z^{\cos t} =$$

$$\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{s=1}^{S}\sum_{p=1}^{P}\left(cc_{it}XS_{ist} + h_{ipt}I_{ipt} + \Pi S_{it}L_{it} + TC_{is}XS_{ist}\right) \tag{1}$$

$$\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{p=1}^{P}\left(cp_{rt}XR_{rt} + h_{rpt}I_{rpt} + \Pi L_{rt}L_{rt} + TC_{r}XR_{rt}\right) \tag{2}$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{p=1}^{P}\left(cd_{jt}XP_{jt} + h_{jpt}I_{jpt} + \Pi P_{jt}LD_{jt}\right) \tag{3}$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{c=1}^{C}\left(TCP_{jC}XD_{jct}\right) \tag{4}$$

The objective function (1) shows the purchasing, maintenance, shortage, and shipping costs for the purchased parts, respectively. The objective function (2) indicates the production, maintenance, shortage, and shipping costs of the produced parts. The objective function (3) shows the assembly, maintenance and shortage costs of the manufactured products. The objective function (4) indicates the cost of shipping products to customers.

These are subject to:

$$\sum_{p=1}^{P} I_{ipt-1} + \sum_{s=1}^{S} XS_{ist} - \sum_{j=1}^{J} n_{ij} XP_{jt} = \sum_{p=1}^{P} I_{ipt} \qquad \forall i, t \tag{5}$$

This limitation relates to ensuring purchased parts (inventory balance of parts) and indicates that the inventory at the end of each period equals the first inventory of the period plus purchases during the period minus consumption for manufacturing products.

$$\sum_{p=1}^{P} I_{rpt-1} + \sum_{e=1}^{E} XR_{rt} - \sum_{j=1}^{J} n_{rj} XP_{jt} = \sum_{p=1}^{P} I_{rpt} \qquad \forall r, t \tag{6}$$

This constraint, like equation (5), relates to ensuring the manufactured parts (inventory balance of parts) in the manufacturing workshop.

$$\sum_{p=1}^{P} I_{jpt-1} + \sum_{j=1}^{J} XP_{jt} - \sum_{p=1}^{P} I_{jpt} = \sum_{c=1}^{C} XD_{jct} \qquad \forall j, t \tag{7}$$

This constraint relates to the inventory balance of the final product. It states that the output of product *j* in period *t* plus the inventory at the start of product j period in the final-product warehouse minus the end-of-period inventory of this product is equal to the value of the product sent to customers from this warehouse.

$$\sum_{r=1}^{R} XR_{rt} \times mm_{re} \le CCP_{et} \qquad \forall e, t \tag{8}$$

This limitation relates to the production capacity at production stations. It suggests that the extent of producing parts should be based on the capacity of machinery available in production stations.

$$\sum_{k=1}^{K} XA_{ket} \times ma_{ke} \le CP_{et} \qquad \forall e, t \tag{9}$$

This constraint relates to the production capacity at assembly stations and indicates that the extent of assembling parts should be based on the capacity of assembly stations.

$$\sum_{j=1}^{J} XP_{jt} \times mp_{j} \le CCPF_{t} \qquad \forall t \tag{10}$$

This constraint relates to the processing capacity of the final product.

$$\sum_{p=1}^{P} IM_{rpt} \ge \sum_{p=1}^{P} SSP_{rpt} \qquad \forall r, t \tag{11}$$

$$\sum_{p=1}^{P} I_{ipt} \ge \sum_{p=1}^{P} SS_{ipt} \qquad \forall i, t \tag{12}$$

$$\sum_{p=1}^{P} I_{jpt} \ge \sum_{p=1}^{P} SS_{jpt} \qquad \forall j, t \tag{13}$$

The constraints (11), (12), and (13) indicate the minimum-reserve maintenance necessary for different parts and products in all warehouses.

$$\sum_{r=1}^{R} I_{rpt} \le CS_{rpt} \qquad \forall p, t \tag{14}$$

$$\sum_{i=1}^{I} IM_{ipt} \le CSP_{ipt} \qquad \forall p, t \tag{15}$$

$$\sum_{j=1}^{J} I_{jpt} \le CS_{jpt} \qquad \forall p,t \tag{16}$$

The constraints (14), (15), and (16) indicate the storage capacity of different warehouses for maintaining different parts and products.

$$n_{ij} D_{jt} - \left[\sum_{s=1}^{S} XS_{ist} + \sum_{p=1}^{P} I_{ipt-1} + n_{ij} \sum_{p=1}^{P} IM_{jpt-1} \right] = L_{it} \qquad \forall i,t \tag{17}$$

This constraint indicates the shortage extent of the purchased parts *i*. The shortage in each period is equal to the number of parts required to estimate demand minus the sum of purchased parts in each period, parts inventory at the beginning of the period, and the extent of parts consumed for product inventory at the beginning of the period.

$$n_{rj} D_{jt} - \left[\sum_{e=1}^{E} XR_{rt} + \sum_{p=1}^{P} I_{rpt-1} + n_{rj} \sum_{p=1}^{P} IM_{jpt-1} \right] = L_{rt} \qquad \forall r,t \tag{18}$$

This constraint, like the constraint (17), expresses the shortage extent of manufactured parts.

$$D_{jt} - \sum_{c=1}^{C} XD_{jct} = LD_{jt} \qquad \forall j,t \tag{19}$$

It indicates the deficit extent of product *j*. The deficit extent of products in each period equals the demand amount for products in each period minus the shipping extent of products to customers in each period.

$$XS_{ist}, I_{ipt}, L_{it} \ge 0 \qquad \forall i,t,s,p \qquad integer \tag{20}$$

$$XP_{jt}, XD_{jct}, IM_{jpt}, LD_{jt} \ge 0 \qquad \forall j,t,c,p \qquad integer \tag{21}$$

$$XR_{rt}, I_{rpt}, L_{rt} \ge 0 \qquad \forall r,t,e,p \qquad integer \tag{22}$$

The constraints (20) to (22) indicate the integer and positive values of variables.

4. Solution Method

To solve the model, MATLAB software was used where input data was achieved from products, warehouses, the capacity of assembly line stations, the capacity of in-house parts manufacturing stations, and marketing. The model was solved through the consideration of the constraints for inventory balance of parts and products in each period, the available capacity in the parts manufacturing unit in each period, the capacity of the product assembly unit in each period, the warehouse capacity, and secure storage in each period. The obtained results of the proposed model were compared with the method currently applied in HEPCO company.

5. Computational Results

In this section, the results of the proposed model are compared with the current situation. The results that were achieved from comparing the current situation with answers of the designed model are shown below.

5.1. Production

In this part, the number of products that were manufactured in each period is compared in Table 4 according to the proposed model and current method.

Table 4. The Number of Produced Items According to the Proposed Model and Current Method

Number of devices produced in each period												
Criterion	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Current method	26	37	44	90	61	27	31	34	23	51	11	84
Proposed model	40	62	69	60	44	39	34	25	41	20	60	25

5.2. Holding Cost

The amount of inventory is affected by the amount of purchase based on the need in each period. If the purchase is in excess of the need, it will increase inventory and eventually its related costs. In Table 5, holding costs are shown based on the proposed model and current method, while Figure 2 gives in a comparison of these costs.

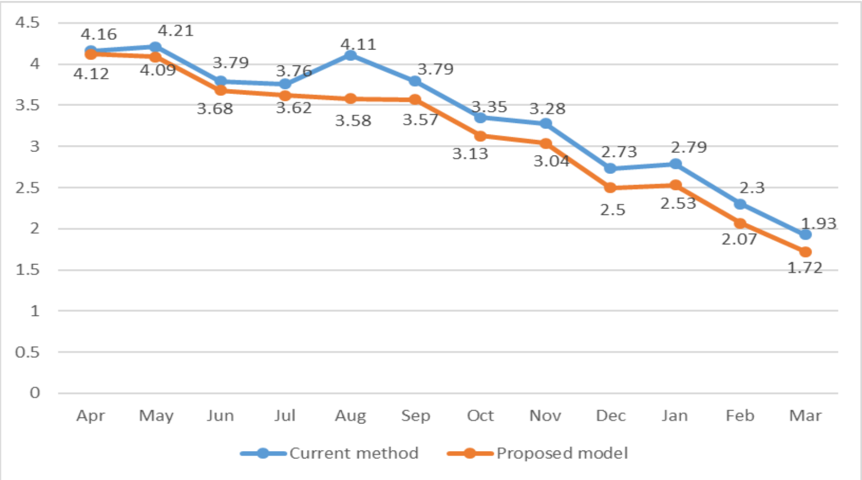

Figure 2. Comparison of Holding Costs Based on the Proposed Model and Current Method

Table 5. Holding Costs Based on the Proposed Model and Current Method

Holding cost in each period (billion rials)												
Criterion	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Current method	4.16	4.21	3.79	3.76	4.11	3.79	3.35	3.28	2.73	2.79	2.30	1.93
Proposed model	4.12	4.09	3.68	3.62	3.58	3.57	3.13	3.04	2.50	2.53	2.07	1.72

5.3. Shortage Cost

Lack of parts prevents the production of items and stops the assembly line; moreover, the shortage of products will result in delay fines due to non-timely delivery to customers. In Table 6, the costs of parts and products shortage are displayed for the current method. In the proposed model, with respect to high costs of parts and products shortage, the number of parts and products shortage reached zero in each period.

Table 6. Shortage Costs According to Current Method

Shortage cost according to current method in each period (billion rials)												
Criterion	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Deficit of parts	0.90	2.40	3.06	1.94	0.82	2.01	2.16	1.03	2.72	0.36	4.30	0.00
Deficit of products	0.33	1.24	1.31	0.71	0.45	0.86	0.98	0.39	1.13	0.23	1.77	0.00
Total	1.23	3.65	4.37	2.65	1.27	2.88	3.14	1.42	3.85	0.60	6.07	0.00

5.4. Transportation Cost

The transportation cost of parts is estimated according to the number of parts that were purchased from different suppliers. In Table 7, the transportation cost of parts from suppliers to the company as well as the transportation cost of products from the company to customers are displayed based on the model and current method. These are compared in Figure 3.

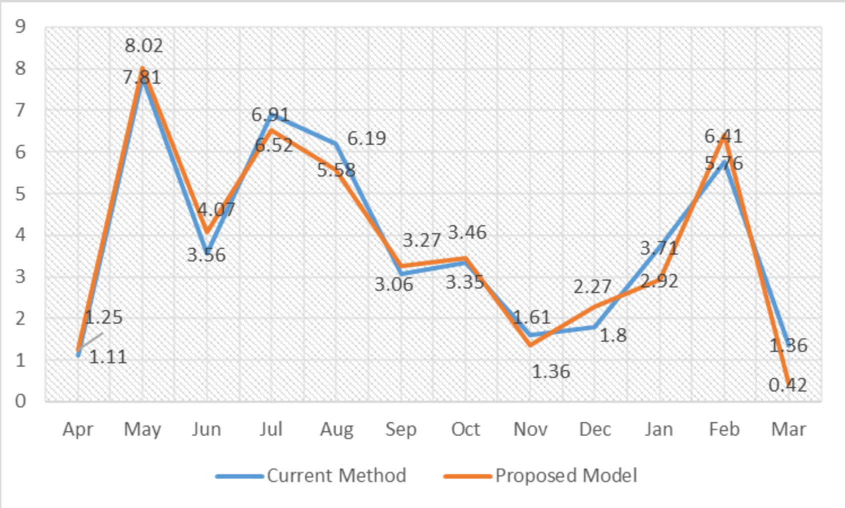

Figure 3. Comparison of Transportation Costs (Billion Rials) of Parts and Products Based on the Model and Implementation Method

Table 7. Comparison of Transportation Cost According to the Model and Current Method

	Transportation cost in each period (billion rials)											
Criterion	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Current method	1.11	7.81	3.56	6.91	6.19	3.06	3.35	1.61	1.80	3.71	5.76	1.36
Proposed model	1.25	8.02	4.07	6.52	5.58	3.27	3.46	1.36	2.27	2.92	6.41	0.42

5.5. Total Supply Chain Cost

Finally, the total cost of supply chain, including costs of purchase, maintenance, shortage, transportation, and assembly for each period, are shown in Table 8 and compared in Figure 4.

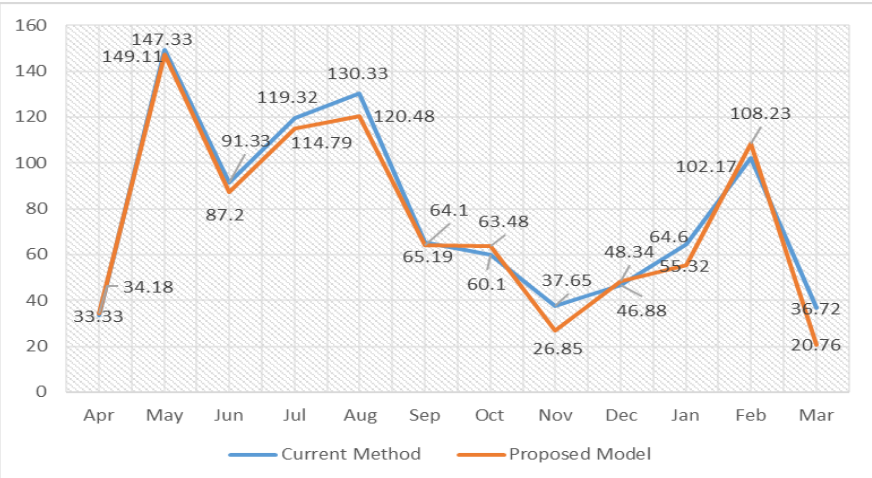

Figure 4. Comparison of Supply Chain Costs According to the Proposed Model and Current Method in Each Period

Table 8. Total Supply Chain Cost Based on the Proposed Model and Current Method

	Total supply chain cost in each period (billion rials)											
Criterion	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Current method	33.33	149.11	91.33	119.32	130.33	65.19	60.10	37.65	46.88	64.60	102.17	36.72
Proposed model	34.18	147.33	87.20	114.79	120.48	64.10	63.48	26.85	48.34	55.32	108.23	20.76

5.6. Model Validation

To conduct the model validation, the results of model implementation, presented by MATLAB software and compared with current method, suggest that there is a reduction in the supply chain costs. The results are shown in Table 10 and compared in Figure 6.

Table 9. The Total Supply Chain Cost According to the Proposed Model and Implementation Method

Criterion	Cost rate (rials)
Total cost of supply chain according to the current method	936,730,551,751
Total cost of supply chain according to the proposed model	891,044,435,816
Reduction rate of supply chain cost	45,686,115,934

The results show a reduction in the supply chain costs based on the proposed model at the rate of 4.877% amounting to 45/68 billion rials compared with the current method. The rate of cost reduction indicates the accuracy and validation of the provided model. In Table 10, the parameters affecting the supply chain will be ranked and the extent of parameters affecting the total cost reduction will be indicated and compared in Figure 7.

Table 10. Ranking of Parameters Affecting Reduction in Supply Chain Costs

Rank	Cost type	Cost reduction (rial)	Percentage
1	Shortage cost	31,124,507,994	68.1 %
2	Purchase cost	11,354,262,594	24.9 %
3	Holding cost	2,529,192,680	5.5 %
4	Transportation cost	678,152,666	1.5 %
Total reduction of supply chain		**45,686,115,934**	**100 %**

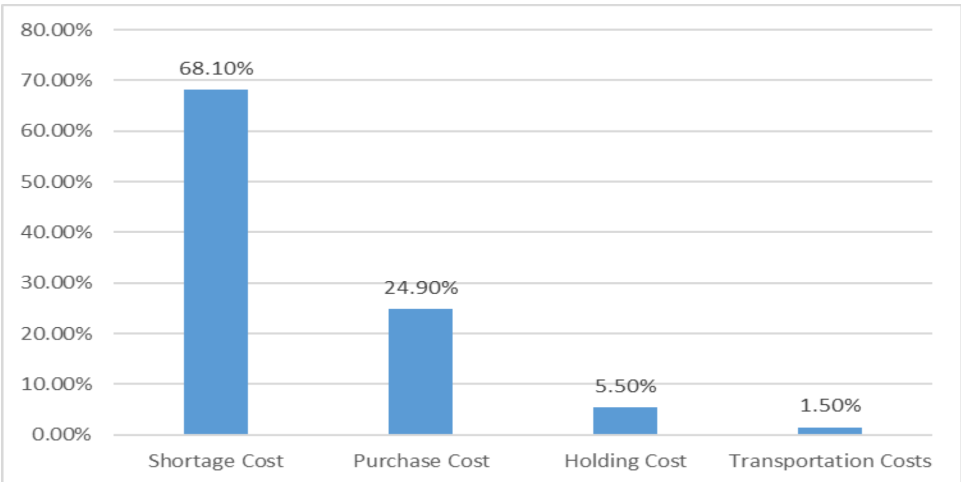

Figure 5. Reduction Percentage of Chain Cost Relative to Total Reduction of Supply Chain Cost

Table 11 indicates the total cost of supply chain and total production cost relative to the cost reduction of the proposed model.

Table 11. Comparison of Total Supply Chain Cost and Production Cost After the Implementation of Proposed Method

Criterion	Cost (rials)	Percentage of cost reduction
Total cost of supply chain according to current method	936,730,551,751	4.877 %
Total cost of producing products according to current method	1,549,337,500,000	2.949 %
Supply chain cost reduction	45,686,115,934	

5.7. Managerial Insight

As a result of decreasing profit margins and the competitive landscape, supply chain managers are forced to design and optimize the operation of their supply chain networks by considering operational and financial performance indexes at the same time. Through the implementation of the proposed model in a real case study, several managerial implications were gained. The model developed in this study was implemented in HEPCO Company as a case study, and its manager can respond to customers' needs and determine correct policies to order raw materials, deliver finished goods, balance the assembly lines, and efficiently manage their operations. What HEPCO basically seeks is to maximize value added for its beneficiaries, one important group of whom are suppliers of parts and raw materials the long term and strong business with whom will certainly contribute to more qualified products and service. This paper presented a mathematical model that simultaneously considered physical aspects in a supply chain planning problem such as balance inventory, assembly capacity, storage capacity, amount of safety stock, and shortage amount. The results showed the applicability of the proposed problem in real life situations to find and manage optimal solutions.

6. Conclusions and Future Studies

The main ambition of a supply chain manager is to ensure correct flow of goods and information through all the supply chain nodes to guarantee the right goods in the right place at the right time. To achieve these results, it is very important to consider the flow of items and finances to/from supply chain nodes, which is generated by market demand and production capacity.

In different organizations, one of the most important goals is the optimal use of all capacities to reach the main objectives. One of the most important decisions in such organizations is based on production and logistics. Making an appropriate decision for planning and production is very important in the long-time horizon. On the other hand, the concept of supply chain is one of the most widely used concepts in the field of production. This concept required development and improvement through production, logistics, and financial decisions.

The most important aim of supply chain managers is to satisfy their customers to enhance the market share of their companies. In this regard, the minimization of the total costs of supply chain networks is considered as the first goal of company executives. By minimizing the total costs of the manufacturing network, the final price of products will be minimized. As a result, more customers will be eager to buy products from the company. In most Iranian manufacturing companies, a traditional viewpoint of supply, production, and distribution planning is still used. Each of these components is designed to operate independently, which increases the total cost in many cases. Company managers tend to improve the cost efficiency of their supply chain networks. Therefore, they aim to minimize the final price of their products to improve their customers' satisfaction. The comprehensive models of supply chain planning contain the production of different parts. This study has developed a mathematical model that presents a comprehensive production and assembly planning supply chain over the medium term. By implementing the model and focusing on the parameters affecting the reduction of supply chain cost, it could be possible to significantly reduce the total cost, including costs of purchase, storage, shortage, transportation, and assembly.

The proposed model was implemented in HEPCO Company as a case study. We developed a deterministic integer linear programming (ILP) model to specify the quantities of parts to be produced or purchased from suppliers, stored and transported in order to meet customers' demands and to minimize the total supply chain costs including purchase cost, transportation cost, holding cost, assembly cost, and shortage cost.

A real data case study was used in order to prove the validity of the proposed model. The results indicate that there is a 4.877% (equivalent to 45.68 billion rials) reduction in the total supply chain cost based on the proposed model. Finally, the total production cost is reduced by 2.949% while the profit margin of road-construction machinery is 10% at most.

Moreover, several suggestions are made for future works as follows. The first suggestion is to incorporate uncertainty into some parameters such as demand and costs in order to obtain a model or solution approach closer to real-world situations. With these extensions, the model would become more complex, thus increasing its computational complexity. Therefore, exploring other types of algorithms, such as metaheuristics, to solve the problem could be another direction for future studies. Furthermore, presenting a large-scale problem solving algorithm such as branch-based and price-based precise algorithms or benders algorithm for the proposed problem can be attractive for research. The model in this paper was implemented in HEPCO as a case study, but any small and medium-sized enterprise (SME) can be investigated as a case study by the proposed model.

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