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Planning in a cross dock network with an operational scheduling overview

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Abstract
Nowadays, cross docking plays an important role in the supply chain networks especially in transportation systems. According to the cross dock system advantages such as reducing transportation costs, lead times, and inventories, scheduling in a cross-dock center would be more complicated by increasing the number of suppliers, customers and product types. Considering the cross dock limited capacities (equipment, storage space, work force, and etc.), sometimes it is not possible to deliver the supplier's products to customers in the right times. Thus, suppliers pay more tardiness penalties for scheduling problems in the cross dock centers. The current paper aims to propose an integer programming mathematical model that enables the suppliers to choose appropriate transportation paths according to amount of products delivered and moreover considering cross docks scheduling time constraints. In fact, cross dock centers present the list of outbound trucks departure times and suppliers reserve certain capacity based on their tardiness, transportation and inventory holding costs. Moreover, in this paper, a Lightening search algorithm (LSA) is developed to solve the proposed model. Additionally, to develop the solving procedure, a heuristic algorithm is proposed and compared with the LSA.

Keywords: Cross dock, scheduling, heuristic, lightening search algorithm, network

1-Introduction

In the past decades, with the development of information technology in the supply chain networks, suppliers found new competitors in their business area (Rahmanzadeh Tootkaleh et al., 2014) and tried to reduce the processing costs and improve their competitive advantages. Transportation costs constitute a major part of companies' total cost (Van Belle, 2012).

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In this area, cross docking is used as a logistics technique to tranship the supplier's product to the customers with a consolidation concept (Boysen and Fliedner , 2010), (Forouharfard and Zandieh , 2010), (Liao et al., 2013) and (Vahdani and Zandieh , 2010).

In a cross dock centre, product batches have been received from the suppliers in a right time and the batches are divided into new shipments and finally, the shipments are consolidated and sent to the customer regions. The process can significantly reduce the network's transportation costs and inventory levels. As a result, many companies have currently considered the cross docking theory as a salient concept in reducing transportation costs (Hill and Galbreth 2008; Lee, Jung, and Lee 2006; Musa, Arnaout, and Jung 2010).

iao et al. (2013) explained that using of cross dock centres will decrease the inventory and ordering costs significantly. Furthermore, Vahdani and Zandieh (2010) have shown that the total costs will reduce up to 70 % by implementing cross dock centres instead of traditional warehouses. Moreover, Lim et al. (2005) have developed a transhipment problem in which different capacitated nodes are considered to transfer the loads. Over the last few years, scheduling of a cross dock is an important issue considered by researchers. Boysen (2010) proposed a model for scheduling of inbound and outbound trucks in a cross dock for transhipment of frozen food products. He assumed that there is no stock in the cross dock facility and products types determined before of scheduling. Furthermore, he employed flowing, processing and delay times in the proposed model's objective function. For the scheduling of cross dock inbound trucks, Liao et al. (2013) developed a cross dock scheduling model in which outbound trucks allotted to the doors beforehand. In his model, temporary storage was considered for the cross dock centre capacities. Also, outbound trucks leave the cross dock in the predefined times and its penalty is paid for delaying in the products loads. Liao's model minimizes the weighted number of shipments delayed and a Tabu Search Algorithm (TSA) and a Simulated Annealing (SA) method is developed to solve the model. In fact, the problem assignment is a part of scheduling problem in which inbound trucks, outbound trucks and resources are assign to the doors in a right time and in the best way.

Lim et al. (2006) proposed a truck scheduling problem in which all loading and unloading process implemented in the fixed time window duration. It was assumed that cross dock capacity is limited and the mathematical model minimized the total travel distance. In the reviewed papers, the researchers tried to schedule trucks and assign them to the cross dock doors in the best condition according to the problem's objective function. The cross dock internal operations considered separately without paying careful attention to the priorities of manufactures. Sometimes, it is important for the manufactures to be aware of the truck's scheduling plans in a cross docks. Thus, regarding to the above overview, the manufactures would like to determine the appropriate path for sending their loads and reserving the cross docks capacities. The current paper tried to suggest a mathematical model to minimize the cross dock network inventory holding costs and trucks tardiness costs. In fact, it has been assumed that each cross dock present its outbound trucks destinations, capacities and departure times at the different periods and the manufactures reserve the cross dock outbound trucks capacities based on the networks costs. This model suggested a multi-period, multi-commodity type's problem for the manufactures outbound trucks. A heuristic algorithm was also presented to solve the model for the large size problems.

Many companies are not aware of how their shipments are delivered to customers through the cross-dock centres and how cross dock departure times are scheduled. Because of complexity in a distribution network, variety of products, and also the number of suppliers, planning in a cross-dock faces many challenges. Limitation in the capacity of shipment transferring, fixed transportation schedules, limited number of trucks, inbound and outbound doors are most important problems that make it difficult to present an efficient plan. Therefore, companies hesitate about whether they should deliver their shipments to customers through these cross-docks or not. They also cannot provide a specific plan for the products delivering process. Accordingly, the current paper suggested a novel mathematical model for planning in the whole distribution network instead of a single cross-dock. In fact, all cross-docks declare their transhipment capacity to each destination as well as the departure time of outbound trucks. Indeed, many companies reserve a specific capacity of cross-docks depending on their costs, and own limitation. Not only does this concept cause decrease in the difficulty of planning and scheduling in a supply chain, but also suppliers will be able to decide on

their delivery times and how to manage their costs. According to the suggested model of current paper, all cross-docks specify the departure time and capacity of their trucks to customers in different periods. Thus, suppliers will send their shipments to these cross-docks consolidated regarding to the present conditions. If suppliers send their shipments to cross-docks earlier than departure time of outbound trucks, inventory holding cost will be charged until they are stored. In addition to inventory cost, transportation and tardiness costs are minimized in the current study. The rest of this paper is organized as follows. Section 2 describes the problem and explains the proposed mathematical model. Section 3 demonstrates the problem solution complexity and presents LSA and a novel heuristic algorithm to solve the model.
Section 4 concludes paper's findings and recommends a number of attractive future research directions.

2-Mathematical model

As it was mentioned in the previous section, the suggested model aims to consider both planning and scheduling in a distribution system. The model allocates the suppliers trucks to the cross dock centres according to the cross dock scheduling plans. Figure 1 shows the problem description in more details.

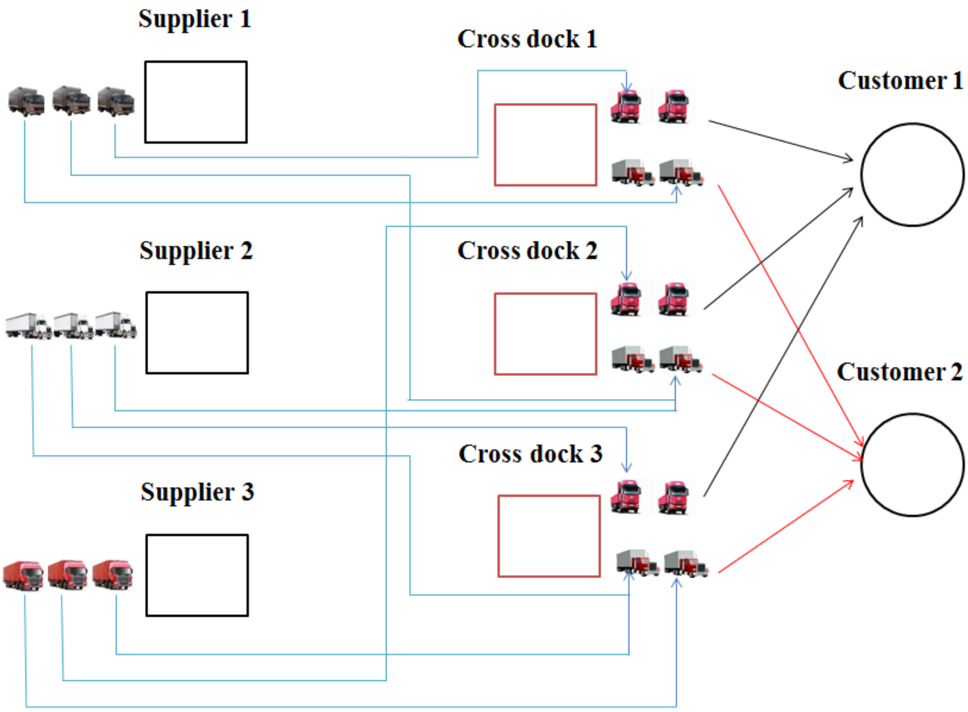

Fig 1. Planning of trucks allocation to the cross dock centers

Assumptions employed in the current paper were presented in the following:
In many cases, products delivering time to the customers is considered as one of the most important requirements for companies such as postal service providers. Thus, leaving time of outbound trucks from cross-docks to destinations for these types of shipments was predetermined and had to be done and, in this paper, it was considered as an assumption.

- All cross-docks have a set of trucks dedicated to particular destinations, departed in specific times. Therefore, there is a definite capacity for each rout.
- All suppliers should deliver shipments to customers by a predefined time; otherwise they should pay a specific tardiness cost to customers.
- All cross-docks have a specific storage space, so there is a limited capacity for each cross-dock.

The notations, parameters and variable employed in describing the model will be introduced as follows:

Indices

I: Set of suppliers $i \in I$
K: Set of cross-docks $k \in K$
J: Set of customers $j \in J$
N_i: Set of trucks belong toi^{th} supplier
H_{kj}: Set of k^{th} cross-dock's trucks dedicated to destination *j*

Parameters

t_{ijn}: Departure time of n^{th} shipment from supplier $i$to destination *j*
t'_{kjh}: Departure time of h^{th}truck from cross-dock k to destination *j*
tc_{ik}: Transshipment time from supplier i to cross-dock k
tc'_{kj}: Transshipment time from cross-dock k to customer *j*
D_{ijn}: Deadline for delivering of n^{th} shipment of supplier $i$to destination *j*
P_{ij}: Delayed cost per unit between the supplier *i* and costumer *j*
h_k: Inventory cost per unit of product at cross-dock k
C_{ikj}: Transportation cost per units of supplier *i* to costumer *j* from cross dock *k*
S_{ijn}: Loads to be shipped of n^{th}shipment from supplier *i* to costumer *j*
d_{kjh}: Capacity of h^{th}truck of cross dock *k* to costumer *j*

Decision variable

X_{ikjnh}: 1 if n^{th} truck of supplier i delivers the shipment to customer *j* through h^{th} truck of cross-dock k, otherwise 0
In this paper, objective function including tardiness, inventory and transhipping cost should be minimized.

Model:

$$\text{Min } z = \sum_i \sum_k \sum_j \sum_{n_i} \sum_{h_j} (x_{ikjnh} \times ((\max(0, t'_{kjh} + tc'_{kj} - D_{ijn}) \times P_{ij}) + \left((t'_{kjh} - t_{ijn} - tc_{ik}) \times h_k\right) + C_{ikj} \times S_{ijn})) \quad (1)$$

s.t:

$$x_{ikjnh} \times (t'_{kjh} - t_{ijn} - tc_{ik}) \geq 0 \qquad \forall\, i \in I,\ \forall\, k \in K,\ \forall j \in J,\ \forall\, n \in N,\ h \in H \quad (2)$$

$$\sum_k \sum_{h_j} x_{ikjnh} = 1 \qquad \forall\, i \in I,\ \forall j \in J,\ \forall\, n \in N \quad (3)$$

$$\sum_i \sum_n x_{ikjnh} \times S_{ijn} \leq d_{kjh} \qquad \forall\, k \in K,\ \forall j \in J,\ \forall\, h \in H \quad (4)$$

$$x_{ikjnh} = \{0,1\} \qquad \forall\, i \in I,\ \forall\, k \in K,\ \forall j \in J,\ \forall n \in N,\ h \in H \quad (5)$$

The objective function of model can minimize the total inventory holding, tardiness and transportation costs. Constraints (1) demonstrated that suppliers will choose trucks not departed the headquarters before reaching loads to these centres. The set of constraints (3) showed that n^{th}

shipment of supplier i to customer j should be allocated to just one cross-dock and just one truck. The obligatory satisfaction of cross docks trucks capacity was represented as the forth constraints. Moreover, constraints (5) define decision variables in a binary template.

3-Solution algorithm

In this section, the model solving process is investigated according to the computational complexity and solution algorithms. The achieved results are compared based on the quality of solutions and the computational running time.

3-1-Computational complexity

Theorem: The proposed mathematical model is NP-Hard in strong sense.

Proof: If the first constraint was relaxed, a Generalized Assignment Problem (GAP) would be achieved. In the relaxed model, trucks delivering shipments to final costumers and trucks transporting shipments to cross-docks can respectively consider machines and jobs in GAP. Due to NP -Hardness of GAP (Martello, 1990), our problem is an NP -Hard problem. As the proposed model was an NP -Hard problem, it can be solved to optimality just for small instances in a reasonable time. Therefore, a completely new efficient and effective heuristic method was developed to solve it.

3-2-Lightening search algorithm

LSA is a novel meta-heuristic algorithm that uses natural lightening phenomenon idea to solve optimization problems. This algorithm was proposed by Shareef et al., (2015) based on the mechanism of step leader propagation using the concept of fast particles. As a simple description of lightening phenomenon, step leaders develop within thunderstorm clouds when charge differences between clouds and earth become too large. Furthermore, a large flow of negative charges move downward to find the best path to reach the ground surface. The tip of step leaders is not sensitive to the actual charge on the ground surface. So, step leaders explore within about 50 meters of step leaders tip environment to find best candidate point. According to the electric field surrounding the step leader, multiple branch of the leader may be emerged and the path of step leader from cloud to ground surface can be very jagged. However, under high electric field, air around the step leader is ionized and additional electrons are generated along the original ones.

LSA defines three projectile types to simulate the transition path of electron from clouds to ground: first-step leaders, space projectiles, and lead projectiles. LSA is a population-based algorithm that uses a population of solutions to proceed to the global solution. Therefore, LSA introduces first-step leader population N in the first step. Each population uses space projectiles to find best solution at each step and lead projectiles present best position among N numbers of step leaders. Projectiles lose energy during elastic collisions with molecules and atoms in the air. So, according to the Sharif et al research, projectiles energy and velocity are calculated as follows:

$$E_p = \left(\left(\frac{1}{\sqrt{1-\left(\frac{v_p}{c}\right)^2}}\right) - 1\right)mc^2 \quad (6)$$

$$v_p = [1 - (\frac{1}{\sqrt{1-\left(\frac{v_0}{c}\right)^2}} - \frac{sF_i}{mc^2})^{-2}]^{-0.5} \quad (7)$$

Where E_p, V_p, and V_0 are current energy, current velocity and initial velocity of projectile respectively. c is a fixed parameter as speed of light. F_i represents the ionization rate; m is projectiles mass, and s is the length of path travelled by projectile. When projectile energy decreases less than a specific level, projectile cannot ionize the space and transmit to the better position and the exploration process will be finished. To present a simple description of algorithm, First, N step leader with random initial energy are created using uniform random distribution. Furthermore, each step leader explores the neighbourhood environment to find the better solution. If the better solution is founded, the step leader position and energy will be updated. In this step, step leaders may be branched based on lightening forking phenomenon using the standard normal distribution. After the each iteration, lead projectile represent the best step leader solution. This algorithm is finished when the optimal solution was founded or step leaders energy decreases too more. In this paper, we use LSA to find optimum or near optimum solution for the proposed model.

3-2-1- Heuristics algorithm

The mathematical model proposed in the current paper was an NP-Hard problem. Moreover, a heuristic algorithm to solve the model has been suggested in the large scale problems. In the first step, it can be tried to define a decision expression to determine the trucks priority in the decision process. Then, the best transportation route was applied for each truck based on the inventory and transportation costs and trucks capacities.

The decision expression was employed to evaluate the trucks priority expressed as below:

S(ijn) is defined as the score of shipment *n* from the supplier *i* to destination j.

The parameters were as follows:

D_{ijn} is the deadline for delivering of n^{th} shipment of supplier $i$to destination j. t_{ijn} is defined as the departure time of n^{th} shipment from supplier $i$to destination j. In this expression, $(D_{ijn} - t_{ijn})$ shows the transportation due date time. If the transportation time be greater than of this value, the delay cost will be considered. Thus, for the loads with the lower value of $\left(D_{ijn} - t_{ijn}\right)$, it should be transported in the faster transportation ways.

P_{ij} shows delayed cost per unit between supplier *i* and costumer *j*. Moreover, S_{ijn} was defined as the number of product in shipment n from supplier i to costumer *j*. The expression of $(P_{ij} \times S_{ijn})$ directly showed the increase of shipments' priority with the loads cost. In fact, $S(ijn)$ plays an inverse relationship to the shipments priority. Heuristic algorithm was suggested as follows:

- **Step 0**: Calculate the expression of $S(ijn)$ for each shipment.
- **Step 1**: Sort the Shipments based on the minimum value of $S(ijn)$.
- **Step 2**: Determine the route with the least inventory and transportation costs based on cross-dock capacity limitation and allot shipment with the higher priority to this route.
- **Step 3**: Determine unallocated shipment with the higher priority and go to Step 2.

This algorithm allocated all shipments based on their delayed cost. The experiments showed a good fitness of heuristic algorithm results to the optimum solution that was obtained from programming of the model in the GAMS software.

To examine the heuristic algorithm efficiency, 20 test problems have been implemented and the heuristic algorithm results were compared to the results of GAMS software solution. As it was shown in the table 1, the computation running time and the model objective function value of the heuristic algorithm was compared to the optimal solution obtained from LSA and GAMS software solution.

Table 1. Comparing of the heuristic algorithm solution with the LSA and GAMS software solutions

Test Problems	*I*	*J*	max(N)	K	max(H)	GAMS software		LSA			Heuristic		
						Objective Function	Run Time (s)	Objective Function	Run Time (s)	Error (%)	Objective Function	Run Time (s)	Error (%)
1	2	3	3	2	2	41534	3.08	46236	2.36	11.32	44974	0.45	8.28
2	5	9	4	4	5	342745	3.87	386557	2.01	12.78	346770	1.11	1.17
3	3	5	4	3	5	111996	3.37	123654	2.22	10.41	114192	0.96	1.96
4	5	6	4	4	4	182725	3.28	225360	3.89	23.33	205356	0.77	**12.39**
5	10	10	5	5	5	825303	20.47	1014630	7.21	22.94	870604	1.83	5.49
6	6	8	5	5	5	442809	15.53	498217	13.67	12.51	471893	1.18	6.57
7	8	15	5	6	5	1522303	58.51	1832201	23.99	20.36	1554275	2.34	2.10
8	10	12	7	5	5	1428875	5698	1733269	461	21.3	1455044	2.42	1.83
9	10	18	7	6	5	1791224	7653	2369852	742	**32.3**	1821619	2.41	1.70
10	10	20	7	7	6	1985568	9012	2403260	1407	21.04	2054865	2.54	3.49
11	8	20	5	7	7	1598698	6326	1976230	1023	23.61	1658987	2.32	3.77
12	9	17	7	7	6	1610385	5789	1967930	1255	22.2	1715952	2.46	6.56
13	12	12	5	6	5	1547865	6128	1612803	1374	4.2	1700253	2.21	9.85
14	15	10	6	6	5	1746053	7236	1963552	1339	12.46	1863540	2.74	6.73
15	11	17	5	7	7	1842369	7960	2039657	1785	10.71	1948632	3.02	5.77
16	14	15	8	4	5	1783260	7461	2292036	1643	28.53	1865974	2.43	4.64
17	18	20	5	6	4	2517846	12254	2884803	4987	14.57	2726940	3.24	8.30
18	10	20	6	5	6	1860395	8125	2147085	2557	15.41	1899854	2.98	2.12
19	13	15	4	5	7	1543262	5812	1604007	3741	3.94	1603298	2.53	3.89
20	9	16	6	6	5	1503954	5896	1689712	1363	12.35	1548623	2.40	2.97

As it was shown in table 1, the GAMS software, LSA and the heuristic algorithm objective function values and computation running times presented based on different test problems. In this regard, the solutions achieved by GAMS software are optimal and the two other algorithms solutions are compared considering the optimal solutions. The heuristic algorithm obtained near optimal solution with less than 13 % of objective function error. Moreover, as it was clear in the test problems, the heuristic algorithm running time was significantly less than the GAMS software solution running time. Therefore, according to the cross dock scheduling time constraints, managers would have tried to find the ways that obtain the solutions in shorter running time periods. Hence, employing a heuristic algorithm would be more acceptable in the cross-dock scheduling problems.

4-Conclusions and future research

The current paper just focused on the planning of the cross-dock network considering cross dock internal scheduling problems. Cross-dock centers presented their truck scheduling problems and suppliers can not only choose but also reserve the appropriate trucks capacities according to their load's lead times and tardiness costs. Moreover, this paper tried to model the problems of network planning to minimize the total tardiness, inventory holding, and transportation costs. This study can model the problem in the time horizon of several days. Furthermore, based on the importance of computation running time in the manager's decisions, a heuristic algorithm was suggested to solve the model. The heuristic algorithm was compared to the LSA and GAMS software solution in the objective function value and computation running time. The results also showed a good fitness of the heuristic algorithm to the optimal values.

For the future studies, stochastic conditions can be added to the parameters of model. Moreover, the model can utilize direct shipment to the transportation problems. Finally, cross-dock internal resources' constraints and costs can be considered in the future research works.

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