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A MULTI-PERIOD MATHEMATICAL MODEL IN WOODEN PRODUCTS SUPPLY CHAIN CONSIDERING ENVIRONMENTAL EFFECTS

Organizations encounter different challenges in order to succeed in worldwide competitive market. Therefore, activities such as supply and demand planning, inventory control, distribution and delivery of after sales service which were considered separately in previous notions of management; are now investigated under new general concept of supply chain in all effective organizations. In this research, a mathematical model is presented for reducing the costs of wooden products supply chain. The research results represent the cost effective performance of the proposed model. Also the results of the sensitivity analysis show that when the demand rate increases, the environmental and production cost will increase. Hence, the contribution of this paper can be summarized as follows: 1. Considering environmental factors in wooden products supply chain, 2. designing a genetic algorithm to reduce the cost of wooden products supply chain, 3. Considering return flow and collection centers in wooden products supply chain.

Keywords: Supply chain; Environmental effects; Inventory control; Meta-heuristic algorithm

1. INTRODUCTION

Due to today's global competition, various products should be available based on the customers' requirements (Wu et al, 2017). Customer's need of high quality and quick services will lead to an increase in pressure that did not exist before. Therefore, companies cannot handle everything alone anymore (Habibi et al, 2017). In the current competitive market, economical and manufacturing companies deal with managing and monitoring external resources in addition to dealing with their internal resources (Chan et al, 2016). The reason is to achieve the competitive advantage or advantages with the aim of gaining a bigger market share. Therefore, activities such as supply and demand planning, materials provision, products production and planning, product maintenance services, inventory control, distribution, delivery and services to customers that were done in company level before, are now transferred to supply chain level (Pedram et al, 2017). The key issue in a supply chain is the control and management of all the activities. Supply chain is a phenomenon that performs this issue in a way that customers can receive quick and valid services along with high quality products with the least cost (Sabotka et al, 2017). Generally, supply chain includes two or more organizations that are separated from each other formally and can be connected to each other by information, material and cash flows (Dondo et al, 2016). These organizations can be companies that produce raw materials, pieces, final products or services such as distribution, storage, retailing, wholesaling. The final consumer can also be one of these organizations. Transportation is an important issue in economic, production and service systems and is an important part of GNP of each country (Mota et al, 2018). Therefore, researchers try to improve the roads and omit unnecessary travels and create short substitute routes. On the other hand, physical distribution of products is one of the key activities of production companies, since approximately more than 20% of the cost of finished products is devoted to physical distribution system. Improvement of distribution system can lead to the reduction of the costs and the enhancement of productivity (Hu et al, 2016). In this research, a chipboard factory is considered in a 5-level supply chain including several material suppliers, one producer, several wholesalers and retailers and recovery centers that provides its wooden raw materials by purchasing cut down trees and also provides different kinds of firewood from specific suppliers; and is going to distribute its products in the country level. Wooden raw materials are transported to the factory by suppliers with specific vehicles. The chipboard products are transported from the factory by determined vehicles to distribution centers (wholesaler and retailer) and then are transported from distribution centers to all the retailers. Reverse supply chain includes: producer, wholesalers, retailers and collection centers (recovery). Wooden raw materials and wood waste are transported from the suppliers to the factory by determined vehicles. The products are transported from the factory to the distribution centers by determined vehicles and then are transported from the wholesalers to the retailers. We are going to find the best raw material transportation rate from each supplier to the factory and finally calculate the total cost of the supply chain. Figure 1 presents the structure of the proposed supply chain in this research. The main objective in this model is finding the optimum rate of purchasing the cut trees to achieve an appropriate logistic cost.

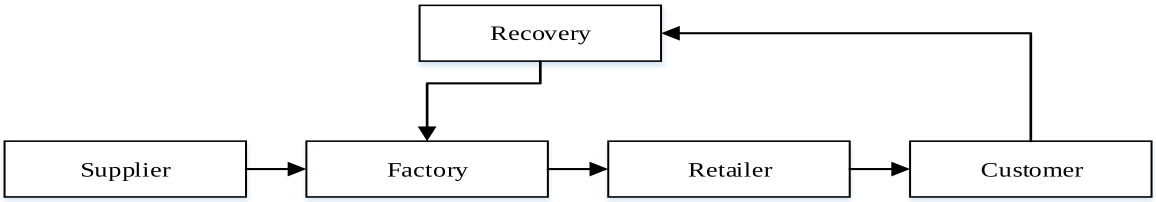

Figure 1. Supply Chain Structure

This research is presented in 6 sections. In the second section, literature review is discussed and in the third section, mathematical model is presented. In the fourth and fifth sections, the algorithm is solved and the calculation results are presented. Finally, in the sixth section, the conclusion is presented.

2. LITERATURE REVIEW

Heydari et al (2018) stated that the main and primary objective of the supply chain management is the integration of organizations that are separated legally. This function allows the organization to reduce the delivery time of products to markets, minimize the stored inventory and reduce the distribution costs. Customers' requirements can also be achieved in the appropriate time with the lowest cost. Cheraqhalipour et al (2018) stated that logistics includes the physical part of the supply chain and all the activities relevant to material flow from raw material provision step to the production of the final products including transportation, storekeeping, etc. One of the new attitudes in logistics management is recovery or reusing the products. In this method, the products that are at the end of their service life are purchased again from their final consumers and after disassembly, usable parts of the products are used in the form of scrap products and return to the life cycle. Yu et al (2018) selected and categorized the distributors based on their similarities using adaptive resonance theory that is one of the artificial neural networks. In the first step, the criteria were defined by decision makers and then the decision makers used a categorization measure to arrange the distributors. In order to improve the performance of this algorithm, it was tested using previous data and finally the proposed algorithm validation was shown by a numerical example. Kim et al (2018) considered a network with several producers that should provide customers' requirements completely with constrained productive capacity and also material shortage was not allowed. In this system there should be a decision about the material rate. Multi-objective objective functions including reducing the costs, and maintaining balance in using production capacity among factories, were considered. They used analytical hierarchy process method for enhancing the objective and genetic algorithm was used to solve the linear model. Flygansvær (2018) presented an exact multi-criteria model for material distribution in direct supply chain considering the cost, response time and customers satisfaction and solved it by fuzzy multi-objective programming method in such a way that, in the first model, the objective was minimizing the distance from rescue equipment and in the second model, the objective was reducing the establishment cost and mean cost of rescue equipment. Phuc et al (2017), discussed the evaluation of supply chain life cycle of tree wood provision for producing palette in Catalonia, Spain. This research investigated the effect of oak wood supply chain for wood and palette production from the forest activities to the factory gate. Evaluation method of life cycle for both products (wood and wooden palette) was done by primary data presented by industry in order to identify the considerable points of life cycle. 6 criteria of average effect were evaluated by descriptive method, weather changes, environmental reduction, earth acidity, dewatering fresh water, farm occupation, poisoning of human and water destruction. Cumulative energy demand was evaluated. They found that electricity consumption has the most influence on wood and palette production. The other study which consider new robust for supply chain network design was conducted by Babazadeh et al (2014) who considering different cost in their proposed model which embarrassing various parameters as well as transportation modes, outsourcing- flexibility and cross-docking options. To cope uncertainly circumstances, they have developed robust optimization counterpart on their proposed model, and the results of this study confirmed outperforming of this model in comparison with the original deterministic one. Wang et al (2017) presented an integrated approach, including genetic algorithm and simulation for optimum planning of distribution in the supply chain. They considered uncertain factors such as queue, failure and repair time. Finally, the presented approach was investigated by a numerical example. Khalili-Damghani et al (2015) investigated a reverse logistic supply chain that in it return products currency is done from customers to collection centers to repair, remanufacture and disposal. They proposed a conceptual framework and using a series of hypotheses investigated the relation among key factors in measurement of RL and SC function. In addition, they used structural Equation Modeling (SEM) to test the hypotheses. The results revealed clear information about the effects of RL factors on SC function. Xu et al (2017) designed the distribution network by goal and fuzzy programming. The model objective was the selection of the optimum number, place and capacity level of factories and storages for delivering the products to the retailer with the lowest cost and highest satisfaction level. Fuzzy theory was used because of inherent uncertainty of the requirements and decision makers' expectation level of objectives. For the investigation of the presented approach, a real case study was conducted. The results revealed that the problem of distribution network design can be solved realistically and flexibly by the proposed model. Li et al (2017) investigated supply chain network, including suppliers, factories and distribution centers. The decisions that should have been made in this network included: setting up factories and distribution centers, production amount and the volume of the products. The objective was reducing the costs. Genetic algorithm based on spanning tree was used to solve this model and the validation of this model was investigated by its comparison with traditional algorithm method. Mrad and Alfares (2016) investigated multi-period production and inventory control with multi-grade and multi- suppliers in Petro-chemistry industries products. Their goal is to achieve maximum total benefit that is equal to sale revenue of all regular grades and off-spec materials, minus raw material and inventory holding costs. Finally, using (MILP), they solved and optimized the problem. Zhang et al (2017) presented a multi-objective integrated distribution production planning linear model, with multiple levels, multiple products and in multiple periods. They considered decision maker's inexact decision levels for objectives using fuzzy goal programming for reflecting the effect of integrated planning on model and providing a real structure for it. Genetic algorithm was proposed for solving the problem with constraints and its results were compared with 2 methods of genetic algorithm and optimization of particle swarm using penalty function. Then, for explaining the model application and the effectiveness of solving method, they performed several calculation tests on a hypothetical case and pointed to the effectiveness of their proposed method through their comparison with each other. Chen and Ulya (2017) since the increase of environmental concerns, used products collection activities for remanufacturing and recycling attracted the attention of many academic and industrial societies Chen and Ulya developed a classical continuous review inventory system for considering activities of collecting used products. They minimized the total cost in time unit through the determination of order quantity, reorder point and return rate. They used iterative search algorithm to find optimal solution and finally presented some numerical examples to show the features of the proposed models. Meng et al (2016) also presented a solution to a multi-criteria distribution production program by developing an optimum algorithm of hierarchical particle swarm based on simulation. Their integrated plan included three objectives: reducing all the costs including normal work, overtime, out sourcing, inventory maintenance, shortage, employment, dismissal and distribution costs; reduction of changes in work-related levels; and minimizing the low utilization of work-related levels. They validated their proposed algorithm with 0 and 1 hierarchical genetic algorithms. Therefore, according to the literature review, the research innovations are as following:

1: Considering the Environmental Factors in Wood Supply Chain. Considering environmental costs is in a way that the objective function considers penalty costs for cutting the trees. Since the objective function is for cost reduction, this penalty leads to the increase of objective function. Therefore, the model tries to consider lower wood weight for producing the products.

2: considering four-level supply chain in closed loop supply chain.

In this research, several suppliers, wholesalers, and retailers w used in four-level supply chain that were not used in previous studies

3: Solving closed loop logistics problem in large scale

3. MATHEMATICAL MODEL

In this research, three major suppliers, five major distributors, five major customers and five collection centers are investigated. Three products and three wooden raw materials are investigated in this 5-level supply chain. Research assumptions are as follows:

1-The supply chain is considered to include five echelons: supplier, factory, retailer, customer and recovery.
2-The products have different types and have capacity limitations at the factory.
3-The shortage in the supply chain is allowed
4-There are two types of vehicles, including departure or non-departure of vehicle.

3.1. Indices and Sets

j Collection center index ($j \in J$)
t Planning period index $t \in T$
h_j The retailers who take service from collection center j
a Supplier index $a \in A$
b Wholesaler index $b \in B$

e Customer index $e \in E$
e_b The retailers who take service from wholesaler b $e_b \subset E$
v Vehicle supplier index $v \in V$
V_a The set of all available vehicles in supplier a $V_a \subset V$
f Factory vehicles index $f \in F$
g Wholesaler vehicle index $g \in G$
i Index of available vehicles in collection centers that carry wooden waste from retailers to collection centers $i \in I$
i_j The set of all available vehicles in collection center j that carry wooden waste from customer to collection center u
i' The set of all available vehicles in collection center for servicing the producer
i'' Index of available vehicles in collection center for servicing the producer$(i'' \in i')$
i'_j The set of all available vehicles in collection center u that carry wooden waste to the factory
G_b The set of all available vehicles in wholesaler b $G_b \subset G$
p Factory products index $p \in P$
m Raw materials index, including lumber $m \in M$
Ba_{pm} The set of all p that transform to m

3.2. Parameters

T_a The approximate time of going back and forth from supplier *a* to the factory
T'_b The approximate time of going back and forth from the factory to wholesaler *b*
T''_{be} The approximate time of going back and forth from wholesaler *b* to retailer *e*
ct_p The production cost of each unit of product *p* in the factory
cs_{bf} The fixed cost of sending vehicle *g* from the factory to wholesaler *b*
cf_{bp} The transportation cost of unit of product *p* from the factory to wholesaler *b*
cr_{beg} The fixed cost of sending vehicle *g* from wholesaler *b* to customer *e*
cd_{bep} The transportation cost of unit of product *p* from wholesaler *b* center to retailer *e*
cp Capacity of factory storage for wooden raw materials
cp' Capacity of factory storage for products
cp''_b Storage capacity of retailer *b*
dem_{ept} Demand of customer *e* from product *p* on day *t*
α_{mp} The consumption coefficient of material *m* in product *p*
I_m The volume of each unit of wooden raw material *m*
I'_p The volume of each product *p*
ch_{mt} The maintenance cost of each wooden raw material *m* in the factory wooden raw material storage on day *t*
P_{ept} The penalty of shortage of product *p* for retailer *e* of on day *t*
$cinv$ The cost of environment destruction for the reduction of each unit of natural resources (tree)
Ts_{ej} The approximate time of going back and forth from customer *e* to collection center *j*
Ts'_j The approximate time of going back and forth from collection center *j* to the factory
M A very large number
Hd Work hours in a day
ck_{ep} The cost of purchasing each unit of wooden waste *p* from retailer *e*
f_{eij} The fixed transportation cost of vehicle i from customer *e* to collection center *j*
cz_{ejp} The transportation cost of each unit of wooden waste *m* from collection center *j* to factory
$f'_{i'j}$ Fixed costs of sending vehicle $i'$from collection center *j* to the factory
cz'_{jm} The transportation cost of each unit of wooden waste *m* from collection center j to the factory
Sp_{i} Capacity of vehicle *I*
ch'_{pt} The maintenance cost of each unit of product *p* in the factory products storage on day *t*
ch''_{bpt} The maintenance cost of each unit of product *p* for wholesaler *b* on *t* day
ch'''_{ept} The maintenance cost of each unit of product *p* for retailer *e* on day *t*
$Sp'_{i''}$ Capacity of vehicle i''

cab_j Storage capacity of collection center *j*
BR_{pe} The percentage of product *p* that returns from retailer *e*
$Cinv'$ The benefit of environment enhancement for each unit of natural resources (tree)
c_{ma} The cost of purchasing each unit of wooden raw material *m* from supplier *a* to the factory
c'_{av} The fixed cost of sending vehicle *v* from supplier *a* to the factory
c''_{ma} The transportation cost of each unit of wooden raw material *m* from supplier *a* to the factory
vol_v Capacity of vehicle *v*
vol'_f Capacity of vehicle *f*
vol''_g Capacity of vehicle *g*

3.3. Variables

w_{avt} The frequency of movement of vehicle *v* from supplier *a* to factory on day *t*
w'_{bft} The frequency of movement of vehicle *f* from factory to wholesaler *b* on day *t*
w''_{begt} The frequency of movement of vehicle *g* from wholesaler *b* to retailer *e* on day *t*
y'''_{begpt} The number of product *p* transported by vehicle *g* from wholesaler *b* to retailer *e* on day *t*
bo_{kpt} The amount of postponed orders of customer *k* from product *p* on day *t*
u'_{mt} Storage inventory (weight) of wooden raw material *m* in the factory on day *t*
u'_{pt} Storage inventory (weight) of product *p* in the factory on day *t*
u''_{bpt} Storage inventory of wholesaler *b* from product *p* on day *t*
u'''_{ept} Storage inventory of customer *e* from product *p* on day *t*

wb_{eijt} The frequency of movement of vehicle *I* from retailer *e* to collection center *j* on day *t*
$wb'_{i''jt}$ The frequency of movement of vehicle *I* " from collection center *j* to the factory on day *t*
x_{avt} Binary variable representing the departure or non-departure of vehicle *v* from supplier *a* to the factory on day *t*
x'_{bft} Binary variable representing the departure or non-departure of vehicle *f* from factory to wholesaler *b* on day *t*
x'''_{begt} Binary variable representing the departure or non-departure of vehicle *g* from wholesaler *b* to retailer *e* on day *t*
yb_{eijpt} The amount of product *p* sent from retailer *e* to collection center *I* by vehicle *j* on day *t*
$yb'_{i''jmt}$ The amount of material *m* sent from collection center *j* to the factory by vehicle *I''* on day *t*
y_{avmt} The amount of wooden raw material *m* sent by vehicle *v* from supplier *a* to the factory on day *t*
y'_{pt} The number of manufactured products *p* by the factory on day *t*
y''_{bgpt} The number of products *p* sent by vehicle *g* from the factory to wholesaler *b* on day *t*
xb_{eijt} Binary variable representing the departure or non-departure of vehicle *I* from retailer *e* to collection center *j* on day *t*
$xb'_{i''jt}$ Binary variable representing the departure or non-departure of vehicle *I''* from collection center *j* to the factory on day *t*

3.4. Objective Function

$$Min\ Z = \left(\sum_{a\in A}\sum_{v\in V_a}\sum_{m\in M}\sum_{t\in T}(c_{ma}y_{avmt})\right) + \left(\sum_{a\in A}\sum_{v\in V_a}\sum_{t\in T} c'_{av}x_{avt} + \sum_{a\in A}\sum_{v\in V_a}\sum_{m\in M}\sum_{t\in T} c''_{am}y_{avmt}\right) + \left(\sum_{p\in P}\sum_{t\in T}(ct_p y'_{pt})\right)$$
$$+ \left(\sum_{b\in B}\sum_{f\in F}\sum_{t\in T} cs_{bf}x'_{bft} + \sum_{b\in B}\sum_{g\in G}\sum_{p\in P}\sum_{t\in T} cf_{bp}y''_{bgpt}\right)$$
$$+ \left(\sum_{b\in B}\sum_{e\in E_b}\sum_{g\in G_b}\sum_{t\in T} cr_{beg}\, x''_{begt} + \sum_{b\in B}\sum_{e\in E_b}\sum_{g\in G_b}\sum_{p\in P}\sum_{t\in T} cd_{bep}y'''_{begpt}\right)$$

$$+\left(\sum_{m\in M}\sum_{t\in T}ch_{mt}u_{mt}+\sum_{p\in P}\sum_{t\in T}ch'_{pt}u'_{pt}+\sum_{b\in B}\sum_{p\in P}\sum_{t\in T}ch''_{bpt}u''_{bpt}+\sum_{e\in E}\sum_{p\in P}\sum_{t\in T}ch'''_{ept}u'''_{ept}\right)$$

$$+\sum_{e\in E}\sum_{p\in P}\sum_{t\in T}P_{ept}bo_{ept}+\left(Cinv\sum_{a\in A}\sum_{v\in V}\sum_{m\in M}\sum_{t\in T}y_{avmt}\right)+\left(\sum_{e\in h_j}\sum_{i\in i_j}\sum_{j\in J}\sum_{p\in P}\sum_{t\in T}ck_{ep}yb_{eijpt}\right)$$

$$+\left(\sum_{e\in h_j}\sum_{j\in J}\sum_{i\in i_j}\sum_{t\in T}f_{eij}\,xb_{eijt}+\sum_{e\in h_j}\sum_{j\in J}\sum_{i\in i_j}\sum_{p\in P}\sum_{t\in T}cz_{ejp}yb_{eijpt}\right)$$

$$+\left(\sum_{j\in J}\sum_{i''\in i'_j}\sum_{t\in T}f'_{i''j}\,xb'_{i'jt}+\sum_{j\in J}\sum_{i'\in i'_j}\sum_{m\in M}\sum_{t\in T}cz'_{jm}yb'_{i'jmt}\right)-\left(Cinv'\sum_{j\in J}\sum_{i'\in i'}\sum_{m\in M}\sum_{t\in T}yb'_{i'jmt}\right)$$

3.5. Model Constraints

$$\left(\sum_{b\in B}\sum_{g\in G_b}y'''_{begpt}+u'''_{ep(t-1)}-u'''_{ept}\right)BR_{pe}=\sum_{j\in J}\sum_{i\in i'}yb_{eijpt}$$ ∀ e∈E, p∈P, t∈T (1)

$$\sum_{e\in h_j}\sum_{i\in i'_j}\sum_{p\in Ba_{pm}}\alpha_{mp}yb_{eijpt}=\sum_{i''\in i'_j}yb'_{i''jmt}$$ ∀ $m\in M$, j∈J, t∈T (2)

$$\sum_{m\in M}I_m u'_{mt}\le cp$$ ∀ t ∈ T (3)

$$\sum_{p\in P}I'_p u'_{pt}\le cp'$$ ∀ t ∈ T (4)

$$\sum_{p\in P}I'_p u'_{bpt}\le cp''_b$$ ∀b∈B, t∈T (5)

$$\sum_{a\in A}\sum_{v\in V_a}y_{avmt}+u_{m(t-1)}=\sum_{p\in P}\alpha_{mp}y'_{pt}+u_{mt}$$ ∀ t∈T, m∈M (6)

$$w_{avt}*T_a\le Hd*x_{avt}$$ ∀ a∈A , v∈V_a , t∈T (7)

$$\sum_{b\in B}w'_{bft}*T'_b\le hd$$ ∀ f∈F, t∈T (8)

$$\sum_{e\in E}w''_{begt}*T''_{be}\le hd$$ ∀ b∈B, g∈G_b, t∈T (9)

$$w'_{bft}\le M.x'_{bft}$$ ∀b∈B, f∈F, t∈T (10)

$$w''_{begt}\le BigM*x''_{begt}$$ ∀b∈B, e∈E_b, g∈G_b, t∈T (11)

$$y'_{pt}+u'_{p(t-1)}=\sum_{b\in B}\sum_{g\in G}y''_{bgpt}+u'_{pt}$$ ∀ p∈P, t∈T (12)

$$\sum_{g\in G}y''_{bgpt}+u''_{bp(t-1)}=\sum_{e\in E_b}\sum_{g\in G_b}y'''_{begpt}+u''_{bpt}$$ ∀ b∈B, p∈P, t∈T (13)

$$\sum_{b\in B}\sum_{g\in G_b} y'''_{begpt} + u'''_{ep(t-1)} + bo_{ept} = dem_{ept} + u'''_{ept} \qquad \forall\ e\in E,\ p\in P, t\in T \qquad (14)$$

$$\sum_{p\in P} I'_p yb_{eijpt} \le Sp_i . wb_{eijt} \quad \forall\ e \in E_j \qquad i\in i'_j,\ j\in J,\ t\in T \qquad (15)$$

$$\sum_{m\in M} I_m yb'_{i''jmt} \le Sp'_{i''} wb'_{i''jt} \qquad \forall\ i''\in i'_j,\ j\in J,\ t\in T \qquad (16)$$

$$\sum_{e\in h_j} wb_{eijt} * Ts_{ej} \le Hd \qquad \forall\ \ i\in i'_j,\ j\in J,\ t\in T \qquad (17)$$

$$wb'_{i''jt} * Ts'_j \le Hd * xb'_{i''jt} \qquad \forall\ i''\in i'_j,\ j\in J,\ t\in T \qquad (18)$$

$$wb_{eijt} \le M * xb_{eijtt} \qquad \forall j\in J,\ i\in i'_j,\ e\in h_j,\ t\in T \qquad (19)$$

$$\sum_{a\in A}\sum_{v\in V_a} y_{avmt} + \sum_{j\in J}\sum_{i''\in i'_j} yb'_{i''jmt} + u_{m(t-1)} = \sum_{p\in P} \alpha_{mp} y'_{pt} + u_{mt} \qquad \forall\ t\in T,\ m\in M \qquad (20)$$

$$\sum_{m\in M} I_m y_{avmt} \le \mathrm{Vol_v . w_{avt}} \qquad \forall\ a\in A,\ v\in V_a,\ t\in T \qquad (21)$$

$$\sum_{p\in P} I'_p y''_{bgpt} \le vol'_f w'_{bft} \qquad \forall\ b\in B,\ f\in F,\ g\in G_b,\ t\in T \qquad (22)$$

$$\sum_{p\in P} I'_p y'''_{begpt} \le vol''_g w''_{begt} \qquad \forall\ b\in B,\ e\in e_b,\ g\in G_b,\ t\in T \qquad (23)$$

4. GENETIC ALGORITHM (GA)

In this section, we discuss how we use GA for solving the defined problem. This section is explained in several parts. The way of solution display (chromosome display), two crossover and mutation operators for increasing the population and producing new responses, parent selection method for crossover operator and algorithm stopping criterion are explained.

4.1. Solution display method

This part of response display includes E*P dimensions and each entry of this matrix is filled with three numbers that the first number is the customer number, the second number is the rate of transported materials and the third number is the kind of the transported material (Figure 2).

	P_1	P_2	P_3	P_4	P_5	P_6
E_1	(3,23,2)	(30,24,1)	(1,20,2)	(3,32,1)	(2,23,1)	(1,18,2)
E_2	(1,39,1)	(3,38,2)	(2,19,1)	(2,33,1)	(2,41,2)	(1,24,1)

Figure2. The third part of the designed solution display

According to the above figure, you can see that customer number 3 transports 23 units of second type material. This matrix is generated randomly according to the number of periods. Because of the large number of the proposed chromosomes, we ignore drawing the others.

4.2. Crossover and mutation operators on the solutions

4.2.1. Crossover operator

This operator creates a new offspring chromosome by combining a pair of selected parents' gens. Like the chromosomes in environment, every new offspring of this operator has a part of the information of the parent chromosomes. It can be said that the major operator of creating the new generation in the reproduction step crossover (Bandyopadhyay et al, 2014).
This operator is a combined operator that selects one pair of the selected chromosomes randomly in the first step, selects a place for integration along chromosomes string randomly in the second step and finally in the third step, replaces the amount of two strings based on the determined integration place. There are different methods of integration and crossover that are used based on user's idea and problem condition. The most important methods include: single point crossover, two-point crossover multi-point crossover, uniform crossover, matrix crossover method, etc. Another important concept is worth mentioning here, crossover rate. By determining this rate, which is a number between 0 and 1, we determine what percent of the current population should participate in crossover operation. Notice that if this amount is very high, the chromosomes will lose corresponding opportunity, and if this amount is very low, the number of generated offspring will not be enough. In the presented algorithm, single- point crossover is used. As an example, figure 3 represents the first part of the solution display for parent 1 and 2. Then from their crossover, 2 new offspring are generated. On the other parts of the solution display, single-point crossover is implemented (Figure 3).

parent 1	39	38	12	54	34	30
	31	34	72	43	56	46
parent 2	12	31	25	36	40	23
	30	18	27	43	25	34
Offspring1	39	38	12	36	40	23
	31	34	72	43	25	34
Offspring2	12	31	25	54	34	30
	30	18	27	43	56	46

Figure 3. Crossover operator/ the reproduction of two solutions from two offspring

4.3. Mutation

The last aspect of Darwin's theory is that after the generation of offspring's chromosomes, some mutations may happen in these chromosomes randomly that will result in better optimization or worsening of the chromosomes. We use this feature in genetic algorithm and create some mutations in generated solutions. This method can be implemented in different ways based on the algorithm designer's innovation. But the general method is changing one or more genes of the chromosomes. For this, we can select two genes randomly and replace them or we can select one gene and assign new amounts to it randomly. Also, we can select a gene randomly and choose its supplement as new amount of the gene. Two popular types of mutations are reversion and swap which we used them in this research. In swap operator for mutation, 2 genes of the related chromosomes are selected and their places are changed (Figure 4). In reversion operator for mutation, two genes of the considered chromosomes are selected, then their selected amounts are rearranged from right to left (Figure 5).

Parent	39	38	12	54	34	30
	31	34	72	43	56	46
Offspring	39	34	12	54	38	30

	31	56	72	43	34	46

Figure 4. Replacement / swap operator for mutation

Parent	39	38	12	54	34	30
	31	34	72	43	56	46
Offspring	39	34	54	12	38	30
	31	56	43	72	34	46

Figure 5. Reversion operator for mutation

4.3.1. Solution selection method

As it is explained, we need two steps for the selection of solutions from all the available solutions. The first step is for crossover and mutation operation. In this step, tournament selection method is used for selecting the parents that was explained before; and for mutation operator, chromosome/ solution and its mutated gene are selected randomly. In the second step, we used roulette wheel selection method for the selecting a part of the population to be transferred to the next generation. It should be mentioned that in order to use roulette wheel selection method, we need fitness function for each solution and since this is a minimization problem, we consider fitness function as reverse of the objective function. The pseudocode of the genetic algorithm is shown in Figure 6.

Algorithm: GA(n, χ, μ)
// Initialize generation 0:
k := 0;
P_k:=a population of n randomly-generated individuals;
// Evaluate P_k:
Compute *fitness*(i) for each $i \in P_k$;
do
{ **// Create generation** k + 1**:**
// 1. Crossover:
Select χ×n members of P_k; pair them up; produce offspring; insert the offspring into P_k+1;
// 2. Mutate:
Select μ ×n members of $P_k + 1$; do Swap and Reversion Mutation;
// Evaluate P_k+1**:**
Compute *fitness*(i) for each $i \in P_k$
// Increment: k: = k + 1;
}
while fitness of fittest individual in P_k is not high enough;
return the fittest individual from P_k;
χ = Crossover Percentage
μ = Mutation Percentage

Figure 6. Pseudo code of GA

We investigated the information for a period of four days and the results of direct model of this supply chain are presented using GA and GAMS Software.

4.4. Computational results of GA algorithm

Since the proposed algorithm is random in nature, it is possible to encounter different results in every implementation. We implemented the algorithm for each sample. The results are presented in the following Table1.

Table 1. The Comparison of GAMS and GA

N		GAMS		GA					
			t(s)	1	2	3	4	5	t_{av}(s)
1		658.2	1	658.2	658.2	658.2	658.2	658.2	1
2		662.1	1	662.1	662.2	662.1	662.3	662.2	1
3		665.1	1	665.1	665.1	665.4	665.1	665.3	1
4		665.8	2	665.9	665.8	665.9	666	665.8	1
5		671.8	3	671.8	671.9	672.0	671.8	671.9	2
6		1723.5	9	1726.2	1725.5	1724.1	1726.6	1726.5	3
7		1738.4	11	1739.6	1740.5	1738.9	1741.2	1740.5	5
8		1756.6	14	1757.5	1757.7	1759.5	1758.8	1759.8	7
9		1774.5	15	1776.2	1775.5	1777.7	1775.4	1778.5	8
10		1780.8	18	1782.6	1781.8	1782.2	1783.3	1783.9	10

Table 1 shows the gradual increase of problem scale. Since it is impossible to test all the possible types, here we investigated only some of them. As it can be seen, when the problem's scale increases, its objective functions (model costs) increases, too. The first five types are related to small scale and the next five types are in medium scale. The results revealed that because of the slight difference of GA with exact algorithm, we can rely on exact algorithm in solving large scale problems. The variables that are initialized in algorithm are as the following:

Table 2, presents the unit amount of wooden raw material *m* that was transported by vehicle *v* from supplier *a* to the factory on day *t*. As an example, according to this table, the amount of the wooden raw material of type 2 that was transported by vehicle 2 from supplier 2 on the third day is 2560 units.

Table 2. Unit amount of wooden raw material y_{avmt}

Variable	Amount	Variable	Amount
$y_{a1,v3,m1,t1}$	2461	$y_{a1,v3,m1,t2}$	4507
$y_{a1,v3,m1,t3}$	3708	$y_{a1,v3,m1,t4}$	1100
$y_{a2,v2,m2,t1}$	3080	$y_{a2,v2,m2,t2}$	6730
$y_{a2v2,m2,t3}$	2560	$y_{a2,v2,m2,t4}$	2500
$y_{a3v5,m3,t1}$	3150	$y_{a3,v5,m3,t2}$	4200
$y_{a3,v5,m3,t3}$	1894	$y_{a3,v5,m3,t4}$	1600

Table3 shows the frequency of movement of vehicle *v* from supplier *a* to the factory on day *t*. According to this table, the frequency of movement of the third type vehicle from the first supplier in the fourth period is 12 times.

Table 3. The frequency of movement of vehicle *v* from supplier a to the factory w_{avt}

Variable	Amount	Variable	Amount
$W_{a1,v3,t1}$	12	$W_{a1,v3,t2}$	13
$W_{a1,v3,t3}$	5	$W_{a1,v3,t4}$	12

$W_{a2,v2,t1}$	15	$W_{a2,v2,t2}$	10
$W_{a2,v2,t3}$	18	$W_{a2,v2,t1}$	10
$W_{a3,v5,t1}$	6	$W_{a3,v5,t2}$	14
$W_{a3,v5,t3}$	9	$W_{a3,v5,t4}$	9

Table 4 shows the binary variable representing the departure or non-departure of vehicle *f* from the factory to wholesaler *b* on day *t*. According to this table, the third vehicle did not depart to visit the third wholesaler in the first period but the second vehicle visited the first wholesaler in the third period.

Table 4. The variable representing the departure or non-departure of vehicle from the factory to distribution x'_{bft}

Variable	Amount	Variable	Amount
$X'_{b1,f1,t1}$	1	$X'_{b1,f1,t2}$	1
$X'_{b1,f1,t3}$	1	$X'_{b1,f2,t1}$	1
$X'_{b1,f2,t2}$	1	$X'_{b1,f2,t3}$	1
$X'_{b1,f2,t4}$	1	$X'_{b3,f3,t1}$	0
$X'_{b4,f4,t1}$	0	$X'_{b4,f4,t3}$	1
$X'_{b4,f4,t4}$	1	$X'_{b5,f5,t1}$	1
$X'_{b5,f5,t1}$	1	-	-

Table 5 shows the output results of variable u'''_{ept}.

Table 5. Customers' demand for the products

	t_1	t_2	t_3	t_4
$e_1.p_1$	2500	1800	2000	1000
$e_1.p_2$	4500	2000	3000	1000
$e_2.p_3$	3000	3000	4000	2000
$e_3.p_1$	4000	1500	2550	2000
$e_4.p_2$	4500	2500	1500	3000
$e_5.p_1$	1000	3500	4500	1000
$e_5.p_3$	1600	2000	3000	2000

Table 6 and Figure 7 discuss the sensitivity analysis considering the basic parameters of the model. In this figure, X_1 is the sum of purchasing cost, X_2 is the sum of production cost, X_3 is the sum of shortage cost, X_4 is the sum of the transportation cost, X_5 is the sum of maintenance cost and X_6 is the sum of environmental cost.

Table 6. The Results of Changes in Demand

	Primary data	The secondary data With 10% increase	The secondary data With 20% increase
x_1	34800000	38280000	41760000
x_2	90500000	99550000	10900000
x_3	11800000	12980000	14160000

x_4	60000000	66000000	72000000
x_5	10400000	11440000	12480000
x_6	50000000	33330000	36360000

As can be seen, when demand rate increases, X_1 the sum of purchasing cost, X_2 the sum of production cost, X_3 the sum of shortage cost, X_4 the sum of the transportation cost, X_5 the sum of maintenance cost and X_6 the sum of environmental cost of the objective function will increase. Among them, the increase in production cost leads to the growth of the objective function in comparison with other parameters.

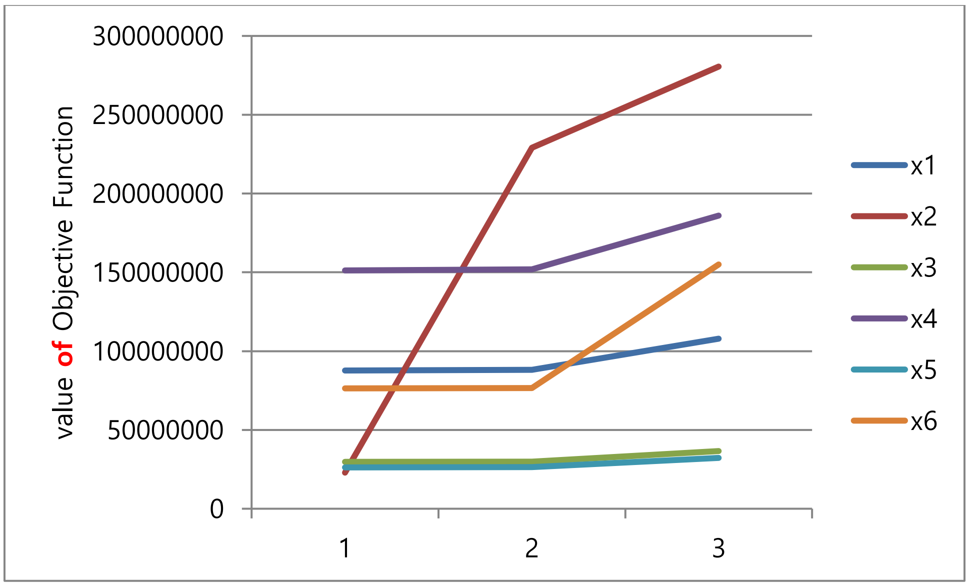

Figure 7. Results of changes in model by changing parameters

5. CONCLUSION

In this research, a multi period and single product mathematical model is presented for minimizing the costs of supply chain. Considering the environmental effects on supply chain is one of the innovations of this research. In this research, a chipboard factory is considered in a five-level supply chain including several suppliers, one producer, several wholesalers and retailers, and recovery centers that provides its wooden raw materials by purchasing cut trees and also provides firewood from determined suppliers; and is going to distribute its products in the country level. The wooden raw materials are transported from the suppliers by determined vehicles in the factory. The products (chipboard) are transported from the factory by determined vehicles to distribution centers (wholesaler and retailer) and then from distribution centers to all the retailers. Reverse supply chain includes producer, wholesalers, retailers, and collection centers (recovery). The wooden raw materials and wooden waste are transported from the supplier by determined vehicles to the factory. The factory’s products are transported from the factory by determined vehicles to distribution centers and then to the wholesalers and retailers. Therefore, the amount of wooden raw material type 2 that was transported by vehicle 2 from supplier 2 on the third day is 2560 units. In addition, the frequency of movement of third type vehicle from the first supplier in the fourth period is 12 times. The results of sensitivity analysis represent that by decrease in amount of demand, the value of the cost-related objective function increases. The purchasing and production costs will decrease. Also, the shortage amount is reduced and maintenance costs reduce very slightly.

The following items can be considered as suggestions for future studies:

1. Considering the data as fuzzy or probabilistic for example considering the demand as fuzzy
2. Considering failure in supply chain or the probability of reopening or closing the distribution centers
3. Increasing the number of levels of the supply chain or considering this supply chain for other industries

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