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Designing a location-routing model for cross docking in green supply chain

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A B S T R A C T

Today, most industrial managers in the world are interested in protecting the environment and biological resources. On the other hand, current technologies are getting momentum towards specialization and globalization. Thus, in order to remain in a highly competitive world market, producers have to respond to the customers' demands under different circumstances. The leading role of distribution centers to deliver products to customers on time and to reduce the costs of stock maintenance has attracted the attention of many supply chain managers in current competitive conditions. Cross docking is a logistic strategy aiming to reduce the stock and increase the level of customer's satisfaction. Products are delivered from the supplier to the customers through cross docking. In this paper, a nonlinear multiproduct vehicle location-routing model is presented with heterogeneous vehicles. Each truck can carry one or more types of products. In other words, compatibility between product and vehicle has been accounted for here. This model aims to find out the possible minimum number of cross dockings among the existing set of discrete locations and minimize the total cost of opening cross docking centers as well as vehicle transportation (distribution and operation cost) costs. In sum, the model aims to find the number of cross docking centers, the number of vehicles and the best route in the distribution network. Since the model is mixed integer programming, to apply the model to medium and large scale problems, meta innovative genetic and particle swarm optimization algorithms are introduced. The results obtained from examining various problems show high efficiency of the proposed methods.

1. Introduction

The notion of supply chain is frequently discussed in the modern world as a major competitive advantage for reducing costs. Supply chain includes purchase and supply, logistics and transportation, marketing, organizational behavior, network, strategic management, information systems management and operation management (Petrudi et al., 2018; Singh et al., 2018). A supply chain is a system consisted of five levels of suppliers, producers, distributers, retailers and the final customers which are all interrelated. Components of supply chain are generally interrelated through both information flow and product physical flow (Van Belle et al., 2012; Kausar et al., 2017). Nevertheless, during various stages of the process, decision making and coordination remain the core issues of the supply chain. Considering the intense competition among manufacturers, if any of these chain links performs poorly,

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the entire system will fail and cannot exhibit expected performance (Nadali et al., 2017). Therefore, the effective management of the supply chain in industries is considered as a major managerial challenge (Cook, 2005). In recent years, many firms and organizations in industrial and developed countries across the world have paid a special attention to supply chain management, and through this, they achieved considerable success. This is evident in increased volume of commercial transactions, high income and money making that an efficient and successful supply chain brings forth. This has caused such firms to surpass their rivals in today's highly competitive markets (Donaldson et al., 1998; Bartholdi III & Gue, 2000, 2004; Chen et al., 2006; Galbreth et al., 2008; Gue & Kang, 2001; Gümüş & Bookbinder, 2004; Vis & Roodbergen, 2008, Waller et al., 2006).

Current technology is gaining momentum towards specialization and globalization. In order to survive in such a global competition, manufacturers should be responsible for various demands of their customers under different circumstances. In current competitive context, influential role of distribution centers to deliver products to customers on time and reduce the stock maintenance costs have attracted the attention of many supply chain managers. This has prompted many producers to implement a lean production and supply chain. Since cross docking is the main component of designing a lean supply chain, logistic companies with high transportation volume have tended to use cross docking (Chen & Lee, 2004; Witt, 1998). Cross docking system has many advantages like agility of supply chain, a high stock turnover, a low cost of stock maintenance and transportation and a smaller required space in comparison with traditional warehousing. The strength of cross docking is the accumulation of products in the warehouse. In this way, the required products of customers from various suppliers would be collected in cross docking instead of direct delivery, and after classifying the products are sent to desirable destination according to the customers' demands and this gather-up decreases the transportation cost.

2. Theoretical Background

Altiparmak et al. (2009) introduced a monotonous genetic algorithm (permanent) to solve the problem of multi product supply chain network design that includes new coding structures for multi-product and multi-stage single-source supply chain network design. Sadjady and Davoudpour (2012) presented a single-period, multi-raised product supply chain network two jumpers design in a given circumstance. They discussed their problem solving Lagrange algorithm based on heuristic algorithms for a real-presented case study. Xu et al. (2008) also developed a nonlinear multi-objective mixed integer mathematical model under fuzzy environment to solve the supply chain network design problem and studied its application in china. Objectives assessed in this regard include: maximizing customer satisfaction and minimizing the cost of transportation between facilities and customers. They compared the results of this algorithm with numerical results available in the factory for the performance of the three proposed algorithms. Pishvaee and Torabi (2010) addressed the problem of supply chain closed loop network design. Given the importance of the problem in industrial and commercial environments, they addressed this problem in uncertain environments and possible planning methods studied in the environment. Their investigations showed that as a result of uncertain circumstance, the existence of risk in such networks needs to overcome the risks of system indefinite parameters. Therefore, they presented a possible two-objective mixed integer mathematical model for the proposed issue. Sung and Yang (2003, 2008) introduced a genetic algorithm adapted to developmental concepts and constraints in order to solve the problem of supply chain network design. The algorithm is a combination of both evolutionary standards adapted to different standards and dynamic changes and it is used to satisfy capacity constraints of the response. This combination makes it easier to find an answer to the problem of supply chain network design. Mello et al. (2012) studied the multi-level and multi-product supply chain network redesign. In fact this redesigned pattern includes the cancellation of allocating the current facilities and credits to new locations under the constraints of budget, planning horizon, prepared box by facility level in stock and the flow of products on the network. Taleizadeh et al. (2011) addressed the multi-buyer, multi-seller, multi-product and multi-restraint aspects of the supply chain network and proposed Searching Harmony Algorithm to address the issue. In this multi-product model, buyers and sellers are limited. Purchasing capacity has limited storage capacity for products. The demand of customers for each product and the lead time is considered randomly. Paksoy and Chang (2010) addressed the problem of multi-stage, multi-period and multi-ideal supply chain network design with temporary storages which can be opened for some weeks or seasons. To solve this problem, they introduced a mixed integer mathematical model.

Pishvaee et al. (2011) proposed a robust optimization method to solve the problem of closed-loop supply chain network design with indefinite parameters. They initially proposed a linear mixed integer mathematical model and then presented a robust model by developing a robust optimization theory. Nickel et al. (2012) investigated the problem of multi-product and multi-level supply chain network design and studied several aspects of financial operations such as supply chain management and risk management decisions.

3. Statement of the Problem

Globalization of economy and information technology development have extensively changed supply-based markets into demand-based markets and organization managers now understand the importance of meeting customers' needs for their own survival. So, supply chain management would be of high importance, because meeting customer needs and interests not only is addressed by the last entity related to customer, namely the end product, but also it is addressed by other upstream suppliers. From the old conventional perspective, supply chain management includes directing all components of supply chain in an integrated and harmonious manner aiming to improve the performance to upgrade the profitability and efficiency, and managers of supply chain sought faster delivery of products and services as well as reduction the costs and improvement of quality. But improvement of biological performance in supply chain and relevance of social costs and environmental degradation failed to be addressed. Pressure of governmental regulations on organizations to obtain environmental standards on one hand, and increasing growth of customers' demands for green product supply (without detrimental effect on environment) on the other hand brought about the concepts of green supply chain and green supply chain management. Today, managers of green supply chain in pioneer firms, through establishing product desirability and satisfaction in terms of environmental standards across supply chain, seek to draw on green logistics and improvement of their environmental performance throughout the supply chain as a strategic means for acquiring sustainable competitive advantage (Stalk et al., 1992; Schaffer, 2000).

In this study, a nonlinear multiproduct multi-period location-routing model with heterogeneous vehicles and with capability of carrying various products is introduced. Split pickup and delivery is also allowed in this model. This aims to determine the possible minimum number of cross docking among the existing set of discrete locations and minimizing the total cost of inaugurating cross docking centers and vehicle transportation costs (distribution and operation cost) under the environmental standards. In sum, the model aims to find out the number of cross docking centers, the number of vehicles and the best route in the distribution network. In order to fulfill this purpose, an integer nonlinear planning model is introduced.

4. Research Assumptions

1. Split pickup and delivery is allowed, i.e. customer is ready to receive the order in multiple times.
2. Vehicles have capacity limitations.
3. Number of vehicles is limited.
4. Vehicles can carry one or more type of a certain goods.
5. All vehicles are placed in various cross dockings.
6. Start and end point of any route of cross docking are identical.
7. Whole pickup value is equal to the whole value that supposed be delivered.

8. Inbound vehicles in each period should arrive cross dockings at the beginning of the period and outbound vehicles should distribute the cargoes during the day.

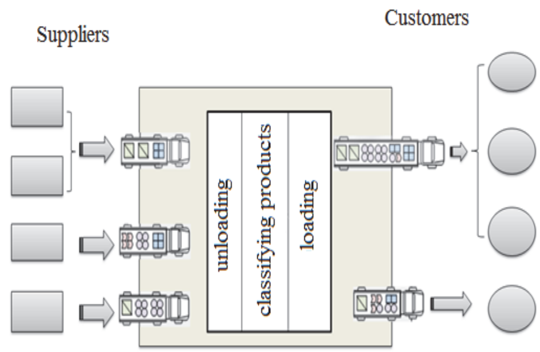
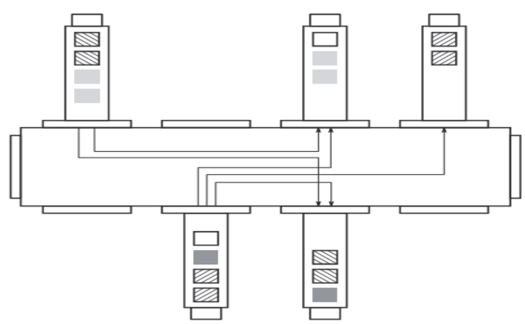


Fig. 1. Schematic image of a cross docking

Fig. 1 shows the schematic view of material control operation within an I-shaped cross docking. Cross docking shifts the attention from supply chain management to demand chain management. Many organizations draw on the combination of conventional warehousing and cross docking to use advantages of both (Apte & Viswanathan, 2000; Specter, 2004). Also, cross docking allows the product transportation by using full capacity of vehicle instead of using less capacity (Agustina et al., 2010).

Input trucks



Output trucks

Fig. 2. material control in a type of cross docking

5. Mathematic Model

In this research, it is assumed that cross docking system acts as follows:

Cross docking receives the information related to the value of demands and picks up the product input trucks from suppliers and unloads in related cross docking. Products are combined by conveyors and barcode readers and based on customer demand are directed to exit gates. Then output trucks deliver the products to various customers. Each truck can carry one or more types of products, in other words, the compatibility between product and vehicle is accounted for.

In this model N stands for the total number of nodes, N_c is the number of customers, Ns is the number of suppliers and No represents the number of available places for opening cross docking centers. For each product customers are assigned to one established cross docking and, similarly, to supply each type of product, established cross docking centers are allocated to several suppliers. The number of cross docking which can be founded is limited, and the cost of founding each one of them is different.

The appropriate vehicles are selected for receiving products from the supplier and sending them to the customers based on the limited number of each type of vehicle in cross docking centers, their capacity limitation and compatibility between vehicle and type of product. Operational cost of each type of vehicle and the cost of their transportation are also different. Direct relationship between supplier and customer has not been considered and there is no link among cross docking centers. The products are delivered from suppliers to the customers through cross docking. It is also important to note that cross docking receives the products from suppliers according to the demand of customers and the amount of admitted products to cross docking should be equal to the amount of exited products.

In a cross docking location-routing model, we seek the following outputs for the problem:

- Determining suitable location for constructing cross docking
- Determining the number of cross dockings to be inaugurated
- Allocating customers and suppliers to cross dockings
- Selecting suppliers
- Selecting cross docking
- Determining the optimum route of transportation for transferring products to cross docking and delivery of integrated cargoes to customers
- Determining the most appropriate vehicles
- Adopting an optimization approach along with minimizing the cost of cross docking inauguration and the total cost of vehicle transportation and operation

5.1. Proposed Model

The proposed model aims to minimize sum of inauguration costs of cross docking centers as well as vehicle transportation (distribution and operational costs) costs.

5.2. Series and subscripts

- N:Set of entire nodes (supplier, cross docking, customer)
- Ns: Set of suppliers in pickup process
- No:Set of cross docking centers
- Nc:Set of customers in delivery process
- R: Set of products
- K: Set of vehicle
- C,i: subscripts for nodes (customer, centers of cross docking, supplier)
- H,o: subscript of cross docking
- K: subscript of type of vehicle
- L: counter of vehicle
- R: subscript for vehicle

5.3. Input parameters

- D_{ir}: customer demand from product r in period t
- $SCAP_{ir}$: amount of product type r that supplier i *can supply.*
- F_o: fixed cost of opening a cross docking o
- c_{ijk}: cost of transportation of vehicle type k to distance unit from node i to node j
- c_k: operational cost of vehicle k
- d_{ij}: distance from point i to point j
- Br**:** volume of each article product r in pack

- E: maximum number of cross docking that can be inaugurated
- Ca_o: capacity of center *o* for maintaining products in volume unit
- M_{kp}: number of vehicle type *k* in cross docking o
- Q_k: maximum capacity of vehicle type *k* in volume unit
- δ_{rk} **:** zero and one matrix of ability of carrying any type of vehicle of any type of product
- M: big M

5.6. Decision variables

- S_{ir} amount of product type r from supplier i

- $z_o = \begin{cases} 1 & \text{if cross warehouse } o \text{ is open} \\ 0 & \text{otherwise} \end{cases}$

- $f_{ior} = \begin{cases} 1 & \text{if cross docking } o \text{ for product } r \text{ is allocated to supplier } i \\ 0 & \text{otherwise} \end{cases}$

- $f_{ojr} = \begin{cases} 1 & \text{if customer } j \text{ is allocated to cross docking } o \text{ for product } r \\ 0 & \text{otherwise} \end{cases}$

- $f_{ijklo} = \begin{cases} 1 & \text{if } 1^{\text{th}} \text{ vehicle type } k \text{ belongs to cross docking } o \text{ from node } i \text{ to node } j \\ 0 & \text{otherwise} \end{cases}$

- $y_{iklo} = \begin{cases} 1 & \text{if } 1^{\text{th}} \text{ vehicle type } k \text{ belongs to cross docking } o \text{ from node } i \\ 0 & \text{otherwise} \end{cases}$

- a_{irklo}: amount of product type *r* loaded by 1^{th} vehicle type *k* belongs to cross docking *o* in node *i*
- z_{irklo}: amount of product type *r* dumped by 1^{th} vehicle type *k* belonging to cross docking *o* in node *i*
- a_{orklo}: amount of product type *r* loaded by 1^{th} vehicle type *k* belonging to cross docking *o* in cross docking
- z_{orklo}: amount of product type *r* dumbed by 1^{th} vehicle type *k* belonging to cross docking *o* in cross docking *o*

5.7. Green parameters (environmental)

- : $\mathrm{ei}_{\mathrm{ijp}}^{\mathrm{pd}}$ the environmental effect of carrying one unit product *p* from point *i* to point *j*
- : $\mathrm{ei}_{\mathrm{jkp}}^{\mathrm{dc}}$: the environmental effect of carrying one unit product *p* from point *j* to point *k*
- : $\mathrm{ei}_{\mathrm{jip}}^{\mathrm{ip}}$: the environmental effect of carrying one unit product *p* from point *j* to point *i*
- : $\mathrm{ei}_{\mathrm{jmp}}^{\mathrm{id}}$: the environmental effect of carrying one unit product *p* from point *j* to point *m*
- : $\mathrm{ei}_{\mathrm{jp}}^{\mathrm{in}}$: : the environmental effect of carrying one unit product *p* from point *j* to point *j*

5.8. Limitations

- Limit of satisfaction of demand

$$\sum_{j} u_{jkp} \geq d_{kp} \qquad \forall k \in K, \quad \forall p \in P \tag{1}$$

Limitation 1: ensures that all customers are satisfied.

- Current flow balances

$$\sum_{i} x_{ijp} - \sum_{i,m} (v_{jip} + T_{jmp}) = \sum_{k} u_{jkp} \qquad \forall j \in J, \quad \forall p \in P \tag{2}$$

$$\sum_{k} u_{jkp} - (1 - s1_p - s2_p) \sum_{i} x_{ijp} = 0 \qquad \forall j \in J, \quad \forall p \in P \tag{3}$$

$$\sum_{m} T_{jmp} - s1_{p} \sum_{i} x_{ijp} = 0 \qquad \forall j \in J, \quad \forall p \in P \tag{4}$$

$$\sum_{i} v_{jip} - s2_{p} \sum_{i} x_{ijp} = 0 \qquad \forall j \in J, \quad \forall p \in P \tag{5}$$

$$\sum_{j} v_{jip} - \sum_{j} x_{ijp} \leq 0 \qquad \forall i \in I, \quad \forall p \in P \tag{6}$$

High constraints guarantee the flow of product flow in production / recycling and inspection / distribution centers in a forward and reverse flow.

Objective function

$$\begin{aligned} \min Z = \sum_{o \in N_o}^{o} F_o w_o + \sum_{i \in N} \sum_{j \in N} \sum_{k \in K} \sum_{l=1}^{m_{ko}} \sum_{o \in N_o} (c_{ijk} d_{ij}) x_{ijklo} + \sum_{i \in N} \sum_{j \in N_c \cup N_s} \sum_{k \in K} \sum_{l=1}^{m_{ko}} \sum_{o \in N_o} c_k x_{ioklo} + [\sum_{i,j,p} (ei_{ijp}^{pd} + ei_{ip}^{pro}) x_{ijp} \\ + \sum_{j,k,p} (ei_{jkp}^{dc} + ei_{jp}^{in}) u_{jkp} + \sum_{i,j,p} (ei_{jip}^{ip} + ei_{ip}^{re}) v_{jip} + \sum_{j,m,p} (ei_{jmp}^{id} + ei_{mp}^{di}) T_{jmp}] \end{aligned} \tag{7}$$

subject to :

$$\sum_{o \in N_o} f_{ojr} \geq 1 \qquad \forall i \in N_c, r \tag{8}$$

$$\sum_{j \in N_c} f_{ojr} \geq w_o \qquad \forall o \in N_o, r \tag{9}$$

$$\sum_{j \in N_c} f_{ojr} \leq M w_o \qquad \forall o \in N_o, r \tag{10}$$

$$\sum_{o \in N_o} w_o \leq E \tag{11}$$

$$f_{ior} \le w_o \qquad \forall \mathrm{i} \in \mathrm{N_s}, \mathrm{o} \in \mathrm{N_o}, \mathrm{r} \qquad (12)$$

$$f_{ojr} \le w_o \qquad \forall \mathrm{j} \in \mathrm{N_c}, \mathrm{o} \in \mathrm{N_o}, \mathrm{r} \qquad (13)$$

$$x_{ioklo} \le w_o \qquad \forall \mathrm{i} \in \mathrm{N_s} \bigcup \mathrm{N_c}, \mathrm{o} \in \mathrm{N_o}, \mathrm{r}, \mathrm{k}, \mathrm{l} \qquad (14)$$

$$x_{ioklo} \le w_o \qquad \forall \mathrm{i} \in \mathrm{N_s} \bigcup \mathrm{N_c}, \mathrm{o} \in \mathrm{N_o}, \mathrm{r}, \mathrm{k}, \mathrm{l} \qquad (15)$$

$$\sum_{\mathrm{j} \in \mathrm{N_s} \bigcup \mathrm{N_c}} x_{ojklo} \le 1 \qquad \forall \mathrm{o} \in \mathrm{N_o}, \mathrm{r}, \mathrm{k}, \mathrm{l} \qquad (16)$$

$$\sum_{i \in N_s} x_{ioklo} = \sum_{j \in N_s} x_{ojklo} \qquad \forall \mathrm{o} \in \mathrm{N_o}, \mathrm{r}, \mathrm{k}, \mathrm{l} \qquad (17)$$

$$\sum_{i \in N} x_{icklo} = \sum_{j \in N} x_{cjklo} \qquad \forall \mathrm{i}, c \in N_c \cup N_s, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (18)$$

$$\sum_{j \in N} x_{jiklo} = y_{iklo} \qquad \forall \mathrm{i} \in N_c \cup N_s, \mathrm{o} \in \mathrm{N_o}, \mathrm{k}, \mathrm{l} \qquad (19)$$

$$x_{ijklo} \le \sum_{c \in N_s} x_{coklo} \qquad \forall \mathrm{i}, \mathrm{j} \in \mathrm{N_s}, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (20)$$

$$x_{ijklo} \le \sum_{c \in N_c} x_{coklo} \qquad \forall \mathrm{i}, \mathrm{j} \in \mathrm{N_c}, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (21)$$

$$\sum_{i \in N_s} x_{ijklo} = 0 \qquad \forall j \in N_c, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (22)$$

$$\sum_{i \in N_c} x_{ijklo} = 0 \qquad \forall j \in N_s, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (23)$$

$$\sum_{k \in K} \sum_{l == 1}^{m_{ko}} x_{iiklo} = 0 \qquad \forall i \in N, \mathrm{o} \qquad (24)$$

$$\sum_{j \in N_o} \sum_{k \in K} \sum_{l == 1}^{m_{ko}} x_{ojklo} = 0 \qquad \forall o \in N_o, \mathrm{o} \qquad (25)$$

$$x_{ihklo} = 0 \qquad \forall \mathrm{i} \in N_s \cup \mathrm{N_c}, \mathrm{h} \in \mathrm{N_o}, \mathrm{k}, \mathrm{l}, \mathrm{o}, \mathrm{h} \ne \mathrm{o} \qquad (26)$$

$$x_{hjklo} = 0 \qquad \forall \mathrm{j} \in N_s \cup \mathrm{N_c}, \mathrm{h} \in \mathrm{N_o}, \mathrm{k}, \mathrm{l}, \mathrm{o}, \mathrm{h} \ne \mathrm{o} \qquad (27)$$

$$x_{ijklo} + x_{jiklo} \le 1 \qquad \forall \mathrm{i}, j \in N_c \cup N_s, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (28)$$

$$\mathrm{y_{iklo}} \le \sum_{r \in R} f_{ior} \times \delta_{\mathrm{rk}} \qquad \forall \mathrm{i} \in N_s, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (29)$$

$$\mathrm{y_{jklo}} \le \sum_{r \in R} f_{ojr} \times \delta_{\mathrm{rk}} \qquad \forall \mathrm{i} \in N_c, \mathrm{k}, \mathrm{l}, \mathrm{o} \qquad (30)$$

$$\sum_{j \in N_c \cup N_s} \sum_{l=1}^{m_{ko}} x_{ojklo} \le M_{ko} \qquad \forall \mathrm{k}, \mathrm{o} \qquad (31)$$

$$\sum_{r\in R}\sum_{k\in K}\sum_{l=1}^{m_{ko}} z_{orklo}\times B_r \le CA_o *z_o \qquad \forall o\in N_o \qquad (32)$$

$$\sum_{i\in N_s}\sum_{r\in R} a_{irklo}\times B_r \le Q_k \qquad \forall i\in N_s ,k,l,o \qquad (33)$$

$$\sum_{i\in N_c}\sum_{r\in R} z_{irklo}\times B_r \le Q_k \qquad \forall i\in N_c ,k,l,o \qquad (34)$$

$$\sum_{o\in N_o}\sum_{k\in K}\sum_{l=1}^{m_{ko}} z_{jrklo} = D_{jr} \qquad \forall i\in N_c ,r \qquad (35)$$

$$z_{jrklo}\times(y_{jklo}\times f_{ojr}\times\delta_{rk}-1)=0 \qquad \forall j\in N_c ,k,l,o \qquad (36)$$

$$\sum_{o\in N_o}\sum_{k\in K}\sum_{l=1}^{m_{ko}} a_{irklo} = S_{ir} \qquad \forall i\in N_s ,r \qquad (37)$$

$$a_{jrklo}\times(y_{jklo}\times f_{ior}\times\delta_{rk}-1)=0 \qquad \forall i\in N_s ,k,l,o \qquad (38)$$

$$S_{ir} \le SCAP_{ir} \qquad \forall i\in N_s ,r \qquad (39)$$

$$\sum_{i\in N_s} a_{irklo} = z_{orklo} \qquad \forall o\in N_o ,r,k,l \qquad (40)$$

$$\sum_{k\in K}\sum_{l=1}^{m_{ko}} z_{orklo} = \sum_{k\in K}\sum_{l=1}^{m_{ko}} a_{orklo} \qquad \forall o\in N_o ,r \qquad (41)$$

$$a_{orklo} = \sum_{i\in N_c} z_{orklo} \qquad \forall o\in N_o ,r,k,l \qquad (42)$$

$$a_{irklo} = 0 \qquad \forall i\in N_c ,r,k,l,o \qquad (43)$$

$$z_{irklo} = 0 \qquad \forall i\in N_s ,r,k,l,o \qquad (44)$$

$$x_{ijklo}, y_{iklo}, f_{ior}, f_{ojr}, w_o \in \{0,1\} \qquad \forall i,j,r,k,l,o,t \qquad (45)$$

$$a_{irklo}, z_{jrklo}, a_{orklo}, z_{orklo} \in Integer \qquad \forall i,j,r,k,l,o \qquad (46)$$

Objective function given in Eq. (7) is related to final objective function of integration of two objective functions, which is the minimization of sum of fixed cost of inaugurating cross docking, operational cost of each vehicle and displacement cost between nodes and objective function of environmental effects. Eq. (8) ensures that each customer for any type of product has been allocated only to one cross docking. Constraints (9-10) show that if any cross docking is inaugurated, for any type of product at least it is allocated to one customer. Constraint (11) shows the maximum number of cross docking that can be opened. Constraints (12-15) ensure that product transportation from supplier to cross docking and from cross docking to customer can take place only when the center is open. Constraint (16) determines that whether a vehicle is used or not, it does not require necessarily a vehicle comes out of cross docking. Constraints (17-19) show successive movement of vehicles. Constraint (20) shows each vehicle can meet only once each node. Constraints (21-22) show that a vehicle can move between supplier and customers when it is out of the cross docking center which belongs to it. Constraints (23-24) show that there is no direct relationship between supplier and customer. Constraint (25) prevents developing loop. Constraint (26) shows that there is no relationship between cross dockings. Constraints (27-28) show that each vehicle should go out of the cross docking belonging to it. Constraint (29) prevents customers and suppliers return back. Constraints (30-31) show that a vehicle belongs to a cross docking goes to supplier and customer node, when at least for one product it has been allocated to that cross docking and the vehicle is able to carry that type of product. Constraint (32) shows the limitation of number of vehicles. Constraint (33) shows the limitation of cross docking capacity. Constraint (34-35) ensure that amount of loaded product in pickup process and the amount of dumped product in the delivery process by the vehicle should not surpass the maximum capacity of vehicle. Constraints (36) shows that in any period, the amount of dumped product by all vehicles in node *i* is equal to demand of the customer at the same day. Constraint (37) ensures that a vehicle belonging to cross docking *o* dumps product *r* in customer *i* when the vehicle meets the node, customer is allocated to cross docking *o* for that product and the vehicle is able to carry that product. Constraints (38-39) are similar to (36-37) but they are for pickup nodes (suppliers). Constraint (40) shows the maximum capacity of each supplier for each product in each period. Constraints (41-43) show the amount of product between nodes. Constraint (44) shows the loading amount in customers is zero. Constraint (45) shows the amount of product delivery in supplier zero. Constraint (46) shows the binary variable (zero and one).

6. Dimensions of Proposed Mathematic Model and Lingo Calculation Results

In Table 1, number of dimensions and variables in the model are examined per various values of suppliers (*Nc*), cross docking (*No*), customers (*Nc*), product (*r*) and type of vehicle (*k*). Applied data are produced, randomly. The numerical solution for example 1 includes two suppliers, two customers, one candid place for cross docking, two types of vehicles and two types of products. Transportation and operational costs of each vehicle, customer demands and the particular amount of a product that each supplier can supply are definite and fixed.

Table 1
Dimensions of model versus different values and results of branch and bound method calculations

No	Counter									Objective function value
	N	N_s	N_c	N_o	E	R	K	Dimensions (number of variables)	Solution time(sec)	
1	5	2	2	1	1	2	2	177	0	184924
2	6	2	2	2	2	2	2	406	2	168615
3	7	2	3	2	2	2	2	522	2	150884
4	7	2	3	2	2	3	2	606	6	214145
5	7	2	3	2	2	2	3	770	3	93231
6	7	2	3	2	2	3	3	890	15	147074
7	8	3	3	2	2	3	3	1691	27	218288
8	9	3	4	2	2	3	3	3578	95	192239
9	12	3	6	3	2	3	3	-	-	-
10	20	6	10	4	3	3	3	-	-	-
11	22	6	12	4	3	4	4	-	-	-
12	27	7	16	4	3	4	4	-	-	-
13	34	12	16	6	4	4	5	-	-	-
14	40	14	18	8	6	5	5	-	-	-
15	45	14	20	11	6	5	6	-	-	-
16	50	16	22	12	6	6	6	-	-	-
17	70	25	30	15	6	6	6	-	-	-
18	80	30	35	15	8	8	6	-	-	-
19	90	35	40	15	8	10	6	-	-	-
20	100	40	45	15	8	10	6	-	-	-

Generally, the index of determining whether dimensions of problem are considered as big, medium or small depends to the time required for obtaining the optimal answer by an accurate approach such as branch and bound method. If the accurate approach is able to find the optimum solution in less than one or one and a half hour, then the problem is considered small dimension. However, if the accurate approach fails to identify the optimum solution, then the problem is deemed as a big problem. As the problem is NP-Hard, we set a time limit for running branch and bound method to obtain the accurate solution. This time is one hour or 3600 seconds. That implies that if branch and bound method fails to find the solution within the given time, the problem solving comes to a halt.

In Table 1, some problems with different dimensions solved by branch and bound method are presented. Dimensions of each problem, time required for solving each of them by branch and bound method and their value of objective function are also shown.

Among the problems given, the first 8 problems arrived at an optimum solution in the given time, and the remaining problems could not be solved by this software. As we can see, as the dimensions of problem increase, the efficiency of software to solve the model with bigger dimensions will decrease and it will move to the point that it is no longer able to solve the problem (Jayaraman & Ross, 2003; Ross & Jayaraman, 2008). For the same reason, we have solved the model in bigger dimensions by genetic algorithm (GA) and particle swarm optimization (PSO).

7. Assumptions and Parameters of the Algorithms

For developing the algorithms, many experiments were conducted with different values of parameters and finally the best results were obtained by using the values:

Genetic algorithm (GA): number of iterations, population size, and elite count percentage for sample problems are 200, 500 and 15%, respectively.

Particle swarm optimization (PSO): number of iterations, number of particles, learning coefficients (c1, c2, Vmax) for sample problems are set for 200, 500, 2, 2 and 6, respectively. Inertia coefficient is set for 1 as well. In sum, parameters of algorithms are presented in the following table.

Table 2
GA algorithm parameters values

500	Population size
200	Number of generations
15%	Probability of elitism operator
85%	Probability of crossover operator
15%	Probability of mutation operator

Table 3
PSO algorithm parameters values

Population size	500	*Number of iteration*	200	
Probability of mutation operator	15%	*Break condition*	30	
C_1	1	*C_2*		1
Vmax	6			

8. Comparing the Results of GA and PSO and Lingo

The program was run using a processor of the computer with specifications of 2.3 GhZ with RAM 6400GB works under operating system of Windows 7. For designing meta-heuristic GA and PSO method, Matlab software has been used. Each problem has been run 10 times with a random manner. We have presented the results of calculations obtained from the selected problems with bigger dimensions. Since branch and bound method fails to solve the models with bigger dimensions, we have used the proposed algorithm to solve problems with large numbers. This helps to determine the performance of the proposed algorithm under different circumstances. For comparing GA and PSO algorithms, a relative percent difference (RPD) has been used based on Eq. (47). Actually two groups, namely big and middle problems are used to measure the efficiency of these algorithms. Results of the experiments, best solutions and the average of solutions are presented in Table 4. The RPD value and run time averages are also set forth in Table 5. For testing the algorithm, 20 problems have been solved. Results obtained from the sample problems by GA and PSO as well as branch and bound method are shown in Table 5. As we can see, the obtained solutions by GA and PSO are close to branch and bound method solution.

$$RPD = \frac{sol_{avg} - sol_{min}}{sol_{min}} \tag{47}$$

Table 4
Symbols used for comparing algorithms

t(s)	**Required time**
f_{opt}	**Branch and bound method objective function value**
f_{best}	**Best value of algorithm objective function**
f_{avr}	**Average of value of algorithm objective function**

Table 5
Values obtained from various runs for two algorithms and branch and bound

No.	Branch and bound		Algorithm GA			Algorithm PSO		
	f_{opt}	t(s	f_{best}	f_{avr}	t(s)	f_{best}	f_{avr}	t(s
1	184924	1	208064	208064	2.5	208046	208064	3
2	168615	2	184191	184191	2.6	184191	186141	3.4
3	150884	5	170088	181852	3.2	170022	186416	4.2
4	214145	6	230697	233686	3.8	214729	230402	4.9
5	93231	3	173445	182340	4.3	173470	184984	5.9
6	147074	15	172257	183272	5.6	182246	201391	6.4
7	218288	27	181937	202645	5.4	193723	205173	6.3
8	192239	436	188937	212342	6.9	193504	207091	7.3
9	-	-	335383	362652	9.3	362338	402338	11.3
10	-	-	854963	988082	14.3	967008	1027789	16.2
11	-	-	1123973	1203547	16.4	1223605	1303139	18.1
12	-	-	2140080	2359474	24.1	2453582	2588264	30.4
13	-	-	1423249	1511535	46	1671639	1901647	51.3
14	-	-	3023791	3127420	57.4	3263430	3553309	64
15	-	-	2007377	2147112	68	2420787	2627483	76.3
16	-	-	4128562	4271063	71.7	4404874	4664193	85.2
17	-	-	6525810	6855864	194	7242315	7609329	204
18	-		8965668	9454502	186	9714609	10192274	197
19	-	-	18287658	19332202	417	20232262	20452267	516
20	-	-	22170352	23202377	647	23849699	24179133	679

The model has been solved for bigger dimensions using the proposed algorithms. Considering the values in Table 4, the algorithms have reached an answer close to optimized solution during a rational period of time. The proposed algorithms took longer time for very small dimensions, compared to branch and bound method optimization software, while calculation times of the proposed algorithms significantly have been reduced as the dimensions of the problem increased. Therefore, the examples showed that in solving large-scale problems the algorithms can reach the acceptable answer in significantly less time compared to branch and bound method. Also, for small dimensions, the value of objective function and solution time of GA and PSO are close to each other, however as dimensions of problems increase, solution time and value of objective function obtained by GA will become smaller than the values obtained by PSO. This could be interpreted as follows: in order for sample problems with small dimensions to achieve a suitable solution, each one of algorithms should cover a smaller search scope. Therefore, the proposed algorithms can be convergent to a suitable solution during a short calculation time. The results obtained show high performance of GA compared to PSO. In terms of both value of objective function and run time, GA outperformed PSO. To allow for a more detailed investigation of the efficiency of the algorithms, RPD values for GA and PSO and the average calculation time are shown in Table 6.

Table 6
Values of RPD and average of calculation time

No.	Number of points	Algorithm GA		Algorithm PSO	
	N	*RPD*	t(s)	*RPD*	t(s)
1	5	0	2.5	0	3
2	6	0	2.6	0.01	3.4
3	7	0.06	3.2	0.09	4.2
4	7	0.01	3.8	0.07	4.9
5	7	0.05	4.3	0.06	5.9
6	7	0.06	5.3	0.10	6.4
7	8	0.11	5.4	0.05	6.3
8	9	0.12	6.9	0.12	7.3
9	12	0.09	9.3	0.11	11.3
10	20	0.08	14.3	0.06	16.2
11	22	0.07	16.4	0.06	18.1
12	27	0.1	24.1	0.05	30.4
13	34	0.06	46	0.13	51.3
14	40	0.03	57.4	0.08	64
15	45	0.06	68	0.04	76.3
16	50	0.03	71.7	0.05	85.2
17	70	0.05	194	0.05	204
18	80	0.05	186	0.04	197
19	90	0.05	417	0.01	516
20	100	0.04	647	0.01	679

For further analyzing the results, RPD values are shown for different number of points in Fig. 3.

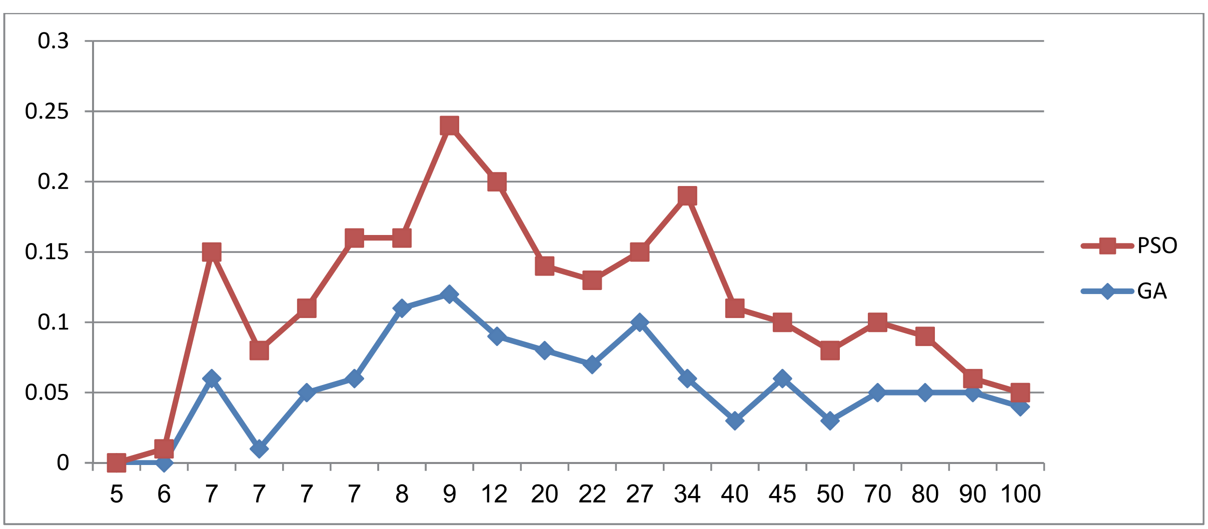


Fig. 3. RPD for different number of points

According to Fig. 3, as the number of difference points increase between values, RPD increases. However, in big dimensions with number of points 90 and greater, this difference is insignificant.

9. Conclusion

For on time delivery of demands to customers and reducing costs, transit warehouse plays a key role. On time delivery of demands is among the key issues in designing lean supply chain. In general, supply chain is considered as one of the most important fields of optimization. In this paper, transit warehouse location-routing model has been developed by considering a multiproduct multiple transit warehouse with split pickup and delivery. The model aimed to minimize transit warehouse construction costs and transportation costs as well. Among the major assumptions of the problem, one can refer to multiproduct, multiple warehouses, split pickup and delivery and heterogeneous vehicles. On the other hand, since the problem is highly complicated and requires long calculation time, it is classified as an NP-Hard problem. Thus we have used a meta-heuristic GA and PSO algorithms for solving the model. A comparison has also been made between results of Lingo outputs and GA and PSO solutions in the study. Results of the comparisons have shown the high efficiency of the proposed algorithms to address transit warehouse location-routing model. Also, outperformance of GA has been demonstrated in terms of solution time and answers, compared to PSO algorithm.

10. Suggestions for Future Research

Underlying assumptions of the study such as multi-product availability, multiple transit warehouse, split pickup and delivery and heterogeneous vehicles could be used in conjunction with the demand and the vehicle for any potential future research. Delivery time and inventory costs (lack of maintenance cost) can also be investigated in any period of time.

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