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A mathematical model of development of the green process in the textile industry: A case study of Oyaz Industrial Company

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Abstract

The development of green product process is a strategic approach to minimizing the effect of an organization's supply chain on the environment while expanding its economic performance. In doing this, the dimensions focused on performance are essential in optimizing resource consumption and achieving sustainability concepts in an organizational context. For this purpose, in this study, a multi-objective mixed integer linear programming model is proposed with the aim of minimizing textile manufacturing time, transportation costs, and product inventory, as well as minimizing environmental effects in the green product development process. In this model, the constraints and parameters of the problem are certain and are solved using weighted sum methods, for which real data obtained from Oyaz Industrial Group are used. By solving the model, an optimal combination for the values of the objective functions is obtained in combination and separately. Finally, the effect of changing key parameters such as the maximum storage capacity of manufacturing centers on the decisions of the proposed model is examined through sensitivity analysis. This change of parameter is determined by consulting textile experts. According to the obtained results, changing the maximum storage capacity has a significant effect on fibers and cotton. Also, in case of changing the capacity to the maximum possible value, it would have the greatest effect on the refiners. The least effect caused by changing the capacity of planting fields of environmentally friendly raw materials occurs when the capacity increases by 20,000. In this case, the least effect is made on the fields. Also, the least effect of a change in capacity on inventory costs in the storage warehouse occurs when the capacity increases by 50,000. Finally, the least effect of changing the capacity over time on the pollution rate occurs when the capacity is increased by 10,000 units.

Keywords: green product development, green process, mathematical modeling, textile
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1 Introduction

Global competition in a constantly changing environment has made organizations realize the importance of flexibility and show thought-out and timely reactions. Today, organizations need to be globalized and present in this big

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arena for their survival, even if they want to be present at the national or regional level, they should think globally [9]. In the studies conducted, the capabilities of this proper model have been emphasized once again by adding a five-letter word to supply chain management. "Green" is a suffix that has turned this concept into green supply chain management, in the sense that by implementing green policies along the supply chain, we can witness the transfer of cleanliness and health from the organization to the environment, the individual, and organizations and have an environmental view of the supply chain. In order to explain this concept, the green supply chain management has been defined as: "adopting environmentally friendly supply chain management practices, including internal environmental management, green purchasing, cooperation with customers and designing environmentally friendly products in line with the development and operational strategies of the company for the sustainability of the environment surrounding the company". Nevertheless, the evidence indicates that organizations have responded to the needs of customers as well as the pressures of international and government organizations supporting environmental issues for several years and have accepted the necessity of environmental management and have implemented green supply chain management in order to compete with global markets [1]. Many buying companies demand that their suppliers implement green supply chain management practices and even meet additional environmental requirements, and the importance of this issue globally is such that suppliers are severely under pressure for finding any business opportunity in the new space without green supply chain management practices and practices. The environmental view of the supply chain is relevant in any country, in any industry and at any level [2].

With the increasing environmental concerns, consumers, governments, and various societies around the world and manufacturing companies are striving to develop environmentally friendly programs such as green product development, green brand, and green technology. These concerns have been extended to various industries to the extent that today one of the important factors in the activities of companies, from the supply of raw materials to the manufacturing process of a new product in the factory and the issues that arise during the use of the product by the consumer, are environmental considerations. Among environmental management measures, measures for the development of environmentally improved products are of great importance [14]. These measures create business opportunities for the organization, improve the organization's image in society, and creates competitive advantages. Organizations with green product development can increase their incomes by increasing customer satisfaction. In other words, greenness improves business practices and can be considered as one of the factors affecting organizational performance because this strategy increases profitability, improves employee motivation and commitment, and customer loyalty. The mentioned factors have caused all organizations across the world to consider the improvement in the development process of green products as one of their most important implementation plans, and as a result, many researchers seek to find optimal values in order to decrease time and cost in the product development process and study and investigate the issues raised in this field [12]. Moreover, the challenges surrounding operations research methods and mathematical planning by modeling and solving these problems in the real world have led to the reduction of costs in organizations. Especially in recent decades, significant progress in the field of computer systems in terms of hardware and software and increasing the integration of information systems have led to the effective and wider use of heuristic and metaheuristic search methods to solve this category of problems [4].

According to mentioned above, the most important objective of this research is to provide a mathematical model to optimize cost and time in the process of green product development. Therefore, the most important contribution of the research is to propose a multi-objective mixed integer linear programming model with the aim of minimizing time and cost, which is able to minimize the environmental effects in the process of green product development in the textile industry. In this model, the constraints and parameters of the problem are certain and are solved using conventional methods. Therefore, the most important innovation of the research is to provide a comprehensive model for green product development by formulating its flow using mathematical programming, while simultaneously examining cost and time in the process of green product development using a multi-objective mathematical modeling.

2 Literature review

In this section of the research, past studies on the development of green product processes are reviewed. For this purpose, Dong et al. [5] investigated the strategic investment of green product development in a supply chain. A two-period model was developed in this study in which the retailer or manufacturer can decide to invest. Also, under certain conditions, the prices were assumed to be lower in the second period. However, the corresponding demand in the second period was always lower than the first period, which includes green products. Raut et al. [13] investigated performance-based indicators for the implementation of green management practices in the agricultural sector in India. In this study, the hard (operational and technology-based) and soft (human-resource-based) performance indicators of the green value chain in the context of the Indian agro-based industry were analyzed. Performance indicators were identified using research sources and analyzed using a quantitative approach. Several hypotheses were developed to examine the interrelationship between "green practices" and "business performance" in the agricultural sector. Zhang et al. [8] developed product capabilities through supply chain quality management. Supply chain quality management was considered as a vital method for product recall management by the manufacturer. This study selected three manufacturers from the food, automobile, and pharmaceutical industries to conduct a case study. The results showed that quality management teamwork and supplier competence had a positive relationship with product recall.

Zindani et al. [15] proposed a decision-making framework making decisions by modeling the settings of experts using fuzzy sets in a fuzzy environment. The proposed decision-making framework was investigated to identify the optimal set of process parameters (weight percentage and duration of chemical treatment) according to technical, environmental, and economic conditions. The validity, accuracy, and robustness of the ranking was carried out by the sensitivity analysis method and solving past case studies. This decision-making framework provided a tool for deriving a set of optimal parameters for green composites from agricultural wastes that could be used to examine the possibilities of designing green products and, consequently, achieve sustainable goals. In a study, Barros et al. [6] investigated the relationship between the circular economy and sustainable businesses, and using a systematic review, drivers were identified. These drivers included strategic planning, cost management, circular supply chain management, quality management, environmental management, process management, logistics and reverse logistics, service management, and research and development. Furthermore, the key effect of changes in product development was provided by the circular economy, helping management for more business sustainability. According to the obtained results, adopting a circular economy-based thinking might provide the possibility of achieving sustainable results. Kong and Liu [10], in their study, created a new system to justify economic, environmental, and social indicators. Based on the evaluation framework, a directional distance function based on the measurement model was adopted to measure the sustainability of port cities from the perspective of external effect and internal interaction. For this purpose, nine port cities in China were selected as the research scope. Lavuri et al. [11] investigated green factors for buying organic products (consequences of sustainable development) in a research. In this research, they created the orientation of consumers towards environmentally friendly products, which is considered as a social challenge, in the natural components of their products. Also, in this study, the effect of green factors on customers' intention to buy organic products has been investigated. They showed that the mediating role of trust and attitude is very important to ensure consumers' sustainable orientation towards organic products.

In their article, Dzikriansyah et al. [7] investigated the role of green supply chain management practices on environmental performance in small and medium enterprises in Indonesia. The results showed that internal factors such as strategic orientation and internal environment management did not lead the enterprises to consider green supply chain management. Meanwhile, the external factor as government regulations played a significant role in adopting green supply chain management. The findings also proved that internal factors did not affect environmental performance through green supply chain management. In this study, Chakraborty et al. [3] investigated the internal factors related to the green supply chain by an interpretive structural modeling approach. In this study, eight factors were identified that could be controlled within the organization. Among these eight factors, senior management commitment was the most important factor for its highest driving force. The reverse logistics process was at the next stage, and material storage and management were at a high level.

According to the investigations carried out in theoretical and experimental studies, the observed research gap is in the field of providing a mathematical model to optimize the process of green product development, and research on this basis has yet to be conducted. Therefore, the innovation and contribution of this research is as follows:

1. Simultaneous investigation of cost and time in the process of green product development using a multi-objective mathematical modeling.
2. Provision of a comprehensive model for green product development by formulating its flow using mathematical programming.

3 Methodology

In this research, a multi-objective model for the manufacturing of green products for the textile industry in the manufacturing of decorative fabrics is proposed. The components of this model include manufacturer, supplier, and consumer. As can be seen from the introduced components, a green supply chain network is considered in which the manufacturer is required to use environmentally friendly materials such as cotton, hemp, and bamboo fibers in the manufacturing of decorative fabric and also to control chemical effluents to the environment. Therefore, in this research, we intend to create saving in terms of transportation and inventory costs for a manufacturer of decorative fabrics while designing and optimizing a logistics network that is able to consider environmental factors in production for manufacturing and supply of green products. In fact, we want to provide a strategic planning for the supply chain of the factory from manufacturing to distribution of textiles in the form of a network. Figure 1 shows the green product manufacturing chain.

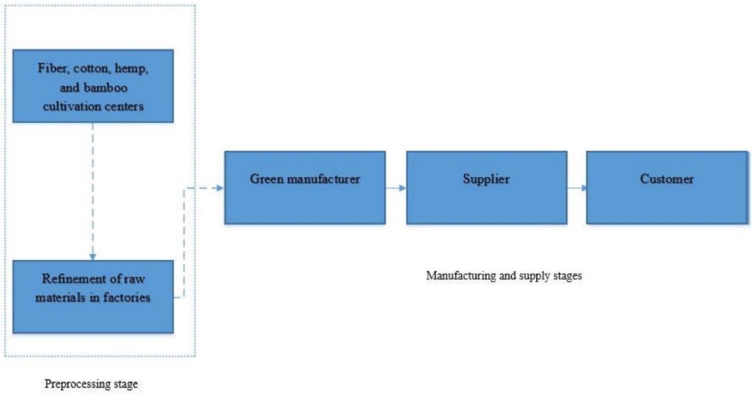

Figure 1: Supply chain structure

3.1 Mathematical modeling

In this section, all symbols used to describe sets, parameters, and variables of the problem are explained.

Sets

I: Set of fields for the manufacturing of environmentally friendly raw materials (cotton, hemp, and bamboo fibers), $1, ..., I$

J: Set of refiners in factories, $1, ..., J$

P: Set of environmentally friendly raw materials, $1, ..., P$

T: Set of periods, $1, ..., T$

D: Set of suppliers $1, ..., D$

S: Set of storage warehouses, $1, ..., S$

C: Set of consumers, $1, ..., C$

H: Set of factories, $1, ..., H$

Indices

$i \in I$: Index related to the set of fields,

$j \in J$: Set of refiners,

$o \in P$: Set of raw materials,

$t \in T$: Set of periods,

$d \in D$: Set of suppliers,

$s \in S$: Set of warehouses,

$c \in C$: Set of consumers,

$h \in H$: Set of factories.

Parameters

$capacity_i$: Maximum capacity of the i-th field,

Cx_{ijt}: Cost of transferring raw materials from the i-th field to the j-th refiner at the t-th time,

Cyj_{jhpt}: Cost of transferring raw materials from the j-th refiner to factory h at time t

Cyd_{dcpt}: Cost of transferring decorative textiles from the d-th supplier to the consumer at the t-th time

Cyh_{hdpt}: Cost of transferring decorative textiles from the h-th manufacturer to the supplier at the t-th time,

Cds_{dst}: Cost of transferring textiles from distributor d to warehouse s,

Csd_{sdt}: Cost of transferring textiles from warehouse s to distributor d,

γds_{dst}: Transfer percentage of textiles from distributor d to warehouse s,

γsd_{sdt}: Transfer percentage of textiles from warehouse s to distributor d,

CI_{jt}: Cost of raw materials imported to refinery center j at time t,

CIc_{ctp}: Cost of consumption of textiles in consumer centers c at time t,

CId_{dtp}: Cost of consumption of textiles in distribution centers d at time t,

CIh_{htp}: Cost of consumption of raw materials in manufacturing centers h at time t,

λ_{ip}: Percentage of the amount of product p (environmentally friendly raw materials) from the entrance of the i-th field,

Dh_{htp}: Amount of demand of factory center h of environmentally friendly raw materials P in period t,

$CIhm_{im,h,t}$: Cost of transferring raw materials from centers i_m to manufacturing center h at time t,

CI'_{jt}: Cost of purchasing materials imported from abroad to refinery center j at time t,

CIh'_{htp}: Cost of manufacturing textile in manufacturing centers h at time t.

Variables

All the variables of this research are of continuous type and do not follow any integer or binary variable. These variables are:

x_{ijt}: Amount of transferring raw materials from the i-th field to the j-th refiner at the h-th time

yh_{jhpt}: Amount of transferring organic cotton from the j-th refiner to manufacturer h at the t-th time,

$y'h_{jhpt}$: Amount of transferring hemp from the j-th refiner to the manufacturer at the t-th time,

$y''h_{jhpt}$: Amount of transferring bamboo from the j-th refiner to the h-th manufacturer at the t-th time,

ds_{dst}: Amount of transferring textiles from distributor d to warehouse s,

sd_{sdt}: Amount of transferring textiles from warehouse s to distributor d,

II_{jt}: Inventory of raw materials imported from the field to refiner j at time t,

Id_{dtp}: Inventory of textiles in distribution centers d at time t,

Ih_{htp}: Inventory of textiles in refinery centers h at time t,

Ic_{ct}: Inventory of textiles in warehouse centers s for consumption at time t,

II'_{jt}: Amount of raw materials purchased for refinery center j at time t,

Ih'_{hpt}: Amount of textile production in manufacturing centers h at time t,

$Ihm_{im,h,t}$: Amount of raw materials from import centers i_m to manufacturing center h at time t,

tx_{htp}: Duration of manufacturing of textiles in the factory.

Objective functions

Considering the above, the mathematical model of linear programming in a certain form is developed for the mathematical modeling of the problem considered in the following equations.

$$\begin{aligned} A = & \sum_{i\in I}\sum_{j\in J}\sum_{t\in T} x_{ijt}\cdot Cx_{ijt} + \sum_{j\in J}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T}(yh_{jhpt}+y'h_{jhpt}+y''h_{jhpt})\cdot Cyj_{jhpt} \\ & + \sum_{j\in J}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T}(yh_{jhpt}+y'h_{jhpt}+y''h_{jhpt})\cdot Cyh_{hdpt} + \sum_{j\in J}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T}(yh_{jhpt}+y'h_{jhpt}+y''h_{jhpt})\cdot Cyd_{dcpt} \\ & + \sum_{j\in J}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} ds_{dst}\cdot Cds_{dst} + \sum_{j\in J}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} sd_{sdt}\cdot Csd_{sdt} \end{aligned} \tag{3.1}$$

equation (3.1) calculates the transfer costs of raw materials and decorative textiles. For this purpose, it calculates the transfer costs from the refinery to the factory, from the factory to the supplier and then from the supplier to the consumer. Also, it takes into account the transfer costs from the warehouse at the manufacturer and supplier.

$$B=\sum_{j\in J}\sum_{t\in T}CI'_{jt}\cdot II'_{jt}+\sum_{j\in J}\sum_{t\in T}CI_{jt}\cdot II_{jt}+\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}CIh'_{htp}\cdot Ih'_{htp}+\sum_{c\in C}\sum_{t\in T}\sum_{p\in P}CIc_{ctp}\cdot Ic_{ctp}$$
$$+\sum_{d\in D}\sum_{t\in T}\sum_{p\in P}Id_{dtp}\cdot CId_{dtp}+\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}Ih_{htp}\cdot CIh_{hpt}+\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}CIh_{im,htp}\cdot Ih_{im,htp} \tag{3.2}$$

equation (3.2) calculates the inventory cost of decorative textiles. For this purpose, the inventory of raw materials to enter the refinery, as well as the inventory of the factory and then the inventory of the supplier is calculated.

$$C=\sum_{i\in I}\sum_{p\in P}\lambda_{ip}\cdot(yh_{jhpt}+y'h_{jhpt}+y''h_{jhpt})+\gamma_{sdt}\cdot\Bigg(\sum_{j\in J}\sum_{t\in T}CI'_{jt}\cdot II'_{jt}+\sum_{j\in J}\sum_{t\in T}CI_{jt}\cdot II_{jt}$$
$$+\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}CIh'_{hpt}\cdot Ih'_{htp}+\sum_{c\in C}\sum_{t\in T}\sum_{p\in P}CIc_{ctp}\cdot Ic_{cpt}$$
$$+\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}Ih_{htp}\cdot CIh_{htp}+\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}CIh_{im,htp}\cdot Ih_{im,htp}\Bigg) \tag{3.3}$$

equation (3.3) calculates the amount of environmental pollution in the manufacturing centers.

$$D=\gamma_{dst}\cdot\left(\sum_{d\in D}\sum_{t\in T}\sum_{p\in P}Id_{dtp}\cdot CId_{dtp}\right) \tag{3.4}$$

equation (3.4) calculates the amount of environmental pollution in the distribution centers.

$$F=tx_{hpt}\cdot\left(\sum_{h\in H}\sum_{t\in T}\sum_{p\in P}Dh_{htp}\right). \tag{3.5}$$

Also, the duration of manufacturing of textiles is considered in Equation (3.5). In general, the objective functions considered in mathematical modeling in this research include textile transfer costs (A) and inventory cost (B), also, the amount of environmental pollution in the manufacturing centers (C) and the amount of environmental pollution in the distribution centers (D) and the duration of textile manufacturing (F). In order to overcome the weakness of the methods when the number of objectives is more than two, due to the fact that some objectives have the same units with each other, such as Objectives A), (B, C), and (D), the sum of objectives with same units is considered as the final objective and the problem becomes a three-objective problem. According to mentioned above, the sum of Equations (3.1) with (3.2) is considered as F1 and (3.3) with (3.4) as F2, and the final objective function is considered as $E=0.33\times F1+0.33\times F2+0.33F$.

Constraints

$$\sum_{j\in J}x_{ijt}\le capacity_i \qquad \forall i\in I,t\in T \tag{3.6}$$

constraint (3.6) ensures that the maximum amount sent is considered from the field to the refiners.

$$II_{jt}=II_{jt-1}+\sum_{i\in I}x_{ijt}-\sum_{i\in I}\sum_{p2\in P}yh_{jhpt}-\sum_{c\in C}\sum_{p1\in P}yh'_{jhpt}-\sum_{h\in H}\sum_{p3\in P}yh''_{jhpt} \qquad \forall i\in I,t\in T \tag{3.7}$$

constraint (3.7) shows the inventory of raw materials imported from refiners.

$$\sum_{i\in I}\sum_{p\in P}(yh_{jhpt}+y'h_{jhpt}+y''h_{jhpt})\le\sum_{i\in I}\lambda_{ip}\cdot x_{ijt} \qquad \forall j\in J,t\in T,p2\in P \tag{3.8}$$

constraint (3.8) guarantees that the amount of raw materials to be sent from refiner j to the manufacturers must not be greater than the maximum input refined product.

$$\sum_{i\in I}\lambda_{ip}\cdot x_{ijt}\ge D_{htp}\forall j\in J,t\in T,p3\in P \tag{3.9}$$

constraint (3.9) guarantees that the amount of manufactured textiles to be sent to other distributors must meet the demand for the desired product.

$$Id_{dtp} = \sum_{s\in S} \gamma sd_{st} sd_{sdt} - \sum_{s\in S} \gamma ds_{st} \cdot ds_{dst} \qquad \forall d \in D, t \in T, p2 \in P \tag{3.10}$$

constraint (3.10) calculates the amount of textiles that can be supplied in the distribution centers.

$$Ih_{htp} = Ih_{h,t-1,p} + \sum_{h\in H}\sum_{t\in T} Ihm_{im,ht} \qquad \forall d \in D, t \in T, p2 \in P \tag{3.11}$$

in Constraint (3.11), the amount of manufactured textiles that can be supplied to supply centers is calculated.

4 Findings

In this section, taking into consideration the items specified in Table 1 as predetermined parameters, the programmed problem is calculated to control the considered parameters in a problem with small dimensions as follows. The mentioned problem is implemented in the GAMS software for the values of the sets given in Table 1. The feasibility of this problem is shown in the third chapter by determining a set of answers based on solving the model in this way.

Table 1: Sets defined for the problem in small dimensions

Defined sets	**value**
Set of fields for the manufacturing of raw materials	$i_1; i_2; i_3$
Set of refiners in factories	$j_1; j_2$
Set of environmentally friendly raw materials	Cotton, fibers, hemp, and bamboo
Time periods	$t_1; t_2; t_3$
Factories	$h_1; h_2$
Distributors	$d_1; d_2; d_3$
Warehouses	$s_1; s_2$

In this case, the cost of transferring raw materials from the i-th field to the j-th refiner at the t-th time (x_{ijt}) is calculated according to Table 2.

Table 2: Optimal value of x_{ijt}

To / From	j_1			j_2		
	First period	Second period	Third period	First period	Second period	Third period
i_1	0	71.489	106.080	85.335	76.101	18.449
i_2	0	0	0	0	0	0
i_3	0	0	0	0	0	0

Based on the calculated results, the total cost of transferring raw materials which includes (fibers, cotton, hemp, and bamboo) is shown in Table 2. The cost of transferring raw materials in the first period from field i_1 to the first refinery center is zero. Also, this value from the second and third centers in all periods to the first and second refinery centers is zero. Moreover, the maximum value of condensate transfer in the third period from the first field to the first center in the third period is 106.080. Also, Table 3 shows the inventory of raw materials imported from the field to refinery center j at time t $t(II_{jt})$.

Table 3: Value of II_{jt}

Refinery	**First period**	**Second period**	**Third period**
j_1	0	0	20.749
j_2	0	7.9.6	13.601

Based on the results obtained for the value of II_{jt}, the value of raw materials in the total of fibers, cotton, hemp, and bamboo imported in the first period to both refineries is zero. Also, the inventory of the refineries center in the second period is zero. On the other hand, the inventory of the refinery in the third period is 20.749, which is the highest value of inventory during the time periods. Table 4 shows the value of transferring organic cotton from the j-th refiner to manufacturer h at the t-th time, (yh_{jhtp}), the value of transferring hemp from the j-th refiner to the manufacturer

Table 4: Optimal values of $(yh_{jhtp}), (y'h_{jhtp}), (y''h_{jhtp}), (y'''h_{jhtp})$

Raw materials	From \ To	First period h_1	First period h_2	Second period h_1	Second period h_2	Third period h_1	Third period h_2
(yh_{jhtp})	j_1	0	0	22	0.070	0	12
	j_2	7	19.342	0	15.577	0	0
$(y'h_{jhtp})$	j_1	0	15	22	0.863	0	14
	j_2	7	16.324	0	15.577	0	0
$(y''h_{jhtp})$	j_1	0	10.214	22	0.070	0	12
	j_2	9	17.247	0	17.542	0	0
$(y'''h_{jhtp})$	j_1	0	0	28	0.956	0	24
	j_2	5	12.254	0	19.247	0	0

at the t-th time, $(y'h_{jhtp})$, the value of transferring bamboo from the j-th refiner to the h-th manufacturer at the t-th time, $(y''h_{jhtp})$ and also, the value of transferring fiber from the j-th refiner to the h-th manufacturer at the t-th time, $(y'''h_{jhtp})$.

The amount of raw materials from import centers i_m to manufacturing center h at time t, (ihm_{imdt}) is according to Table 5.

Table 5: Value of (ihm_{imdt})

To-From	Period 1	Period 2	Period 3
$i_1 \to h_1$	55.886	0	48.150
$i_1 \to h_2$	51.886	0	49.150
$i_2 \to h_1$	0	0	0
$i_2 \to h_2$	39.902	0	0

According to the calculated results, the value of raw materials imported to the first and second factories in the second period is zero. Also, the imported raw materials sent to the first and second factories in the first period have the highest value, among them, the highest value of raw materials is from the import department of the first factory in this period, which is 55,886. Finally, Table 6 shows the value of transferring textiles from warehouse s to distributor d, (sd_{sdt}).

Table 6: Value of (sd_{sdt})

To-From	Period 1	Period 2	Period 3
$s_1 \to d_1$	0	0	0
$s_1 \to d_2$	0	0	0
$s_1 \to d_3$	0	0	0
$s_2 \to d_1$	112.960	0	0
$s_2 \to d_2$	86.760	0	0
$s_2 \to d_3$	234.104	0	0

By calculating the aforementioned values, the value of the objective function is calculated according to Table 7. Given that the multi-objective problem in this thesis is calculated using the weighted sum method, the optimal value of the objective function depends on the weight value that is considered for the objective functions. Since the form of the objective function in the weighted sum problem is as $w_1 f_1 + w_2 f_2 + w_3 f_3$ and the sum of the weights is equal to one $(\sum w_i = 1)$, different modes can be considered for the coefficients as shown in Table 7.

Table 7: Value of the objective function for different weights

Row	w_1	w_2	w_3	Value of objective function
1	0.1	0.7	0.2	35996.988
2	0.2	0.7	0.1	57969.729
3	0.3	0.5	0.2	76014.309
4	0.5	0.4	0.1	92482.238
5	0.3	0.2	0.5	108570.220
6	0.6	0.2	0.2	12815.680
7	0.7	0.1	0.2	134993.518
8	0.2	0.4	0.4	128171.356
9	0.5	0.3	0.2	161349.194

According to the results obtained for the objective function, it can be seen that the value of the objective function is strongly dependent on the weight of the first objective. With an increase in its value, the value of the objective function increases, and on the other hand, the higher the weight of the second objective function, the lower the value of the objective function.

4.1 Sensitivity analysis

In this section, the effect of changing key parameters such as the maximum storage capacity of manufacturing centers on the decisions of the proposed model is investigated. This change of parameter is determined in consultation with textile experts. As shown in Figure 2, the change of maximum storage capacity has a significant effect on fiber and cotton. Figure 2 shows the value of parameter change for different values in each product.

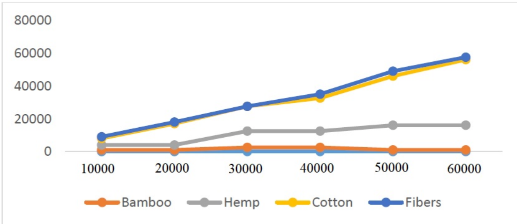

Figure 2: Change of the parameter "capacity" on the amount of textile raw materials

It is also important to mention that the change of the key parameter on the entire objective function is investigated. For this purpose, the value of the objective function is calculated for each center. According to the results of the objective functions, the effect of the parameter "maximum capacity" was ignored. Figures 3, 4, and 5 show the effect of the parameter "maximum capacity" on transfer costs, inventory costs, and environmental pollution, respectively. According to Figure 3, if the capacity is changed to the maximum possible value, it has the greatest effect on the refiners. The least effect from the change in capacity occurs when the capacity is increased by 20,000, in which case the fields are least affected.

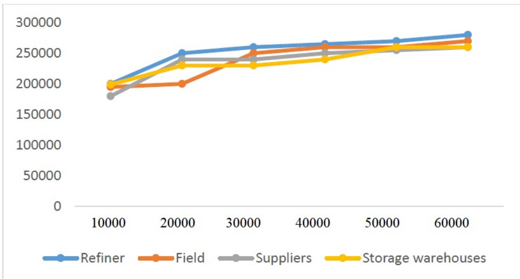

Figure 3: Effect of capacity on transfer costs

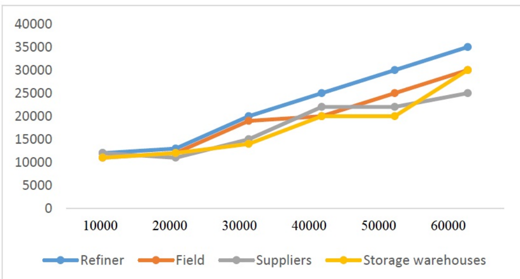

Figure 4: Effect of capacity on inventory cost

According to Figure 5, if the capacity is changed to the maximum possible value, the suppliers in the chain will have the greatest effect of pollution. The least effect caused by the change in capacity occurs when the capacity is increased by 10,000 units, in this case, the pollution would be determined by the suppliers.

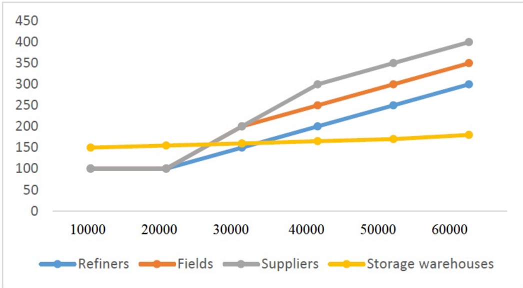

Figure 5: Effect of capacity on the amount of pollution

5 Conclusion

In this study, a mathematical modeling method was proposed for the manufacturing of green textiles in a textile company, addressing the importance of paying attention to the green supply chain, taking into account the reduction of environmental pollution. Based on the proposed mathematical model, the design of the green product supply chain brought favorable effects to those involved in this field: improving the company's image, increasing customer value and customer loyalty, reducing customer complaints, product compliance with global standards. Also its internal effects: increased supply chain integration (e.g., increased information access, process productivity, and supply chain collaboration), increased sales revenue, productivity logistics, and competitiveness. Therefore, considering the above content and its importance in this research, a multi-objective mixed integer linear programming model with the aim of minimizing textile manufacturing time and transfer costs, and product inventory as well as minimizing environmental effects in the process of green product development was provided. In this model, the constraints and parameters of the problem are certain solved certainly using weighted sum methods, for which real data obtained from Oyaz Industrial Group was used. Finally, the effect of changing key parameters such as the maximum storage capacity of manufacturing centers on the decisions of the proposed model was investigated through sensitivity analysis. This parameter change was determined by consulting with textile experts. Based on the obtained results, changing the maximum storage capacity had a significant effect on fibers and cotton. Also, if the capacity was changed to the maximum possible value, it would have the greatest effect on the refiners. The least effect from the change in capacity occurred when the capacity was increased by 20,000, in which case the fields were least affected. Furthermore, if the capacity was changed to the maximum possible value, it would have the greatest effect on the inventory of refiners. The least effect from the change in capacity occurred when the capacity was increased by 50,000, in which case the least inventory cost was placed in storage warehouses. Finally, if the capacity was changed to the maximum possible value, the suppliers in the chain would have the greatest effect of the pollution. The least effect caused by the change in capacity occurred when the capacity was increased by 10,000 units, in this case the pollution would be determined by the suppliers. For further research, it is suggested to use the robust planning approach in the developed model. Also, meta-heuristic methods should be used to measure the capability of the model in small, medium, and large dimensions. Because if the degree of difficulty of the model increases, the mathematical model may not be able to solve the problem in large or very large dimensions. For this purpose, the use of meta-heuristic methods is suggested.

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