Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 109 (2014) 1180 – 1184

Procedia
Social and Behavioral Sciences

2nd World Conference On Business, Economics And Management- WCBEM 2013

Simulated annealing approach for transportation problem of cross-docking network design

İlker Küçükoğlu[a] *, Nursel Öztürk[a]

[a] Uludag University, Faculty of Engineering and Architecture, Industrial Engineering Department, Gorukle Campus, 16059 Bursa, Turkey
[b] Uludag University, Faculty of Engineering and Architecture, Industrial Engineering Department, Gorukle Campus, 16059 Bursa, Turkey

Abstract

Cross-docking is one of the effective methods applied in supply chain management in order to minimize total transportation costs while satisfying the customer demands. This paper addresses the transportation problem of cross-docking network design where products are transferred from suppliers to customers through cross-docking centers without storing them for a long time. Two-dimensional truck loading constraints are taken into account for different sized products in order to find exact capacity of each truck. This assumption allows decision makers to find idle vehicle capacities and evaluate the capacity utilizations as a cost factor. The problem is formulated using mixed integer programming and solved using simulated annealing (SA) meta-heuristic algorithm which has great potential to solve NP-Hard problems. The proposed algorithm is performed for several randomly generated examples and compared with the optimum solutions. Results show that proposed algorithm demonstrates effective and efficient solutions to reduce the total transportation costs in cross-docking network design.

© 2014 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
Selection and peer review under responsibility of Organizing Committee of BEM 2013.

Keywords: Cross-docking, transportation problem, heuristic algorithm, simulated annealing;

1. Introduction

The efficiency of transportation is one of the most important factors for supply chain management. For this reason, many companies develop various strategies to boost customer satisfaction and bring down the total costs. Cross-docking which almost eliminates the storage costs and speeds up the product flows is one of these strategies. It can be described as the process of moving products from suppliers to customers through cross-docking centers without storing products for a long time in these centers. At each center, incoming trucks loaded from different suppliers arrives to incoming doors and unloaded to incoming area quickly. These products are sorted and consolidated according to their destinations and then reloaded to outgoing truck for distribution. This strategy provides different advantages compared with traditional distribution centers: the consolidation of shipments, a shorter delivery lead time, the reduction of costs, improved customer service, fewer overstocks, etc. (Belle et al., 2012). As a result of these advantages, cross-docking has become an interesting logistics strategy that can give companies important competitive benefits.

Until now, lots of studies considering cross-docking have been studied in the literature and they categorized in many ways. Belle et al. (2012) presented a comprehensive literature review about cross-docking and classified them

* Corresponding author: İlker Küçükoğlu. Tel.: +90-224-294-2091
E-mail address: ikucukoglu@uludag.edu.tr

1877-0428 © 2014 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
Selection and peer review under responsibility of Organizing Committee of BEM 2013.
doi:10.1016/j.sbspro.2013.12.608

based on the problem type: location of cross-docks, cross-docking layout design, cross-docking networks, vehicle routing, dock door assignment, truck scheduling, storage and other issues. Some of these problems are more concerned about long term decisions (strategic or tactical), while others deal with short-term decisions (operational).

Cross-docking network problem consists of supplier, customer and cross-docking facility sets. Each set contains one or more locations and the aim is to determine the flow of goods from suppliers to customers through cross-docks in order to reduce the total transportation cost. Lim et al. (2005) studied the cross-docking network problem by extending the traditional transshipment problem. The transshipment problem consists of a number of supplier, transshipment and demand nodes with the capacitated arcs. Moreover, supplier and customer time windows are considered to determine inventory holding costs in this study. Chen et al. (2006) studied a similar problem in cross-docking network design. The noticeable differences between these studies are that supplies and demands are not allowed to split and different products can be considered. An integer programming formulation of the problem is provided and three heuristic algorithms are proposed as a solution approach. Musa et al. (2010) evaluates the total cost as distinct from other studies by considering vehicle transportation costs. They formulated the problem with integer programming and proposed an ant colony optimization meta-heuristic algorithm to solve the problem. Ma et al. (2011) studied similar problem by considering only one type of product and formulated the problem with time costs and truck setup costs. The authors proposed a solution approach which consists of two stage heuristics. Alpan et al. (2011) studied the transshipment scheduling problem in a multiple inbound and outbound dock configuration. Direct shipping and inventory holding strategies are allowed in the problem. The objective is to find best schedule of transshipment operations. They proposed several heuristic algorithms to attain the solution. Miao et al. (2012) considered the transshipment problem with soft and hard time windows constraints. They proposed two types of meta-heuristics algorithms: tabu search and genetic algorithm.

On the other hand, there are considerable numbers of study related with the truck loading or pallet loading in the literature. Chen et al. (1991) proposed a binary mathematical model for two-dimensional pallet packing problem for non-uniform box sizes and multiple pallets. Zachariadis et al. (2009) developed a tabu search meta-heuristic algorithm for vehicle routing problem with two-dimensional loading constraints and tested their algorithm on several benchmark instances. They achieved to several new best solutions. Fuellerer et al. (2010) considered the vehicle routing problem with three-dimensional loading constraints. They presented an ant colony optimization algorithm as a solution approach. Zachariadis et al. (2012) introduced a new transportation problem called the pallet-packing vehicle routing problem and used tabu search based heuristic algorithm to solve problem. Finally, Leung et al. (2013) used the simulated annealing meta-heuristic algorithm for heterogeneous fleet vehicle routing problem with two-dimensional loading constraints and tested with benchmark instances derived from the two-dimensional loading vehicle routing problem. However, only a paper which considers truck loading in cross-docking network problem could be found to the best of our knowledge. Charkhgard and Tabar (2011) considered three dimensional products and truck shapes to find exact capacity of the trucks. But only one type of trucks and cubic products are assumed in their study. Moreover, there is no decision variable for truck loading plan.

In this study, we consider the two-dimensional loading problem in cross-docking network design. The two-dimensional shapes are applied for both trucks and loads in order to find exact capacity of each truck in basis of each product. The objective is to find the best network flow routes and truck loading plan decisions that minimize the total transportation cost. The rest of the paper is organized as follows. In Section 2, problem definition and mixed integer mathematical model is presented. In Section 3, proposed algorithm is explained. Computational experiments are shown in Section 4. Finally, Section 5 concludes the study.

2. Problem description

In this paper, cross-docking network design with two-dimensional truck loading is considered for S suppliers, D customers and C cross-docking facilities. The products flow from suppliers to customers through cross-docks according to customers demand. Each product of suppliers is loaded into incoming and outgoing trucks by considering its destination. Thus, the objective is to find the best transshipment plan regarding the two dimensional truck loading operations in order to minimize total transportation costs. Also, idle truck capacities are used as additional cost factor. Musa et al. (2010) and Charkhgard and Tabar (2011) considered some assumptions in their mathematical models. In this paper we have accepted several of them and enhanced our model with the following new conditions:

- Directly shipping is not allowed from suppliers to destinations.
- Truck capacity is considered with dimensional constraints on the contrary of weight or amount of load.
- Loads and trucks considered as a rectangular shapes.
- The trucks may have different sizes. Thus, loading plans are affected by the truck choices. Moreover each product to be sent from different origins to different destinations may have different sizes.
- The transportation costs are related with only travelled distances among the locations.

The concept of the two-dimensional loading problem in cross-docking network is depicted in Figure 1, which illustrates an example of two suppliers, two cross-dock facilities and three customers.

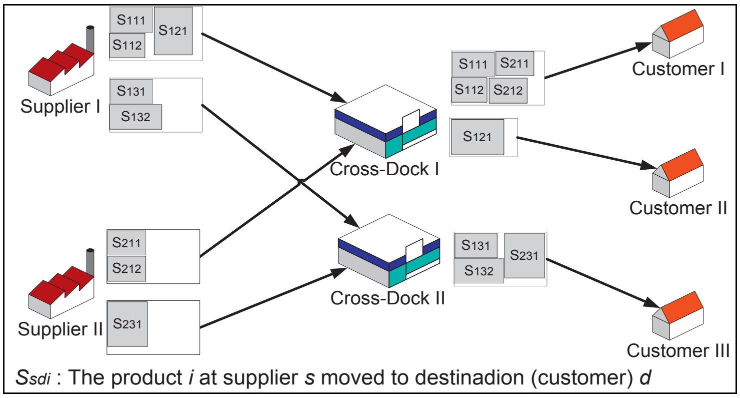

Figure 1. An illustrative example of described problem

According to assumptions described above the problem is formulated with mixed integer programming (MIP) and tested with several illustrative examples. Although example results show that proposed model introduces comprehensive product flow plans with truck loading layouts, MIP is inadequate to solve large scale problems.

3. Proposed algorithm

Because of the exact model is so difficult, simulated annealing algorithm is proposed for the problem. Simulated annealing is a stochastic method for solving combinatorial problems proposed by Kirkpatric, Gelett and Vecchi in 1983 (Kirkpatric et al., 1983). The SA methodology draws its inspiration from annealing process in metallurgy. It works by emulating the physical process so that a solid is heated to a high temperature and step by step cooled to low it to crystallize.

SA uses a stochastic approach to guide the search. In addition to accepting better solutions, SA allows the search to proceed to a neighbouring state even if the move causes the value of the objective function to become worse. SA processes the local search in the following way. If a move to neighbour X' in neighbourhood ensures improvement in objective value, or leaves it unchanged, then the move is always accepted. More precisely, the solution X' is accepted as the new solution if $\Delta \leq 0$, where $\Delta = f(X') - f(X)$ and $f(X)$ is the value of objective function. Moves, which increase the objective function means that $\Delta > 0$, are accepted according to a probability function $e^{(-\Delta/T)} > \theta$, where T is the parameter of temperature, and θ is a random number between [0, 1]. The value of T varies from a relatively large number to a small value close to zero, which is often controlled by linear equations for reducing temperature linearly. Stopping criteria of SA is generally based on the probability that a move from a local minimum to a neighbour with the lowest score is accepted. If that probability is low compared to the selection probability the algorithm is stopped in that approach (Otten and Ginneken, 1988).

The steps of the proposed SA algorithm are shown in Figure 2.

T = Initial temperature, c = Cooling Parameter
Generate initial solution X
$X^{best} = X$
Do
    Generate X′ from X by λ-interchange local search
    If $f(X') \leq f(X)$ Then
        $X = X'$
    Else
        $\Delta = f(X') - f(X)$
        If $exp\ (-\frac{\Delta}{T}) > random[0,1]$ Then
            $X = X'$
        End If
    End If
    $T = T \times c$
    If $f(X) < f(X^{best})$ Then
        $X^{best} = X$
    End If
Loop Until (Stopping Criteria)

Figure 2. Steps of the proposed SA algorithm

To find a solution, we encode the solution representation into three parts. Part 1 represents the product priority. Part 2 and Part 3 represent the incoming truck and outgoing truck priorities respectively. According to these priorities, each product is inserted in the existing network by greedy search approach. Furthermore, λ-interchange local search method introduced by Osman and Christofides (1994) is used for all parts to generate a new solution.

4. Computational experiments

Cross-docking network design and two-dimensional truck loading problem have been not considered jointly before, and so there is no benchmark test set available. Therefore, we generated our own data sets randomly to identify proposed SA and described with four basic parameters ($S/C/D/F_{max}$): the number of suppliers S, the number of cross-dock facilities C, the number of destinations D and maximum flow amount in network F_{max}. According to these parameters, 10 different instances are generated and each instance includes two main cases. First case is based on single product and single truck type (consists of same products and same trucks) and second case is based on multiple products and multiple trucks type (consists of different sized products and trucks). Also each case is examined for $F_{max} = 5$ and $F_{max} = 10$.

Table 1. Computational results

	Single Product and Single Truck Type						Multiple Products and Multiple Trucks Type					
	$F_{max} = 5$			$F_{max} = 10$			$F_{max} = 5$			$F_{max} = 10$		
Problem Description	Optimum Solution	SA Solution	CPU Time	Optimum Solution	SA Solution	CPU Time	Optimum Solution	SA Solution	CPU Time	Optimum Solution	SA Solution	CPU Time
$3/2/4/F_{max}$	672.0	672.0	1.2	863.0	863.0	9.2	672.0	672.0	1.9	942.0	993.0	13.5
$5/2/10/F_{max}$	1353.0	1353.0	1.7	1847.0	1847.0	17.6	1586.0	1613.0	10.4	2014.0	2231.0	33.7
$5/5/3/F_{max}$	751.0	751.0	2.3	1135.0	1205.0	15.5	751.0	751.0	6.7	1365.0	1392.0	54.8
$8/1/10/F_{max}$	1835.0	1835.0	5.3	2456.0	2456.0	21.4	2016.0	2085.0	16.4	-	2743.0	46.9
$10/2/12/F_{max}$	1919.0	1919.0	1.8	1978.0	2025.0	20.9	2175.0	2175.0	11.5	2249.0	2291.0	49.1
$4/1/20/F_{max}$	2328.0	2328.0	4.5	2918.0	2918.0	16.0	2642.0	2773.0	14.4	2873.0	2956.0	30.2
$12/3/8/F_{max}$	1747.0	1747.0	7.2	1892.0	1926.0	36.8	1793.0	1867.0	19.6	-	2093.0	42.8
$4/2/15/F_{max}$	1822.0	1822.0	11.3	-	2217.0	74.9	1822.0	1896.0	23.7	2467.0	2642.0	116.3
$4/3/18/F_{max}$	2149.0	2149.0	8.9	2283.0	2362.0	66.4	2082.0	2179.0	36.3	-	2297.0	108.5
$7/5/12/F_{max}$	1547.0	1547.0	12.4	-	1879.0	68.8	1857.0	2019.0	32.8	-	2159.0	143.9

Table 1 shows the representative results which contain optimal solutions, proposed SA solutions and CPU times of algorithm (in seconds). For all instances, the results indicate that SA exhibits superior performance for the first case problems such that the average gaps (%GAP) between optimal solutions and SA solutions are %0.00 for F_{max} = 5 and %1.74 for F_{max} = 10. For the second case problems, the average gaps slightly increase due to the products and trucks are different sized. These values are %3.15 for F_{max} = 5 and %5.00 for F_{max} = 10. Moreover, exact model is extremely difficult and for some cases of the problem optimum solutions cannot be reached, proposed algorithm provides feasible solutions in less than two minutes except for the last instance.

5. Conclusion

In this paper, cross-docking network design problem is studied with two-dimensional truck loading constraints in order to minimize the total transportation cost, and also truck utilizations are considered as a cost factor. Thus, loading and transportation operations can be carried out more realistic and applicable in real life. Problem is formulated with the mixed integer mathematical model and solved using simulated annealing algorithm. Proposed algorithm is tested with several randomly generated problems. On the basis of these problems, computational results show that proposed SA exposes effective and efficient solutions in a short time with respect to the optimum solutions.

References

Alpan, G., Laider, A., Larbi, R., & Penz, B. (2011). Heuristic solutions for transshipment problems in a multiple door cross docking warehouse. Computers & Industrial Engineering, 61, 402 – 408.

Belle, J.V., Valckenaers, P., & Cattrysse, D. (2012). Cross-docking: State of the art. Omega, 40(6), 827 – 846.

Charkhgard, H., & Tabar, A.A.Y. (2011). Transportation problem of cross-docking network with three-dimensional trucks. African Journal of Business Management, 5(22), 9297 – 9303.

Chen, P., Guo, Y., Lim, A., & Rodrigues, B. (2006). Multiple crossdocks with inventory and time windows. Computers & Operations Research, 33, 43 – 63.

Chen, C.S., Sarin, S., & Ram, B. (1991). The pallet packing problem for non-uniform box sizes. International Journal of Production Research, 29(10), 1963 – 1968.

Fuellerer, G., Doerner, K.F., Hartl, R.H., & Iori, M. (2010). Metaheuristics for vehicle routing problems with three-dimensional loading constraints. European Journal of Operational Research. 201, 751 – 759.

Kirkpatrick, S., Gellat, C.D., & Vecchi, M.P. (1983). Optimization by simulated annealing. Science, 220 671 – 681.

Leung, S.C.H., Zhang, Z., Zhang, D., Hua, X., & Lim, M.K. (2013). A meta-heuristic algorithm for heterogeneous fleet vehicle routing problems with two-dimensional loading constraints. European Journal of Operational Research, 225, 199 – 210.

Lim, A., Miao, Z., Rodrigues, B., & Xu, Z. (2005). Transshipment through crossdocks with inventory and time windows. Naval Research Logistics, 52(8), 724 – 733.

Ma, H., Ziao, Z., Lim, A., & Rodrigues, B. (2011). Crossdocking distribution networks with setup cost and time windows constraint. Omega, 39, 64 – 72.

Miao, Z., Yang, F., Fu, K., & Xu, D. (2012). Transshipment service through crossdocks with both soft and hard time windows. Annals of Operations Research, 192, 21 – 47.

Musa, R., Arnaout, J., & Jung, H. (2010). Ant colony optimization algorithm to solve the transportation problem of cross-docking network. Computers & Industrial Engineering, 59, 85 – 92.

Osman, I.H., & Christofides, N. (1994). Capacitated clustering problems by hybrid simulated annealing and tabu search. International Transactions in Operational Res., 1(3) 317 – 336.

Otten, R.H.J.M., & Van Ginneken, L.P.P.P. (1988). Stop criteria in simulated annealing. In IEEE Computer Design: VLSI in Computers and Processors, 549 – 552.

Zachariadis, E.E., Tarantilis, C.D., & Kiranoudis, C.T. (2009). A guided tabu search for the vehicle routing problem with two-dimensional loading constraints. European Journal of Operational Research, 195, 729 – 743.

Zachariadis, E.E., Tarantilis, C.D., & Kiranoudis, C.T. (2012). The pallet-packing vehicle routing problem. Transportation Science, 46(3), 341 – 358.