A genetic algorithm for truck scheduling in cross docking systems

Hamid Davoudpour, Pedram Hooshangi-Tabrizi, and Pooya Hoseinpour*

Department of Industrial Engineering, Amirkabir University of Technology, Tehran, Iran
p.hoseinpour@aut.ac.ir

Abstract: Cross docking is a kind of warehousing systems in which products are unloaded from inbound trucks and loaded into outbound ones. In order to minimize total operation time of the system, this research finds the best scheduling of both inbound and outbound trucks by considering a temporary storage, and also variable product moving time from inbound to outbound which has been ignored in the previous proposed models. This problem is in the class of NP-hard problems. Therefore, a Genetic Algorithm (GA) is developed to handle the complexity. To evaluate the efficiency of the results a lower bound is developed for the problem.

[Hamid Davoudpour, Pedram Hooshangi-Tabrizi, and Pooya Hoseinpour. A genetic algorithm for truck scheduling in cross docking systems. Journal of American Science 2012; 8(2):96-99]. (ISSN: 1545-1003). http://www.americanscience.org. 14

Keywords: Cross docking; Truck scheduling; Genetic Algorithm (GA).

1. Introduction

Cross docking is a system in warehousing that has great potential for reducing the costs as well as enhancing the level of customer services [1]. Cross docking links unloading materials from incoming trucks and loading them into outgoing trucks. Cross docking has the potential of eliminating the two most expensive warehousing operations, storage and retrieval, by synchronization of flows in inbound and outbound docks. Here, we attempt to scheduling of trucks in a cross docking system with the purpose of minimizing total completion of operation times, makespan. In order to avoid the complexity of truck scheduling, the problem is reduced to a "one inbound dock serves one outbound dock" setting similar to recent related researches, [2] and [3].

[4] presented one of the first papers on cross docking systems. The success of using cross docking systems has been realized by applying it in many industries with high amount of distribution cost such as WalMart [5], UPS [6], and Toyota [7].

In the field of truck scheduling, [2] suggested a cross docking system with temporary storage in front of the docks. The objective of the study was to find the best scheduling for both inbound and outbound trucks to minimize makespan; simultaneously, the product assignments from inbound trucks to outbound trucks are also determined. [3] deal with the problem of truck scheduling problem, which generally contains the assigning of each truck to the inbound and outbound docks as well as determining the schedule of all trucks assigned to each dock. They show that minimizing makespan is strongly NP-hard even if all processing times are equal.

Other fields of researches related to cross docking systems are dock assigning, layout determining, and some integrated models. For review of recent works in these areas see [8-10].

In this paper, the model considers the variable time for products moving from inbound docks to outbound docks which would complicate the structure of the model. This assumption is considered for the first time in addition to the other ones such as temporary storage (see other assumptions in [11]). The rest of the paper is as follows. In Section 2, our model is proposed mathematically. The solution approaches are discussed in Section 3. In Section 4, the experimental analysis is shown. A conclusion is derived in Section 5.

2. Model description

32 various cross docking models are defined depending on available dock numbers, pattern of docks, and the existence of temporary storage [11]. In this paper, the focus is on one of the 32 problems which is firstly mentioned in [2]. Considering the additional assumption mentioned in Section 1, the mathematical programming is defined as follows:

- **Parameters**

R Number of inbound trucks

S Number of outbound trucks

N Number of product types

r_{ik} Number of units of product type k that was initially loaded in inbound truck i

s_{jk} Number of units of product type k that was initially needed for outbound truck j

T_k Moving time of product k from the receiving dock to the shipping dock

Ct Changeover time of truck

Ie_i Entrance time of inbound truck i

Id_i Departure time of inbound truck i

Oe_i Entrance time of outbound truck j

Od_i Departure time of outbound truck j

M Big number

Ms Makespan

- **Variables**

x_{ijk} Number of units of product type k that transfer from inbound truck i to outbound truck j

y_{ij} Binary variable takes 1 if any products transfer from inbound truck i to outbound truck j otherwise 0.

z_{ij} Binary variable takes 1 if inbound truck i precedes inbound tuck j in the inbound truck sequence otherwise 0.

w_{ij} Variable takes 1 if outbound truck i precedes outbound tuck j in the outbound truck sequence otherwise 0.

The model for scheduling inbound and outbound trucks is proposed as:

Mathematical model

$$\min \quad Ms$$

$$s.t. \quad Ms \geq Ol_j \quad \text{for all } j, \tag{1}$$

$$\sum_{j=1}^{S} x_{ijk} = r_{ik} \quad \text{for all } j,k, \tag{2}$$

$$\sum_{i=1}^{R} x_{ijk} = s_{jk} \quad \text{for all } j,k, \tag{3}$$

$$x_{ijk} \leq My_{ij} \quad \text{for all } i,j,k, \tag{4}$$

$$Id_i \geq Ie_i + \sum_{k=1}^{N} r_{ik} \quad \text{for all } i, \tag{5}$$

$$Ie_j \geq Id_i + Ct - M(1 - z_{ij}) \quad \text{for all } i,j \;\; i \neq j, \tag{6}$$

$$Ie_i \geq Id_j + Ct - Mz_{ij} \quad \text{for all } i,j \;\; i \neq j, \tag{7}$$

$$z_{ii} = 0 \quad \text{for all } i, \tag{8}$$

$$Od_j \geq Oe_j + \sum_{k=1}^{N} s_{ik} \quad \text{for all } j, \tag{9}$$

$$Oe_j \geq Od_i + Ct - M(1 - w_{ij}) \quad \text{for all } i,j \;\; i \neq j, \tag{10}$$

$$Oe_i \geq Od_j + Ct - Mw_{ij} \quad \text{for all } i,j \;\; i \neq j, \tag{11}$$

$$w_{ii} = 0 \quad \text{for all } i, \tag{12}$$

$$Od_j \geq Ie_i + \max_k \{T_k \mid x_{ijk} > 0\} + \sum_{k=1}^{N} x_{ijk} - M(1 - y_{ij}) \quad \forall i,j \tag{13}$$

$$\text{All variables} \geq 0$$

Constraint (1) enforces makespan not to be less than the time that the last scheduled outbound truck leaves the shipping dock. Constraint (2) guarantees that the total number of units of product type k that are moved from inbound truck i to all outbound trucks the same of the number of units of product type k that were initially loaded in inbound truck i. Constraint (3) is similar to Constraint (2) for outbound truck j. Constraint (4) set relation between x_{ijk} and y_{ij} variables. Constraints (5)–(7) make a correct sequence for arriving times for the inbound trucks based on their order. Constraints (5)–(7) for inbound trucks, Constraints (9)–(11) function for the outbound trucks. Constraints (8) and (12) ensure that no outbound truck can precede itself in the inbound or outbound truck sequence respectively. Constraint (13) connects the entrance time of inbound trucks to the departure time of outbound trucks. Here, it is assumed that any product has different moving time from inbound to outbound, T_k. By considering the variable product moving time from inbound to outbound the model becomes more complex than before.

3. Solution approach

Here, an attempt is made to solve the model. For doing so, a solution method using meta-heuristics is developed as the model is in the class of NP-hard problems [12].

3-1. Genetic algorithm

GA, method for solving some problems, is developed based on the process of natural evolution and uses its features, such as inheritance, mutation, selection, and crossover. GA has been widely studied, experimented and applied in many fields in engineering worlds. The steps of GA are presented below:

Step 1: Generate an initial population randomly

Step 2: Evaluate the fitness for each individual in current population

Step 3: Define selection rule and choose best individuals to produce new population

Step 4: Call the crossover operator for selected individuals with probability P_c to generate new individuals

Step 5: Call the mutation operator for each member with probability P_m

Step 6: If the termination condition is met, then stop; otherwise, repeat steps (2)–(5).

The components of GA applied to solve the scheduling of cross docking problems are briefly described as follows:

- Solution representation

The inbound and outbound tucks sequence is represented as chromosome. For example, in a 3 inbound and 2 outbound trucks scheduling a chromosome could be [2,3,1:2,1]. This solution represents a sequence [2,3,1] for inbound trucks and [2,1] for outbound trucks in scheduling of a cross docking system.

- Initial population

The initial population consists of N randomly generated truck sequences.

- Fitness evaluation

In order to sort individuals, the fitness evaluation function is calculated for each member representing their relative superiority (or inferiority) according following:

$$f_j = Ms_j \Big/ \sum_{i=1}^{n} Ms_i$$

where Ms_j denotes the makespan of the j^{th} chromosome.

- Selection rule and reproduction

Roulette wheel selection rule is used for this proposed GA. According to this rule, chromosomes are selected according to their fitness. Imagine a roulette wheel where are placed all chromosomes in the population, each has its place big accordingly to its fitness function. Then a marble is thrown there and selects the chromosome. Chromosome with bigger fitness will be selected more times. These selected chromosomes are reproduced by crossover and mutation operators until the number of population equals N. Best chromosomes copies to new population straightly. This method is Elitism. Elitism can very rapidly increase performance of GA.

- Crossover and Mutation

Two-point crossover operator is applied for both inbound and outbound truck sequences separately. Two crossover points are selected randomly, binary string from beginning of chromosome to the first crossover point is copied from one chromosome, the part from the first to the second crossover point is copied from the second chromosome and the rest is copied from the first chromosome. Mutation is done by choosing two different locations on a chromosome randomly and interchanging the trucks at this location. This operator is done on both outbound and inbound truck sequences.

- Termination criterion

The stopping criterion is set to the computational time limit fixed to $R \times S \times 40$ milliseconds. R and S are the number of inbound and outbound trucks, respectively. Our pseudo code of the decoding is presented in the following:

Take a permutation for inbound and outbound

Initialization

$x_{ijk} = 0, y_{ij} = 0 \quad i = 1, \ldots, R, \; j = 1, \ldots, S, \; k = 1, \ldots, N$

For $i = 1$ **to** R **do**

    If $i = 1$ **do**

        $Id_i = \sum_k r_{ik}$

    Else

        $Id_i = Id_{i-1} + Ct + \sum_k r_{ik}$

    End if

End for

Determine y_{ij}

Determine x_{ijk}

$T_{\max_{ij}} = \text{Find} \max_k \{T_k \mid x_{ijk} > 0\} \; i = 1, \ldots, R, \; j = 1, \ldots, S$

$h_1 = \max_{1 \le i \le R} \left\{ y_{ij} \left(Id_i - \sum_{k=1}^{N} r_{ik} + \sum_{k=1}^{N} x_{ijk} + T_{\max_{ij}} \right) \right\}$

$h_2 = Od_{j-1} + Ct + \sum_{k=1}^{N} s_{jk}$

$Od_j = \max\{h_1, h_2\}$

Find $\max_j \{Od_j\}$ equals to makespan.

3-2. Lower bound

Although GA present a solution by an error that in some cases may be zero, it is not proved that these suggested algorithms meet the global optimum solution. The lower bound suggested by [13] is used to evaluate GA's solutions as the following formula:

$$LB = \begin{cases} \sum_{i=1}^{R} \sum_{j=1}^{S} \sum_{K=1}^{N} x_{ijk} + V_{\max} + (S-1)D & R \le S \\ \sum_{i=1}^{R} \sum_{j=1}^{S} \sum_{k=1}^{N} x_{ijk} + V_{\max} + (S-1)D + (R-S)D & R > S \end{cases}$$

4. Numerical study

In order to evaluate the efficiency of GA, 26 test problems presented by [2] were also randomly generated. The number of inbound and outbound trucks is between 4 and 20 and total number of items is in the range of 1030 to 6384 units. In all problem sets, it is assumed that the loading and unloading time of each product takes one unit of time in duration. The transfer time of the products is uniformly distributed between 60 and 140 time units and truck changeover time is fixed and equals 75 time units.

To measure the performance of GA, Relative Percentage Deviation (RPD) is used which is defined in the following formulas:

$$RPD(\%) = \frac{ALG - OPT}{OPT} \times 100$$

where *OPT* and *ALG* are respectively the optimal objective value and the average objective value with respect to the solution obtained by the GA. Because of the complexity of the problem, in large scale problems, the global optimum solution cannot be reached in reasonable time. So, the presented lower bound is used instead of optimal objective value to measure the performance of GA. The GA is implemented in Visual C++ and run on a PC with 1.6 GHz Intel Core 2 Duo and 2 GB of RAM memory. GA ran 5 times for each instance. In the GA the parameters are set as P_m = 0.1, P_c = 1, the initial population size was set to 50. Table 1 reports the average *RPDs* of some instances.

Table 1. Makespan and RPDs obtained by GA.

Problem set	*R*	*S*	*K*	*N*	*LB*	GA	
						Average solution	*RPD(%)*
1	5	4	6	1030	1438	1490.8	3.672
2	9	9	9	2123	2849	3024	6.143
3	10	9	10	2164	2960	3183.5	7.551
4	11	10	10	3115	4000	4251.8	6.295
5	11	11	11	2200	3090	3437.1	11.233
6	11	12	11	2760	3724	4061.1	9.052
7	12	12	12	3060	4025	4394.4	9.178
8	13	11	13	2614	3794	3967.5	4.573
9	12	13	12	2782	3822	4177.6	9.304
10	14	12	10	2925	4037	4268	5.722
11	13	13	11	3454	4493	4914.6	9.383
12	14	14	13	5040	6154	6599	7.231
13	14	15	12	5655	6843	7286.6	6.483
14	15	13	13	4099	5287	5681.1	7.454
15	15	15	14	5060	6235	6850.2	9.867
16	16	13	15	5351	6607	7118.9	7.748
17	14	16	13	4609	5857	6343.5	8.306
18	16	16	11	4720	5978	6432.2	7.598
19	15	16	12	4603	5866	6373.9	8.658
20	16	17	16	5676	7007	7645.6	9.114
21	17	17	12	5724	7059	7597.7	7.631
22	18	16	14	5905	7316	7892.9	7.885
23	17	18	11	5377	6779	7251.3	6.967
24	19	19	13	6384	7869	8494.4	7.948
25	20	17	14	5488	7045	7564.5	7.374
26	20	20	12	5314	6875	7398.3	7.612

R = # of inbound trucks, *S* = # of outbound trucks, *K* = # of product types *N* = Total # of products, *LB* = Lower bound.

5. Conclusion

In this research, truck scheduling of a cross docking system is studied by considering variable product moving time from inbound to outbound addition to some other assumptions. The problem is modeled as a mathematical programming where the objective of the model is to find the best truck sequences for both inbound and outbound trucks to minimize total operation time. Simultaneously, the product assignments from inbound to outbound trucks are determined. The solution approach based on GA is implemented. For evaluating the accuracy of GA, the lower bound is developed for the problem. And finally, it is shown how the makespan can be affected by assuming the variable moving time. Relaxing some other assumptions is released to future research and authors hope that it would be tractable.

Corresponding Author:
Pooya Hoseinpour
Department of Industrial Engineering
Amirkabir University of Technology
Tehran, Iran
E-mail: p.hoseinpour@aut.ac.ir

References

1. Apte, U.M. and S. Viswanathan, Effective cross docking for improving distribution efficiencies. International Journal of Logistics, 2000. 3(3): p. 291-302.
2. Yu, W. and P.J. Egbelu, Scheduling of inbound and outbound trucks in cross docking systems with temporary storage. European Journal of Operational Research, 2008. 184(1): p. 377-396.
3. Boysen, N., M. Fliedner, and A. Scholl, Scheduling inbound and outbound trucks at cross docking terminals. OR spectrum, 2010. 32(1): p. 135-161.
4. Rohrer, M. Simulation and cross docking. 1995. IEEE.
5. Gue, K.R., Crossdocking: just-in-time for distribution. Graduate School of Business & Public Policy Naval Postgraduate School, Monterey, CA, 2001. 8.
6. Forger, G., UPS starts world's premiere cross-docking operation. Modern Material Handling, 1995. 36: p. 38.
7. Witt, C.E., Crossdocking: Concepts demand choice. Material Handling Engineering, 1998. 53(7): p. 44-49.
8. Lim, A., H. Ma, and Z. Miao, Truck dock assignment problem with time windows and capacity constraint in transshipment network through crossdocks. Computational Science and Its Applications-ICCSA 2006, 2006: p. 688-697.
9. Lim, A., H. Ma, and Z. Miao, Truck dock assignment problem with operational time constraint within crossdocks. Advances in applied artificial intelligence, 2006: p. 262-271.
10. Li, Y., A. Lim, and B. Rodrigues, Crossdocking-JIT scheduling with time windows. Journal of the Operational Research Society, 2004. 55(12): p. 1342-1351.
11. Yu, W., Operational strategies for cross docking systems, 2002, Iowa State University.
12. Garey, M. and D. Johnson, Computers and Intractability: A Guide to the Theory of NP-Completeness.(1979) WH Freeman. New York.
13. Vahdani, B. and M. Zandieh, Scheduling trucks in cross-docking systems: Robust meta-heuristics. Computers & Industrial Engineering, 2010. 58(1): p. 12-24.

2/1/2012