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Selective vehicle routing problem with cross docking

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Abstract

Competitiveness in global markets has force organizations to develop and improve their policy to satisfy customers different needs in the best way with minimum cost. Cross docking is a new distribution strategy which is widely used by many companies practically and attracts the researchers attention to study in recent years. In this paper we introduce a selective vehicle routing problem with cross docking (SVRPCD). Products are collected by inbound vehicles from suppliers and after consolidation process in the cross-dock, immediately are delivered by outbound trucks to customers. Products have purchasing and selling price and available sources like budget are limited. In the real world it is not possible to serve all customers and suppliers, so they will be in the plan only if it is profitable to serve them, so satisfying of all demands is not necessary. A mixed integer linear programming (MILP) is utilized for the goal of increasing total benefit of cross docking system. In order to evaluate the performance of the proposed model of this paper, different examples of a real data set are solved and analyzed. The results confirm superiority of the acquired tour plan by the proposed approach to deal with real world instances.

Keywords: Cross docking; Vehicle routing; Purchasing and selling price; Selective vehicle routing.

1- Introduction

The cross docking strategy is one of the most efficient distribution strategies in logistics that todays is widely used by companies in order to reduce inventory level and increase customer satisfaction in the supply chain [1]. With implementation of cross docking, the products before transferring to final destinations, are gathered to a cross dock. Different products according to their destinations are sorted, labeled and grouped, then products with same destination are consolidated and transferred to the customers as soon as possible [5]. Long storage in the cross docking system is not allowed and products must be transferred to destinations at less than 24 hours. This kind of distribution strategy leads to costs reduction (inventory, holding and transportation), faster product flow, less product loss and damage risks and increasing customer satisfaction [4].

Integrating the vehicle routing problem with cross docking system as an important decision can significantly increase the capability of designing an efficient system in this kind of warehousing. In addition, companies must improve their servicing to satisfy clients. One of the most important factors in the success of the companies is the final earned benefit of their strategies. In this paper we introduce a selective vehicle routing problem with cross docking that servicing to all customers is not necessary. In the real world for satisfying customers demand, we are faced with many constraints such as resource limitations. So it is not possible to satisfy all the customers and we must select the best strategy to utilize all resources and gain the best result. In this paper each product in each node has specific purchasing and selling price and according to the budget, capacity and customer time windows limitation, the system should decide to serve selected suppliers and customers. We present a mixed integer linear programming model in order to maximize the total benefit of the system. The paper structure is organized as follows:

In section 2, a brief review on the literature is presented. Problem description and mathematical formulation is presented in the sections 3 and 4 respectively. Section 5 reports the results of computational experiments and discusses sensitivity analysis. Finally, the conclusion is given in section 6.

2- Literature review

The vehicle routing problem with cross-docking (VRPCD) was first introduced by Lee et al. [6] to minimize the transportation and fixed costs of used vehicles. A Tabu search algorithm was used to solve the problem. In their model it was assumed that the vehicles must be arrived to the cross-dock simultaneously. Liao et al. [7] proposed another Tabu search to solve the same problem in better computational time and with less used trucks. Wen et al. [10] considered a pickup and delivery problem with consolidation which orders are consolidated at a cross dock after pickup phase then immediately are delivered to customers. In consolidation phase, orders are labled, packed and sorted according to their destinations. The goal of the model was minimizing travel time and it was formulated as a MILP and solved by Tabu search for large instances. A transportation problem in a network of cross-docks was considered by Musa et al. [8] which was an extension of proposed model by Donaldson et al. [2] with two types of transportation: transferring from suppliers to customers directly and through cross-docks.

Santos et al. [9] applied a Branch and Price algorithm (B&P) to solve the VRPCD for minimizing loading and unloading cost and transportation cost. The B&P has better results than the Branch and Bound (B&B) algorithm for the problem. Hasani-Goodarzi and Tavakkoli-Moghaddam [3] proposed a VRPCD with split deliveries by different vehicles. The model was solved in small size with GAMS software. Although many characteristics have been considered in the integration of VRP and cross-docking but as authors best of knowledge the selective vehicle routing problem with cross docking has not been focused in the previous studies of VRP with cross-docking concept.in addition in the most papers the goal is decreasing total costs. In this paper, a mixed integer linear programming model is presented for selective vehicle routing problem with cross-docking in order to maximize the total earned benefit of the system.

3- Problem definition

In this problem, orders are collected from suppliers by a homogeneous fleet of vehicles and are moved to the cross-dock for consolidation process, then immediately delivered to customers. We have many suppliers and customers that should be visited but according to the resource limitation, satisfying all of them is not possible. So the most profitable customer and suppliers are selected from available customers and suppliers. It is clear that the total purchasing cost of all selected products must not exceeds the budget limitation. Fig.1 represents an example of our problem including 15 suppliers, 15 customers and a cross-dock. Inbound vehicles start their tour from cross dock and pickup product from selected suppliers and comeback to the cross dock and unload them to the receiving doors. Then outbound vehicles reload products and deliver them to the selected customers after consolidation process at cross dock based on destinations including labeling, packing, sorting and etc. The customers and suppliers are corresponding, so each customer receives its demand from predetermined supplier.

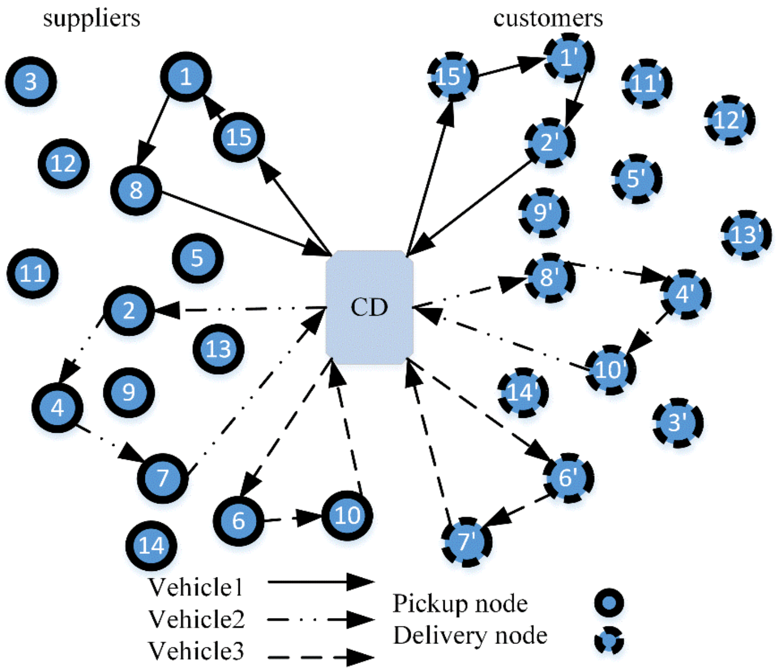

Figure 1: An example of selective vehicle routing problem with cross docking

4- Mathematical formulation

A mixed integer linear programming formulation with following notations is proposed for the problem.

Sets:

P set of pickup nodes (suppliers)
D set of delivery nodes (customers)
N set of all nodes
K set of trucks

Indices:

i, j, h index of nodes
k index of inbound/outbound trucks
R receiving door at the cross-dock
S shipping door at the cross-dock

Parameters:

M	an arbitrarily large constant;
c_{ij}	transportation cost between node i and j
t_{ij}	transportation time between node i and j
Pu_i	purchasing price for demand of node i $(i \in P)$
Se_i	selling price for demand of node i $(i \in P)$
B	available budget
$[a_i, b_i]$	time window for node i $(i \in N)$
d_i	demand of node i $(i \in P)$
T	truck capacity
F	fixed time of preparing trucks for unloading/reloading process at the cross-dock;
V	variable time for unloading/reloading each product unit.
n	number of pickup/delivery nodes

Binary variables:

x_{ijk} 1, if vehicle k travels from node i to node j; 0, otherwise $(i, j \in N)$
u_{ik} 1, if vehicle k unloads demand i at the cross-dock; 0, otherwise $(i \in P, k \in K)$
r_{ik} 1, if vehicle k reloads demand i at the cross-dock; 0, otherwise $(i \in P, k \in K)$
q_k 1, if vehicle k stops at the cross-dock for unloading process; 0, otherwise $(k \in K)$
q'_k 1, if vehicle k stops at the cross-dock for reloading process; 0, otherwise $(k \in K)$

Continous variables:

l_{ik} leaving time of truck k from node i $(i \in N, k \in K)$
f_k finish time of the unloading operation of truck k at the cross-dock $(k \in K)$
s_k start time of the reloading operation of truck k at the cross-dock $(k \in K)$
g_i finish time of the unloading operation of request i at the cross-dock $(i \in P)$

The proposed MILP model is formulated as follows:

$$Max\ z = \sum_{i \in D}\sum_{j \in D}\sum_{k \in K} d_i Se_i x_{ijk} - \sum_{i \in P}\sum_{j \in P}\sum_{k \in K} d_i Pu_i x_{ijk} - \sum_{i \in N}\sum_{j \in N}\sum_{k \in K} c_{ij} x_{ijk} \tag{1}$$

$$\sum_{j \in P}\sum_{k \in K} x_{ijk} \le 1 \qquad \forall i \in P, i \ne j \tag{2}$$

$$\sum_{j \in D}\sum_{k \in K} x_{ijk} \le 1 \qquad \forall i \in D, i \ne j \tag{3}$$

$$\sum_{j \in P} x_{Rjk} = 1 \qquad \forall\ k \in K \tag{4}$$

$$\sum_{j \in D} x_{Sjk} = 1 \qquad \forall\ k \in K \tag{5}$$

$$\sum_{i \in P} x_{iRk} = 1 \qquad \forall\ k \in K \tag{6}$$

$$\sum_{i\in D} x_{iSk} = 1 \qquad \forall\, k \in K \qquad (7)$$

$$\sum_{i\in P}\sum_{j\in P} d_i x_{ijk} \le T \qquad \forall\, k \in K, i \ne j \qquad (8)$$

$$\sum_{i\in D}\sum_{j\in D} d_i x_{ijk} \le T \qquad \forall\, k \in K, i \ne j \qquad (9)$$

$$\sum_{i\in P} x_{ihk} = \sum_{j\in P} x_{hjk} \qquad \forall h \in P, \forall\, k \in K, i \ne j \qquad (10)$$

$$\sum_{i\in D} x_{ihk} = \sum_{j\in D} x_{hjk} \qquad \forall h \in D, \forall\, k \in K, i \ne j \qquad (11)$$

$$l_{jk} \ge l_{ik} + t_{ij} - M(1 - x_{ijk}) \qquad \forall i, j \in N, \forall\, k \in K, i \ne j \qquad (12)$$

$$l_{jk} \le M x_{ijk} \qquad \forall i, j \in N, \forall\, k \in K, i \ne j \qquad (13)$$

$$a_i \le l_{ik} \le b_i \qquad \forall i \in N, \forall\, k \in K \qquad (14)$$

$$\sum_{j\in(P\cup R)}\sum_{k\in K} x_{ijk} = \sum_{j\in(D\cup S)}\sum_{k\in K} x_{(i+n)jk} \qquad \forall i \in P \qquad (15)$$

$$\sum_{i\in P}\sum_{j\in P}\sum_{k\in K} d_i Pu_i x_{ijk} \le B \qquad (16)$$

$$u_{ik} - r_{ik} = \sum_{j\in(P\cup R)} x_{ijk} - \sum_{j\in(D\cup S)} x_{(i+n)jk} \qquad \forall i \in P, \forall\, k \in K \qquad (17)$$

$$u_{ik} + r_{ik} \le 1 \qquad \forall i \in P, \forall\, k \in K \qquad (18)$$

$$\frac{1}{M}\sum_{i\in P} u_{ik} \le q_k \le \sum_{i\in P} u_{ik} \qquad \forall\, k \in K \qquad (19)$$

$$f_k = l_{Rk} + Fq_k + V\sum_{i\in P} d_i u_{ik} \qquad \forall\, k \in K \qquad (20)$$

$$s_k \ge f_k \qquad \forall\, k \in K \qquad (21)$$

$$s_k \ge g_i - M(1 - r_{ik}) \qquad \forall i \in P, \forall\, k \in K \qquad (22)$$

$$g_i \ge f_k - M(1 - u_{ik}) \qquad \forall i \in P, \forall\, k \in K \qquad (23)$$

$$\frac{1}{M}\sum_{i\in P} r_{ik} \le q'_k \le \sum_{i\in P} r_{ik} \qquad \forall\, k \in K \qquad (24)$$

$$l_{Sk} = s_k + Fq'_k + V\sum_{i\in P} d_i r_{ik} \qquad \forall\, k \in K \qquad (25)$$

Eq. (1) maximizes the total benefit of the system including the terms of the total revenue, purchasing and transportation cost respectively. Constraints (2) and (3) ensure that for the selected nodes each truck visits each node once and each node is visited by one truck for pickup and delivery process respectively. Constraints (4) and (5) imply that each inbound truck must start from the cross-dock and each outbound truck must start from the cross-dock. Constraints (6) and (7) ensure that vehicles will return to the cross-dock at the end of their tours. Constraints (8) and (9) ensure that the total volume of transported products by inbound and outbound trucks must not exceed their capacity. Constraints (10) and (11) indicate the routs continuity, i.e., for each node if a truck travels from node i to node h it must leave node h for both pickup and delivery tours. Constraints (12) and (13) determine the traveling time between two nodes if they are traveled consecutively by the same truck. Constraint (14) implies that trucks must visit nodes within their hard time windows. Constraints (15) implies that if products are picked up from supplier i by truck k, they must be delivered to its corresponding customer $i+n$. Constraints (16) ensures that the total purchasing cost of products must not exceed the available budget. Consolidation decisions are determined by constraints (17) and (18). According to these constraints: if products are picked up from supplier i by truck k and delivered to its corresponding customer $i+n$, loading and unloading is not necessary and products remain into the truck; if products are picked up from supplier i by truck k but aren't delivered to its corresponding customer $i+n$, products must be unloaded at the receiving doors of the cross-dock; if products aren't picked up from supplier i by truck k but must be delivered to its corresponding customer $i+n$ by that truck, products must be reloaded to truck k at shipping door of the cross-dock. Constraint (19) implies that truck k has a loading/unloading process or not. Constraint (20) calculates total loading/unloading time in the cross-dock for each vehicle. Constraints (21)-(23) imply that reloading process should be started after completing of unloading process of all products. Constraints (24) and (25) are similar to (19) and (20) for the reloading process.

5. Computational experiments

In the following sections, numerical results are presented to show the performance of the proposed model. The model has been coded in the GAMS software version 24 and solved using CPLEX solver for 10 different instances. The used data set was introduced by wen et al. [10] generated from a real data set belonging to a Danish logistics consultancy from Copenhagen. The instances are randomly derived from data set (20a) with 40 suppliers and customers. Table 1 indicates the computational experiments of 10 different test problem. The optimal objective value of the instances, run time and the number of selected nodes for each test problem are provided in the table 1.

Table 1- Results of experiments on different instances

instance	No. of nodes	No. of vehicles	No. of products	GAMS		No. of selected nodes
				Run time(s)	Best solution (optimal)	
1	8	2	34	0.36	901.49	4
2	10	2	37	0.4	281.74	8
3	14	2	49	0.94	1260.31	10
4	16	2	52	0.78	592.70	10
5	18	2	58	3.92	1280.65	16
6	20	2	66	3.72	1705.38	14
7	26	3	87	326.53	1462.82	20
8	30	4	104	1027.91	1219.93	20
9	36	5	135	8752.7	2210.29	32
10	40	5	145	12362.3	2138.62	22

5-1- Sensitivity analysis on the purchasing cost.

In this section a comparison is performed between the objective value of the main problem, increased and decreased purchasing costs. Fig 2 indicates the effect of %20 increaseing and decreasing on the objective value. It shows that increasing the purchasing cost will decrease the total benefit of the system and decreasing the purchasing cost will increase the total benefit of the system.

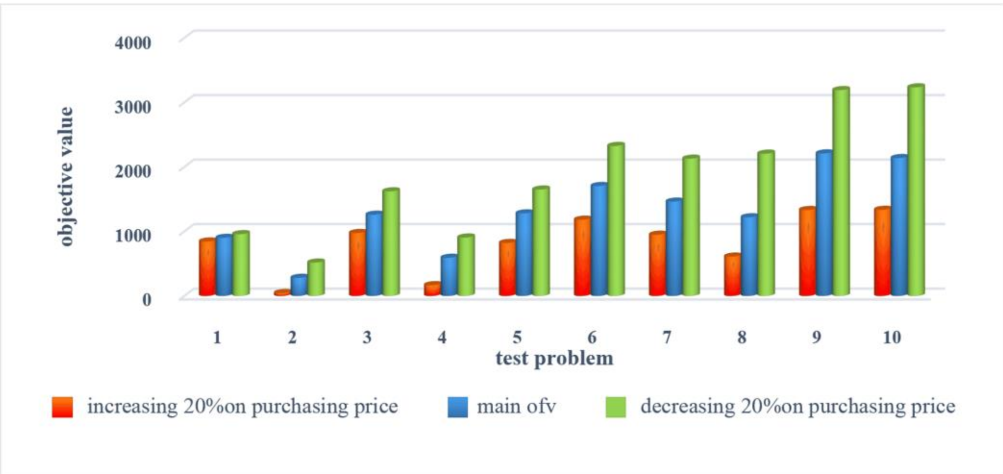

Figure 2: increasing and decreasing purchasing cost

5-2- Sensitivity analysis on the budget.

In this section the effect of budget on the total benefit of the system is presented in fig 3. As illustrated in fig 3, the total benefit of the system will be increased by increasing the available budget to purchase the products. Mentioned sensitivity analysis confirm the validity and valid performance of the proposed mathematical model for selective vehicle routing problem with cross docking.

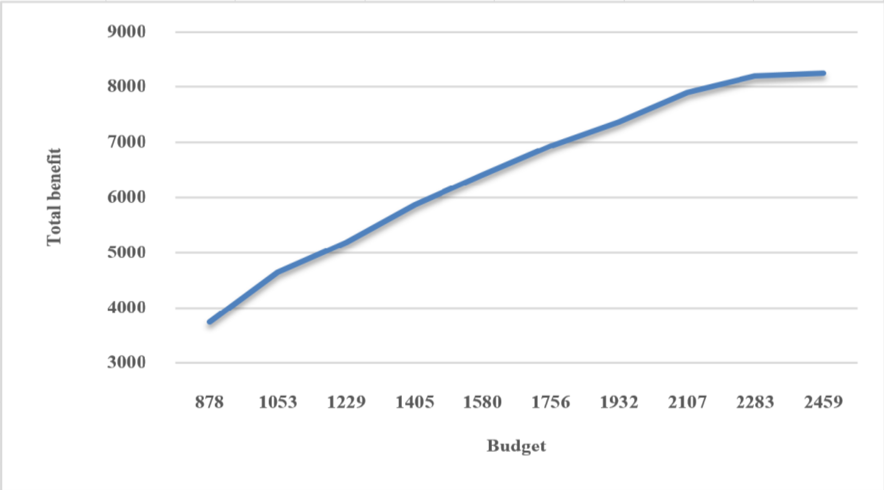

Figure 2:The effect of budget on the total benefit

6- Conclusion

Cross docking as a new distribution strategy enables consolidation shipments in order to better managing physical flow of products in the supply chain. Although a lot of works have been investigated on the integration of vehicle routing and cross docking, there is no study on selective vehicle routing with cross docking. In this paper a selective vehicle routing problem with cross docking are introduced. It is not necessary to visit all suppliers and customers, so they will be selected only if it is profitable to serve them based on the purchasing and selling price considering the budget limitation. A MILP model is proposed to the model and10 different test problems are optimally solved and analyzed in order to show the performance of the proposed model. Using heuristic and metaheuristic algorithms to solve the large problems can be as a direction for future researches.

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