IJE TRANSACTIONS B: Applications Vol. 29, No. 11, (November 2016) 1595-1603

International Journal of Engineering

Journal Homepage: www.ije.ir

Trucks Scheduling in a Multi-product Cross Docking System with Multiple Temporary Storages and Multiple Dock Doors

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PAPER INFO

Paper history:
Received 15 December 2015
Received in revised form 10 September 2016
Accepted 30 September 2016

Keywords:
Cross-docking
Truck Scheduling
Direct Shipment
Temporary Storage
Mixed-integer Non Linear Programming

ABSTRACT

In order to reduce costs and increase efficiency of a supply chain system, cross docking is one of the most important strategies of warehousing for consolidation shipments from different suppliers to different customers. Products are collected from suppliers by inbound trucks and then moved to customers by outbound trucks through cross dock. Scheduling of trucks plays important role in the cross docking system. In this paper, we consider a single cross dock multi-product with multiple dock doors which sequence of products and trucks scheduling are specified simultaneously. Also, we have considered multiple temporary storages with different capacities and equipment و each of which is used for a specific set of products. These products are perishable; so, avoiding from storage is necessary. A two- level optimization model for this problem is proposed. The first level includes scheduling of inbound and outbound trucks aim to minimizing makespan and second level is maximizing direct shipment in order to reduce the level of storage. The problem is mathematically formulated by a mixed integer, nonlinear programming (MINLP). A real data set is used to solve the model and results confirm better efficiency and less storage.

***doi**: 10.5829/idosi.ije.2016.29.11b.14*

1. INTRODUCTION

Distribution systems play important role in supply chain management, hence designing an efficient distribution system leads to reduction of total costs. Distribution consists of all activities to deliver a product to the final customer. In a distribution system, raw materials and semi-finished products are transferred from suppliers to manufacturers and final products from manufacturers to customers [1]. There are two factors to assess the performance of a distribution system: responsibility of customer requirements and the cost of meeting customer requirements [2]. So, in a supply chain, for applying an appropriate distribution system, this two factors must be considered. Different distribution systems have different costs. For designing a distribution system, we will face some costs including: inventory, transportation, facilities and information costs [2]. Regarding the nature and type of products and supply chain strategies, products are distributed with five policies [3]:

(1) Direct shipment, (2) Milk run, (3) Hub and spoke, (4) Pool distribution, and (5) Cross docking

In direct shipment policy, distribution networks transfer products from suppliers to customers directly. Certainly, in the case that the amount of products is equal to the capacity of the trucks (FTL), this policy is the most economical to satisfy customer's demand. But, in the case that the total transported products are less than trucks capacity (LTL), other types of transportation networks are implemented [4]. Milk run strategy is a distribution strategy which products have been delivered from a supplier to multiple retailers by a vehicle. Another strategy is hub and spoke as a well-known strategy that includes a set of nodes and hubs which are connected by arcs/spokes to transfer products within the distribution network. Pool distribution is the fourth strategy that includes two levels. In the first level, products are transferred directly to the regional

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Please cite this article as: F. Zabihi, R. Sahraeian, Trucks Scheduling in a Multi-product Cross Docking System with Multiple Temporary Storages and Multiple Dock Doors, International Journal of Engineering (IJE), TRANSACTIONS B: Applications Vol. 29, No. 11, (November 2016) 1595-1603

terminals, and then in the second level they are transferred to final customers.

The cross docking strategy is one of the most efficient distribution strategies in logistics and todays is widely used by companies in order to reduce inventory level and increase customers' satisfaction in supply chain [5]. With implementing cross docking, the products before transferring to final destinations, are gathered to a cross dock. Different products according to their destinations are classified, labeled and grouped, then products with same destination are consolidated and transferred to the customers as soon as possible [6]. Long storage in cross docking system is not allowed and products must be transferred to their destination in less than 24 hours [7]. In some cases, the storage time has been considered less than 12 hours [8]. In a cross docking strategy, products are collected from suppliers by one or more inbound trucks and transferred to cross dock, then immediately after internal operations are reloaded to outbound trucks and are delivered to customers. Internal operations includes: sorting, packing, labeling, etc. This kind of distribution strategy leads to cost reduction (inventory, holding and transportation), faster product flow, less loss and damage risks and increase of customer satisfaction [9].

Nowadays, efficiency is one of the critical factors in distribution networks and its improvement must be considered more than ever since the customers demand higher level of servicing. This issue indicates the importance of accuracy in transferring products. One of the fundamental factors in increasing accuracy in transferring products is truck scheduling in order to minimize the total cost of system. Minimizing the total time of operations (makespan) is the most important goal in scheduling problems because decreasing makespan straightly decreases total cost of the system [10]. Inventory holding cost is another important cost that usually is neglected by managers and must be considered and planned to reduce the total costs. In the distribution systems of perishable products like food and drugs, even cross docking strategy is more costly and even short storage might cause decay on products. Therefore, decreasing inventory level in cross docking for this kind of products is significantly necessary [11]. In a cross docking system we can reduce inventory level by efficient scheduling trucks in the way that products are transferred from receiving doors to shipping doors directly without storage as much as possible. The goal of this paper is finding the most suitable sequence of inbound and outbound trucks in order to minimize the makespan in the first level and maximize direct flow from receiving doors to shipping doors in the second level. In fact, the proposed model is a multi-objective model. The objective functions are arranged in order of importance by the decision maker. In this context, the primary objective should be the makespan and the direct shipment can be treated as a secondary objective. Lexicographic method is a way to handle multi-objective optimization problems in general, where a pre-determined order can be established amongst the objective functions. In this paper, we know the order of objectives. This paper addresses a truck scheduling problem which products are perishable, so the makespan is significantly more important than direct shipment. Therefore, here we use the main idea of the lexicographic method. The primary and the main objective is to minimize the makespan and is very important. The secondary objective is to maximize the direct shipment. On the other hand, the proposed problem is a multi-objective problem which the order of objectives are known and the proposed approach is one of the well-known approaches to handle this types of multi-objective problems.

Also the sequence of products in unloading phase from inbound trucks and reloading phase into outbound trucks are determined by the model. In addition, routing from inbound trucks to outbound trucks are specified.

Cross docking as an effective strategy to achieve logistic goals attracts many researchers attention in the last decade. Many aspects of this strategy have been studied in the literature so far. There are three review papers on cross docking concept which many types of problems are nicely summarized and categorized based on their decision level:

(1) Strategic, (2) Tactical, and (3) Operational.

Boysen and Flinder [12] , Van Bell et al. [13] and Buijs et al. [10] classified the decisions on cross docking. Buijs et al. [10] proposed a framework to specify the interdependencies between different cross docking problem aspects and clarified future researches based on inputs and outputs of each problem aspect. According to the categories introduced by Van Bell et al. [13] decisions in cross docking can be summarized as following category:

(1) Location of cross docks, (2) Layout design, (3) Cross docking Network design, (4) Vehicle routing, (5) Dock door assignment, and (6) Truck scheduling and temporary storage.

There are numerous papers in the literature which considered the above-mentioned decisions individually. Different types of cross-docking operations and benefits of cross-docking strategy, were introduced by Napolitano, Education and Gross [14]. Some papers focused on cross-docks design to reduce the operational cost [8]. Also, some authors have considered a network structure of cross docking system to determine location and allocation decisions to the cross docks and customers, respectively [15]. In addition, some authors have studied vehicle routing and cross docking to reduce transportation costs [16].

As mentioned, efficient scheduling of inbound and outbound trucks can significantly improve performance of cross docking system and decreases costs. Therefore, majority of papers are focused on truck scheduling problem. Truck scheduling is assignment of inbound and outbound trucks to dock doors in a short term horizon. Sequence of trucks and the time of loading and unloading shipments at dock doors are specified by this problem. Several authors considered a simplified truck scheduling with a single inbound door and a single outbound door to study.

Yu and Egbelu [17] considered a single door cross dock to minimize the makespan by finding the best sequence of both inbound and outbound trucks. In their proposed model, the sequence of trucks and assignment of shipments are simultaneously determined by a heuristic algorithm. Their work were studied by other researchers to improve results and solving methods. Boysen and Flinder [18] developed another heuristic algorithm to the same problem for minimizing makespan. Also, many metaheuristic algorithms are proposed and compared for both deterministic and stochastic scheduling scenarios to the problem introduced by Yu and Egbelu [17]. Vahdani and Zandieh [19] introduced five metaheuristic algorithms including: Genetic algorithm (GA), Tabu search (TS), Simulated annealing (SA), Electromagnetism-like algorithm (EMA) and Variable neighborhood search (VNS). Arbani et al. [20] introduced other five metaheuristic algorithms including: GA, TS, Particle swarm optimization (PSO), Ant colony optimization (ACO) and differential evolution (DE). They used the above-mentioned algorithms to find the best sequence of trucks to minimize the makespan and compared the results obtained by different algorithms.

McWilliams et al. [21, 22] considered a problem with assignment of trucks to dock doors and a GA with simulation-based solution approach developed to minimize products traveling time. Boysen [23] Studied a truck scheduling problem in cross docking for food supply chain. Three terms for objective function of the problem have been considered including: minimizing flow time, processing time and tardiness of outbound trucks. A dynamic programming with SA are used to solve the problem and results show that SA can solve real size instances in an acceptable CPU time. Soltani and Sadjadi [24] developed a hybrid algorithm of SA and VNS to find the best sequence of outbound trucks in order to minimize the total flow time. The problem has been modeled as a zero inventory problem that storage in cross dock was not allowed and Taguchi method are used to show robustness of the proposed algorithm. Larbi et al. [25] introduced a scenario-base model to solve the scheduling problem and considered 3 scenarios:

(1) Complete information about sequence and arrival time of inbound trucks are available
(2) Partial information about sequence and arrival time of inbound trucks are available
(3) There is no information about inbound trucks

A graph-based model was used to solve the problem and results were reported.

In order to make the problems more realistic, some researchers considered cross docking with multiple inbound and outbound dock doors but only focused on inbound trucks scheduling. Rosales et al. [26] worked on assignment of inbound trucks to inbound dock doors to minimize distance traveled and manpower required in the cross dock. Although some authors study on scheduling both inbound and outbound trucks simultaneously. Alpan et al. [27] introduced a model with scheduling both inbound and outbound trucks in order to minimize inventory holding cost and truck replacement cost and developed three metaheuristic algorithms to solve the problem.

In addition, one of the most important factors in cross dock problems is maximizing direct flow from inbound to outbound doors. In the case of perishable food, drugs and frozen freights, it is important to transfer products from inbound trucks to outbound trucks without storage or avoiding storage as much as possible. The quality of these kinds of products is straightly deepens on the time of storage. Maximizing direct shipment in the cross dock leads to decrease level of temporary storage and ensures the quality of products.

In this paper, we introduce a two-level multi-product multi-door vehicle scheduling problem for both inbound and outbound trucks which in the first level objective is minimizing the makespan and the second level is maximizing direct shipment from inbound to outbound trucks. Minimizing the makespan decreases cross docking costs but also might increase the inventory level. To prevent increasing inventory level, in the second phase the model maximizes direct shipment by changing the plan of scheduling and sequence of trucks in the minimum time obtained by the first level. On the other hand, the minimum makespan obtained by the first level is an upper bound for the second level and the time of planning to maximize direct flow must be less than, or equal to the makespan.

2. PROBLE DEFINITION

The truck scheduling problem considered in this paper is a planning for scheduling inbound and outbound trucks in order to specify the best sequence of trucks at both sides of a cross dock. In addition, there are two key decisions to be made:

1- assignment of trucks to dock doors
2- product consolidation

In this problem, we have a cross dock as a distribution center with multiple receiving and shipping doors. Multiple products are collected from origins by inbound trucks and brought to the cross dock yard, then they must be unloaded to one of the receiving dock doors. Products are moved from receiving doors to appropriate shipping doors by an automatic system such as conveyors, then reloaded to outbound trucks immediately. Finally outbound trucks deliver products to their destinations.

In the multiple dock doors cross dock, moving time of products from receiving doors to shipping doors is significant because this period depends on relative distance between the dock doors to which inbound and outbound trucks have been assigned. Usually in the literature it is assumed that the moving time inside cross dock for products is constant or is not considered. On the other hand, the sequence of inbound trucks was assumed the same as outbound trucks and when a truck starts unloading process at receiving doors, related outbound truck should be at the shipping doors and products should be directly transferred to outbound trucks. Also, few papers considered a temporary storage in the case that if the outbound truck was not available at shipping doors, products would be stored behind the shipping doors until appropriate outbound truck comes into the shipping door. A temporary storage for perishable products, must have special facilities to avoid decay. In multi-product problems each product needs specific instruments and keeping all products in one temporary storage might not be possible. In this paper, we consider more than one temporary storage area behind the shipping doors to make our model more flexible. Products are transferred from receiving doors to shipping doors directly or transferred to related temporary storages until an appropriate outbound truck comes into the shipping door. Figure 1 represents a cross docking system.

2. 1. Assumptions The assumptions and characteristics of our model are presented below:

- All trucks are available at the time zero
- All inbound and outbound trucks must stay in the dock doors until they finish their loading/unloading process
- The total amount of received products must be equal to the total amount of shipped products, i.e. there are no inventory at the end of the planning horizon
- The sequence of inbound and outbound trucks, assignment of trucks to dock doors, unloading/ reloading sequence of products and the number of units of products transferred from inbound trucks to outbound trucks is determined by the model
- Products can be loaded/unloaded one by one and products can't be loaded/unloaded multiply at a time
- The capacity of temporary storage area is limited
- Each temporary storage area is for specific set of products and can't be used for other sets of products.
- Amount and types of products loaded into inbound trucks are known
- Amount and types of products that should be reloaded into outbound trucks are known and predetermined
- Interruption in loading and unloading process is not allowed, e.g. pre-emption.

3. PROPOSED MODEL FORMULATION

A mixed integer nonlinear programming formulation is presented for the problem.
The notations of the formulation are listed below:

3. 1. Data and Input Parameters

R	Number of receiving doors
S	Number of shipping doors
I	Number of inbound trucks
O	Number of outbound trucks

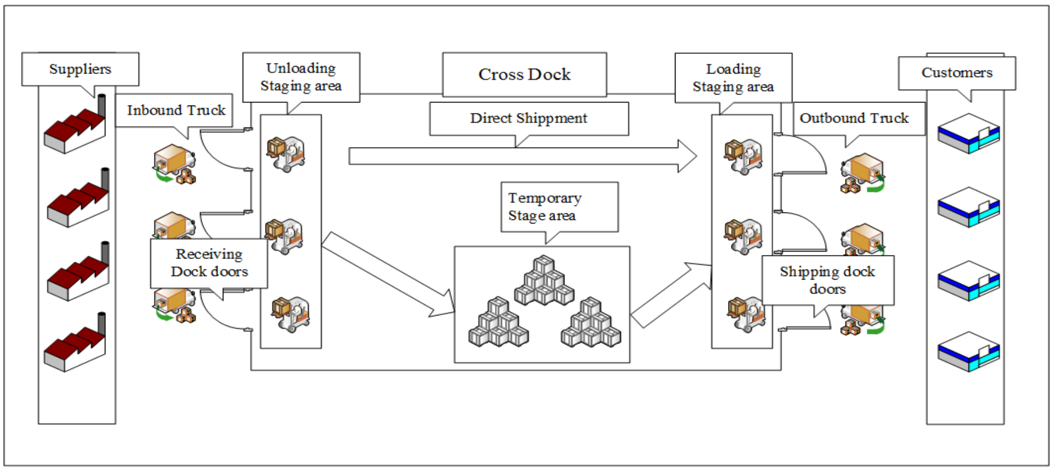

Figure 1. Cross docking system

K	Number of product types
n_1	Number of product types which can be stored in the temporary storage 1
n_2	Number of product types which can be stored in the temporary storage 2
n_3	Number of product types which can be stored in the temporary storage 3
r_{ik}	Number of products type k collected by inbound truck i
s_{jk}	Number of products type k reloaded to outbound truck j
Ct	The needed time for changing trucks at doors
M	An arbitrary big constant

3. 2. Continues Variables

T	Makespan
ati_i	Arrival time of inbound truck i to receiving door
rt_i	Release time of inbound truck i from receiving door
ato_j	Arrival time of outbound truck j to shipping door
dt_j	Departure time of outbound truck j from shipping door
u_{ij}	Starting time of unloading products from inbound truck i into outbound truck j
L_{ij}	Starting time of reloading products into outbound truck j that come from inbound truck i

3. 3. Integer Variables

x_{ijk}	Number of products type k transferred from inbound truck i into outbound truck j

3. 4. Binary Variables

$v_{ij} = \begin{cases} 1; & \text{if inbound truck } i \text{ assigned to receiving door } j \\ 0; & \text{otherwise} \end{cases}$

$w_{ij} = \begin{cases} 1; & \text{if outbound truck } i \text{ assigned to shipping door } j \\ 0; & \text{otherwise} \end{cases}$

$p_{ij} = \begin{cases} 1; & \text{if inbound truck } i \text{ and } j \text{ assign to the same door and truck } i \text{ precedes truck } j \\ 0; & \text{Otherwise} \end{cases}$

$q_{ij} = \begin{cases} 1; & \text{if outbound truck } i \text{ and } j \text{ assign to the same door and truck } i \text{ precedes truck } j \\ 0; & \text{otherwise} \end{cases}$

$z_{ij} = \begin{cases} 1; & \text{if a product transfer from inbound truck } i \text{ to outbound truck } j \\ 0; & \text{otherwise} \end{cases}$

$Dc_{ij} = \begin{cases} 1; & \text{if product type } k \text{ transfer from inbound truck } i \text{ to outbound truck } j \text{ directly} \\ 0; & \text{otherwise} \end{cases}$

$g_{ijh} = \begin{cases} 1; & \text{if unloading } Z_{ij} \text{ precedes } Z_{ih} \text{ in unloading sequence from inbound truck } i \\ 0; & \text{otherwise} \end{cases}$

$h_{ijh} = \begin{cases} 1; & \text{if reloading } Z_{ih} \text{ precedes } Z_{jh} \text{ in reloading sequence into inbound truck } h \\ 0; & \text{otherwise} \end{cases}$

3. 4. Mathematical Formulation

$$Z = Min \quad T$$

$$T \ge dt_j \ \forall j \tag{1}$$

$$\sum_{j=1}^{R} v_{ij} = 1 \ \forall i \tag{2}$$

$$\sum_{j=1}^{S} w_{ij} = 1 \ \forall i \tag{3}$$

$$\sum_{j=1}^{O} x_{ijk} = r_{ik} \ \forall i, k \tag{4}$$

$$\sum_{i=1}^{I} x_{ijk} = s_{jk} \ \forall j, k \tag{5}$$

$$x_{ijk} \le M z_{ij} \ \forall i, j, k \tag{6}$$

$$p_{ij} + p_{ji} \ge v_{ih} + v_{jh} - 1 \ \forall i, j, k \ ; i > j \tag{7}$$

$$p_{ij} + p_{ji} \le 1 \ \forall i, j \ ; i > j \tag{8}$$

$$p_{ii} = 0 \ \forall i \tag{9}$$

$$ati_j \ge rt_i + Ct - M(1 - p_{ij}) \ \forall i, j \ ; i \ne j \tag{10}$$

$$q_{ij} + q_{ji} \ge w_{ih} + w_{jh} - 1 \ \forall i, j, h \ ; i > j \tag{11}$$

$$q_{ij} + q_{ji} \le 1 \ \forall i, j \ ; i > j \tag{12}$$

$$q_{ii} = 0 \ \forall i \tag{13}$$

$$ato_j \ge dt_i + Ct - M(1 - q_{ij}) \ \forall i, j \ ; i \ne j \tag{14}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{O} \sum_{k \in n_1} (1 - Dc_{ijk}) x_{ijk} \le Q_1 \tag{15}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{O} \sum_{k = n_2} (1 - Dc_{ijk}) x_{ijk} \le Q_2 \tag{16}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{O} \sum_{k \in n_3} (1 - Dc_{ijk}) x_{ijk} \le Q_3 \tag{17}$$

$$g_{ijh} + g_{ihj} \geq z_{ij} + z_{ih} - 1 \ \forall\, i, j, h\,; j > h \tag{18}$$

$$g_{ijh} + g_{ihj} \leq 1 \ \forall\, i, j, h\,; j > h \tag{19}$$

$$u_{ih} \geq u_{ij} + \sum_{k=1}^{4} x_{ijk} - M\,(1 - g_{ijh}) \ \forall\, i, j, h\,; j \neq h \tag{20}$$

$$u_{ij} \geq ati_i - M\,(1 - z_{ij}) \ \forall\, i, j \tag{21}$$

$$rt_i \geq u_{ij} + \sum_{k=1}^{4} x_{ijk} \ \ \forall\, i, j \tag{22}$$

$$L_{ij} \geq u_{ij} + mt - M\,(1 - z_{ij}) \ \forall\, i, j \tag{23}$$

$$h_{ijh} + h_{jih} \geq z_{ih} + z_{jh} - 1 \ \forall\, i, j, h\,; i > h \tag{24}$$

$$h_{ijh} + h_{jih} \leq 1 \ \forall\, i, j, h\,; i > h \tag{25}$$

$$L_{jh} \geq L_{ih} + \sum_{k=1}^{4} x_{ijk} - M\,(1 - h_{ijh}) \ \forall\, i, j, h\,; i \neq h \tag{26}$$

$$L_{ij} \geq ato_j - M\,(1 - z_{ij}) \ \forall\, i, j \tag{27}$$

$$dt_j \geq L_{ij} + \sum_{k=1}^{4} x_{ijk} \ \ \forall\, i, j \tag{28}$$

$$u_{ij} + mt - L_{ij} \leq M * Dc_{ijk} - \varepsilon \ \forall\, i, j, k \tag{29}$$

$$u_{ij} + mt - L_{ij} \geq -M * (1 - Dc_{ijk}) \ \forall\, i, j, k \tag{30}$$

All variables ≥ 0.

Constraint (1) indicates that the makespan must be greater than or equal to departure time of the last outbound truck from shipping door. Constraint (2) ensures that each inbound truck must assign to only one receiving door. Constraint (3) is the same as constraint (2) for outbound trucks. Constraint (4) ensures that the total number of units of product type *k* that was initially loaded in inbound truck *i* must be transferred to outbound trucks. Constraint (5) ensures that the total number of units of product type *k* that are needed for outbound truck *j* must be transferred from inbound trucks. Constraint (6) shows the connection between the x_{ijk} and z_{ij} variables. Constraints (7) and (8) determine the sequence of inbound trucks in the case that they assign to the same receiving dock. Constraint (9) ensures that no inbound truck can precede itself in the inbound truck sequence. Constraint (10) calculates the arrival and release times for the inbound trucks according to their docking sequence. Constraints

(11) to (14) are the same as constraints (7) to (10) for outbound trucks. Constraints (15) to (17) indicate the capacity of staging area for each set of products based on desired facilities to holding. Constraint (15) ensures that total number of products which can be stored in temporary storage 1 must be less than or equal to its capacity. Constraints (16) and (17) are the same as constraint (15) for temporary storages 2 and 3. Constraints (18) to (20) calculate the starting time for unloading products according to unloading sequence if any product is transferred from inbound trucks to outbound trucks. Constraints (18) and (19) determine unloading sequence if any product is transferred from inbound trucks to outbound truck. Constraint (20) calculates starting time for unloading product according to unloading sequence. Constraint (21) ensures that unloading products starts after arrival of inbound trucks to receiving doors. Constraint (22) calculates the release time of inbound trucks from receiving doors that must be greater than or equal to the sum of the starting time for unloading product from the inbound truck to the outbound truck and the unloading time for those products. Constraint (23) calculates the starting time for loading products into an outbound truck that should be greater than or equal to the sum of the starting time of unloading products and the moving time of the products from receiving door to the shipping door. Constraints (24) to (26) are the same as constraints (18) to (20) for outbound trucks. Constraint (27) is the same as constraint (21) for loading products into outbound trucks. Constraint (28) is the same as constraint (22) for outbound trucks. Constraints (29) and (30) determine the Dc_{ijk} variables, if transportation time for product type *k* from inbound truck *i* to outbound truck *j* is less than or equal to starting time of reloading that product to outbound truck j. This means that products are transferred directly from receiving door to relative shipping door, then $Dc_{ijk}=1$, and if transportation time for product type *k* from inbound truck *i* to outbound truck *j* is greater than the starting time of reloading that product to outbound truck *j*, this means products are stored at staging area before reloading to the shipping doors, then $Dc_{ijk}=0$.

3. 5. Linearization of the Proposed Model

Multiplying a binary variable in a continuous variable causes nonlinearity in the equations and this type of nonlinearity appears in Constraints (15) to (17).

The nonlinearity of these constraints are caused by multiplying Dc_{ijk} as a binary variable in x_{ijk} as a continuous variable. We assume that $Dc_{ijk}\, x_{ijk} = Dx_{ijk}$; therefore, nonlinear constraints are linearized as follows [28]:

$$Dx_{ijk} \leq x_{ijk} \tag{31}$$

$$Dx_{ijk} \geq x_{ijk} - M\,(1 - Dc_{ijk}) \tag{32}$$

$$Dx_{ijk} \leq M \times Dc_{ijk} \tag{33}$$

Therefore, the above-mentioned constraint are replaced by:

$$\sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in n_1} x_{ijk} - \sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in n_1} Dx_{ijk} \le Q_1 \tag{34}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in n_2} x_{ijk} - \sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in n_1} Dx_{ijk} \le Q_2 \tag{35}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in n_3} x_{ijk} - \sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in n_3} Dx_{ijk} \le Q_3 \tag{36}$$

4. COMPUTATIONAL EXPERIMENTS AND RESULTS

The MILP problem is coded in GAMS software version 24 and solved by CPLEX solver in different instances. In order to test validity of the proposed model, A well-known real data set introduced by Yu and Egbelu [17] is used and results are reported. The so mentioned data set includes 29 test problems, out of which 10 test problems are randomly. The time needed to change trucks at the dock doors is assumed 75 time unit and transportation time for products from inbound trucks into outbound trucks in the direct shipment is assumed 100 time units.

Table 1 indicates the results for test problems of minimizing the makespan. Problem sets, number of doors, number of trucks, number and type of products, run time, makespan and the number of directed transportation are shown in Table 1.

The optimal objective value of the main problem in different instances with minimizing makespan have been acquired in acceptable CPU time. Due to complexity of the model in some problems, it is difficult to reach feasible solution even in several hours. In order to report the results of those problems, a time limitation of 15000s has been applied and the best objective value obtained in the limited time are reported. As mentioned, even temporary storages in food supply chain and perishable products may cause decay on products. Increasing direct shipment from receiving doors to shipping doors will result in better quality of products and better servicing, therefore we consider this issue as a second objective function and maximize direct shipment of products (Dc_{ijk}), therefore we maximize Dc_{ijk} as follows: Objective function is replaced by Equation (37)

$$Z = Max \sum_{i=1}^{I}\sum_{j=1}^{O}\sum_{k\in K} Dc_{ijk} \tag{37}$$

This approach might increase the makespan, so in order to avoid increasing the makespan, Equation (38) is added to the constraints of the main problem.

$$T \le T_0 \tag{38}$$

where T_0 is the makespan obtained by the main problem reported in Table 1. The model with mentioned changes is solved again with the same assumptions and results are reported in Table 2. In the model with minimizing makespan, results indicate that majority of products are transferred from inbound trucks to outbound trucks indirectly and trough staging, but Table 2 shows that the direct shipment is obviously increased by this approach.

TABLE 1. Results for first level

Problem	**No. of receiving doors**	**No. of shipping doors**	**No. of inbound trucks**	**No. of outbound trucks**	**No. of Product types**	**Run time(s)**	**Makespan**	Dc_{ijk}
1	2	2	4	5	4	15000	809	28
2	2	2	5	4	6	15000	854	64
3	2	2	3	3	8	15000	575	60
4	2	2	5	5	8	1.06	545*	56
5	2	2	5	3	8	0.78	627*	32
6	2	2	4	4	5	86.25	779*	25
7	2	2	5	4	6	312.16	515*	48
8	2	2	3	5	7	109.23	759*	42
9	2	2	3	4	8	306.91	588*	56
10	2	2	3	4	9	2.14	820*	54

* Optimal solution

TABLE 2. Results for second level

Problem	No. of receiving doors	No. of shipping doors	No. of inbound trucks	No. of outbound trucks	No. of Product types	Run time(s)	makespan	Dc_{ijk}
1	2	2	4	5	4	21.42	809	76*
2	2	2	5	4	6	15000	854	168
3	2	2	3	3	8	15000	575	102
4	2	2	5	5	8	0.56	545	112*
5	2	2	5	3	8	0.75	627	64*
6	2	2	4	4	5	958.57	779	70*
7	2	2	5	4	6	269.63	515	114*
8	2	2	3	5	7	146.72	759	98*
9	2	2	3	4	8	235.05	588	104*
10	2	2	3	4	9	2.09	820	99*

* Optimal solution

5. CONCLUTION AND FUTURE RESEARCHES

Cross docking as an effective distribution strategy is a warehousing strategy that currently is widely used by many companies in order to reduce costs and satisfy customers. Although a lot of investigation have been made in truck scheduling in cross docking system, there is no study on the problems with this approach. The problem studied in this paper is a planning for scheduling trucks in order to specify the best sequence of trucks at both sides of a cross dock. Moreover, assignment of trucks to dock doors and product consolidation decisions are considered. A cross dock with multiple receiving and shipping doors are considered and multiple products are planned to be delivered to their destinations. In addition, we consider more than one temporary storage area behind the shipping doors to make our model more flexible. For efficient planning of the problem, a two-level approach is applied to solve the model.in the first level. The main model is solved by minimizing the makespan then the makespan obtained by the first level is added to the model as a constraint. In the second level, the model with new constraint is solved to maximize direct shipment from receiving doors to shipping doors. Results of solving different test problems indicate that the proposed approach efficiently increases direct shipment without increasing the makespan just by changing the planning of trucks. Because of the complexity of the problem, using metaheuristic algorithms to solve large size problems would be a direction for future researches. As another future research, it would be interesting to consider pre-emption to the problem.

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Trucks Scheduling in a Multi-product Cross Docking System with Multiple Temporary Storages and Multiple Dock Doors

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P A P E R   I N F O

Paper history:
Received 15 December 2015
Received in revised form 10 September 2016
Accepted 30 September 2016

Keywords:
Cross-docking
Truck Scheduling
Direct Shipment
Temporary Storage
Mixed-integer Non Linear Programming

چکیده

به منظور کاهش هزینه‌ها و افزایش کارایی سیستم زنجیره‌تأمین، انبارداری عبوری یکی از مهمترین استراتژی‌های انبارداری برای ترکیب محصولات از تامین‌کننده‌های مختلف به مشتریان مختلف است. محصولات با کامیون‌های ورودی از تأمین‌کنندگان جمع‌آوری شده و سپس به وسیله‌ی کامیون‌های خروجی از طریق انبار عبوری به سمت مشتریان حرکت داده می‌شوند. زمان‌بندی کامیون‌ها نقش مهمی در سیستم انبارداری عبوری ایفا می‌کند. در این مقاله یک انبار عبوری با چند نوع محصول و چند درب در نظر گرفته شده است که ترتیب محصولات و زمان‌بندی کامیون‌ها به صورت هم‌زمان تعیین می‌شود. هم‌چنین چندین انبار موقت با ظرفیت‌های متفاوت و تجهیزات مختلف پیش‌بینی شده است که هرکدام برای نوع خاصی از محصولات مورد استفاده قرار می‌گیرند. محصولات از دو نوع فاسدشدنی و فاسدنشدنی هستند که برای محصولات فاسدشدنی، اجتناب از انبارش ضروری است. یک مدل بهینه‌سازی دوسطحی برای این مسأله پیشنهاد داده شده است. سطح اول شامل زمان‌بندی کامیون‌های ورودی و خروجی با هدف کمینه‌سازی زمان کل عملیات و سطح دوم بیشینه‌سازی جریان مستقیم به منظور کاهش سطح انبارش است. مسأله با یک برنامه‌ریزی عدد صحیح مختلط غیرخطی به‌صورت ریاضی فرمول‌بندی می‌شود. یک مجموعه داده‌ی واقعی برای حل مدل استفاده شده است و نتایج، کارایی بهتر و انبارش کمتر را نشان می‌دهند.

***doi**: 10.5829/idosi.ije.2016.29.11b.14*