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MATCHING ALGORITHM FOR THE VEHICLE ROUTING IN CONTAINERS DELIVERY AND COLLECTING PROBLEMS

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Abstract

In this paper the problem of transporting commodity from/to a set of suppliers to a depot with a fleet of vehicles is considered. Namely, the problem of distributing and collecting of ISO, and small containers may be described as a variant of Vehicles Routing Problem with Backhauls (VRPB), which may be formulated and solved as a multiple matching problem.In VRPB vehicle is loaded at the depot with aim to serve demanding customers (linehauls), and to collect containers from supplying customers. Collected goods should be brought back to the depot (backhauls). For the case of 40ft containers, where only one commodity may be carried on, the problem corresponds to bipartite matching, but in case of 20ft, and small containers the problem becomes more complex, and needs multiple matching of supply – demand nodes.

Mentioned problems arise in different logistics systems, but typical examples for the case of ISO containers are container sea ports. Similarly, for the case of small containers which represent new city logistics concept, the problem of supplying urban areas means multiple matching of delivery nodes with nodes where empty containers should be collected.

The paper formulates mentioned vehicle routing problems, and proposes matching heuristics. Numerical examples presented are based on the data related to Izmir seaport container terminal.

***Keywords**: Container distribution, vehicle routing problem with backhauls, matching heuristics*

1. INTRODUCTION

Typical problems in many distribution systems are truck fleet size planning problems and problems in the operative planning field, when it is necessary to determine optimal plan of an existing fleet exploitation. Methods for optimal fleet sizing and operative planning are numerous, regarding to great diversity of tasks in transportation and distribution processes. Different problems in this area become very important as a consequence of high competition in trucking industry, and probably more than ever before, it is very important to reinvestigate planning concepts in this area.

The distribution problems studied here are typical for ISO containers distribution processes in regions which are oriented to container sea port or inland container terminal. In this case two kinds of transportation flows dominate:

- *Distribution flows* - Those flows denote distribution of containers from the port or terminal to the customers (very often those flows are denoted as "import orders")
- *Collecting flows* - Those flows denote collection of containers are at a customers places, and moving them to the port or inland terminal (very often those flows are denoted as "export orders")

Thereby, all transportation flows have either the same origin or destination point, and may be represented as it is shown in Figure 1. Mentioned transportation processes can be described as a pickup – delivery (PD) problem. The main difference between the conventional PD problem and the problem studied here is that no demand for containers exists between network nodes themselves, but only between the terminal and customers. In case of simultaneously existence of pickup and delivery tasks, distribution – collecting tasks could be realized in one sequence which gives similarity with conventional PD problem.

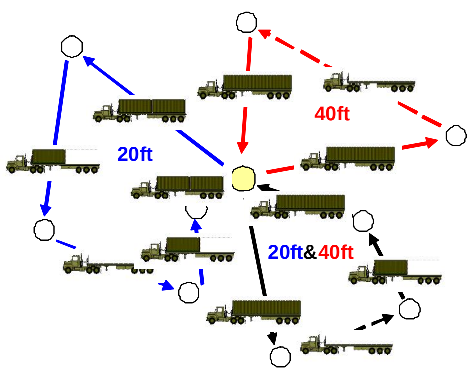


Figure 1 The ISO containers' pickup - delivery problem

The problem of transporting commodity from a set of suppliers to a set of demand points with a fleet of limited capacity vehicles is called the Capacited Vehicle Routing Problem with Pickup and Deliveries. Mentioned problems were studied in several papers. Vidovic (1988) studied problem of servicing nodes in separate cycles. The problem was formulated as a two dimensional cutting. M. Savellsbergh and M. Sol (1995) gave an excellent survey of literature treating the general pickup and delivery problems (GPDP), predominantly of those handling the deterministic models. M.Gendreau, A. Hertz and G. Laporte (1996) propose new heuristics for the Traveling Salesman Problem with Backhauls. E. Tailard, G. Laporte and M. Gendreau (1996) treat the vehicle routing problem with multiple use of vehicles. A tabu search heuristic is developed for this problem. S.R. Thangiah, J. Potvin and T. Sun (1996) treat the vehicle routing problem with backhauls and time windows (VRPBTW) which include the pickup and goods' delivery at different customer locations, including earliest and latest deadtimes as well as varying demands. S. Anilu and J. Bramel (1999) considered the Capacitated Traveling Salesman Problem with Pickups and Deliveries (CTSPPD). They presented the MATCH Algorithm. H. Ghaziri and I. Osman (2003) consider neural network algorithm for TSP with backhauls. Also, most recently Coslovich at al. (2004) studied problems in this area, but their formulation covers slighltly different concept then this shown here. However, problem very similar to this considered here may be found in the work of Nishimura at al. (2005), where authors solve yard trailer routing problem at a maritime container terminal. They formulate multi trailer routing problem with the objective of minimizing total distances traveled, and propose genetic algorithm solution approach.

The problem of distributing – collecting ISO containers (20ft, and 40ft), studied here, may be described as a variant of Vehicle Routing Problem with Backhauls (VRPB).
In VRPB vehicle is loaded at the depot with aim to service "-" customers (linehauls), and to collect new goods "+" customers. Collected goods should be brought back to the depot (backhauls). Variant of VRPB - ISOVRPB - has two particular characteristics: zone tariffs, and two types of commodities (20ft, and 40ft cont.). From there, the main intention of this paper was to formulate routing problem under mentioned conditions, and to propose solution approach. The paper has been relied to the previous work of Vidovic at al. (2003), and represents its extension. Also, this paper includes cognitions, and observations from the container distribution and collecting processes realized by the ARKAS company, as logistics operator in Port of Izmir container terminal.

Rest of the paper is organized as follows. Problem formulation and notation are introduced in section 2. Matching algorithm and solution approach are described in the section 3. Some results of numerical experiments and computational experience are given in the section 4. Section 5 gives concluding remarks.

2. PROBLEM FORMULATION AND NOTATION

Let $G(N,E)$ be a graph, where $N=\{n_0,...n_n\}$ is the set of nodes, and $E=\{(n_i,n_j): i\neq j, n_i, n_j \in N\}$ is the edge set. The set of nodes is partitioned into $N=\{\{n_0\}, N^{20+}, N^{20-}, N^{40+}, N^{40-}\}$, where n_0 is a depot. Sets N^{20-}, and N^{40-} correspond to linehaul customers for 20ft, and 40ft containers respectively, and sets N^{20+}, and N^{40+}

correspond to backhaul customers for 20ft, and 40ft containers respectively. Sets $N^{20+}, N^{40+}, N^{20-}, N^{40-}$ are disjoined, which means that one node cannot be simultaneously demanding or supply, neither for 20ft nor 40ft containers. Demand or supply of each node is exactly one container. All linehaul containers are available at the node n_0, and all backhaul containers are available at customer places $n_i \in N^{20+} \cup N^{40+}$, at the beginning of observed interval T_R, during which all of pickup and delivery tasks should be realized. With E is associated matrix $D=\{d_{ij}\}$ representing distance. Transport costs are proportional to distance, i.e. $c_{ij} = c_t \cdot d_{ij}$. All vehicles are identical with capacities for carrying one 40ft, or two 20ft containers, and travel times are deterministic and same for loaded and empty trips. Without loss of generality it is assumed that container handling times at nodes may be neglected, i.e. cycle times are equal to travel times.

The objective is to minimize total distance (costs) while serving all customers' nodes $N \backslash \{n_0\}$, without violating available time restriction T_R.

Hence, under mentioned assumptions, to solve the ISOVRPB it is enough to match all customer nodes into sets of routes of minimal length, without violating vehicle capacity restriction, and maximum available time, and respecting necessity of servicing linehaul customer before backhauls. This is equivalent to the vehicle routing problem with backhauls but in case when vehicle can carry only one 40ft, or two 20ft containers simultaneously.

The problem may be considered in different ways, but because of limited number of containers that may be carried on simultaneously, it may be also described as a multiple matching problem, where possible matchings include all feasible combinations of 20ft, and 40ft that should be transported from/to backhaul/linehaul customers (Figure2).
Obviously, there are several possible matchings (n_0 - 20^- - 20^+ - 20^- - 20^+ - n_0; n_0 - 20^- - 20^- - 20^+ - 20^+ - n_0 ; n_0 – 20^- - 20^- - 40^+ - n_0; ...) and it is worthwhile to choose those which provide minimal route length.

Here, it is important to be pointed out the idea of visiting more than two nodes in one route means that the problem must be considered as a multiple matching, while the case when only 40ft containers are considered may be formulated and solved optimally very simple, as a assignment problem.

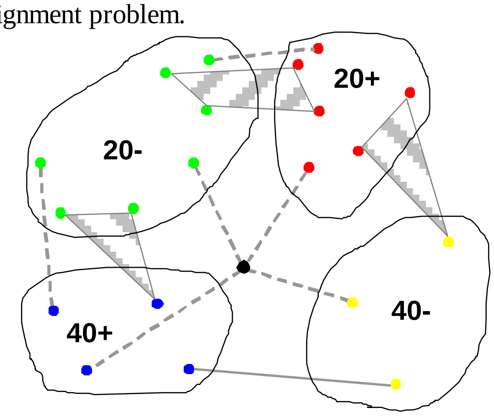


Figure 2 – Possible nodes' matchings in ISOVRPB

3. ROUTES CONSTRUCTION HEURISTICS FOR THE ISOVRPB

To solve mentioned routing problem it is necessary to find optimal multiple matchings of nodes in sets $N^{20+}, N^{40+}, N^{20-}, N^{40-}$, so as to minimize total distance traveled, without violating vehicle capacity restriction, maximum time restriction, and visiting linehaul before backhaul customers.

Approach to route construction proposed here is based on the Double Cycle heuristic for solving TSPB (Gendrau at all [1996]). This heuristic, particularly its version DC1, has been adopted to solve specific problem considered here. This adopted heuristics is denoted as ISO-DC1.

GENDRAU'S DOUBLE CYCLE HEURISTIC

Step 1: Constructing two separate Hamiltonian cycles for pickup (P) and delivery (D) nodes

Apply a TSP solution algorithm to construct a Hamiltonian cycle through the vertices of the set P and apply it again on the set D. Let E_p and E_d denote, respectively, the set of edges in the tour over P and the set of edges in the tour over D.

Step 2: (Joining these two cycles and the depot to construct a TSPB solution)

For each pair of edges $(i, j) \in P$ and $(k, l) \in D$ do the following and retain the best solution.

Remove the considered pair of edges and add three new edges to construct a TSPB solution. There are four possible combinations of such edges and the least cost one should be chosen. For example, after removing (i, j) and (k, l) we may add (1, i), (j, k) and (l, 1). The other three edge triplets that could be added are: {(1, i), (j, l), (k, 1)}, {(1, j), (i, k), (l, 1)} or {(1, j), (i, l), (k, 1)}.

However, in ISOVRPB there are two pickup N^{20+}, and N^{40+}, and two delivery sets N^{20-}, and N^{40-}. Hence, by following idea of DC1 heuristics, it is necessary to construct Hamiltonian cycles, through the vertices of the sets N^{20+}, and N^{20-}. Then it is necessary to join those two cycles with nodes from sets N^{40+}, and N^{40-}. From there, ISO-DC1 heuristics is modified and adopted for solving ISOVRPB in following way:

Instead of joining only pairs of edges in the TSP cycles, ISO-DC1 joins edges in the TSP tour together with matching of edges in TSP with nodes from the sets N^{40+}, N^{40-} as well as matching of nodes from those sets themselves.

Also, instead of four possible matching of two edges with depot, in ISO-DC1 following combinations exist:

- In case of matching nodes from sets N^{20+}, and N^{20-}, there are eight possible combinations that must be considered. Namely, after removing edges (i, j) and (k, l) from sets N^{20+}, and N^{20-} respectively, if depot is denoted as 0, possible combinations (sequences) are:

0 i j k l 0

0	i	j	l	k	0
0	i	k	j	l	0
0	i	l	j	k	0
0	j	i	k	l	0
0	j	i	l	k	0
0	j	k	i	l	0
0	j	l	i	k	0

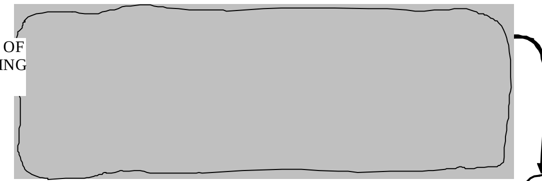
- In case of matching nodes from sets N^{20-}, and N^{40+} two possible matching exist
- In case of matching nodes from sets N^{20+}, and N^{40-} two possible matching exist
- In case of matching nodes from sets N^{40+}, and N^{40-} obviously, only one possible matching exist

To find the best matching, because of four possible types which differ in number of nodes covered, and from there in expected distance traveled, instead of route length, savings resulting from matching is proposed here as a measure of worthiness. This measure is similar to well known Clark-Wright's concept of savings, which means that savings resulting from nodes' matching are calculated as difference between the total length would be traveled in case when nodes were served separately, one by one, and the total length of the shortest route joins linehaul and backhaul nodes. In case of matching nodes (i,j), and (k,l), from sets N^{20+}, and N^{20-} savings S_{ijkl}, for the case when the shortest route assumes sequence 0-i-j-k-l-0 is given by $S_{ijkl}=2(d_{0i}+d_{0j}+d_{0k}+d_{0l})-(d_{0i}+d_{ij}+d_{jk}+d_{kl}+d_{l0})$.

Therefore, the DC1 heuristics had to be modified because of few reasons. Not only edges must be analyzed, but also combinations of edges in TSP cycles from sets N^{20+}, and N^{20-} are combined with nodes from sets N^{40+}, and N^{40-}. Because linehaul customers have to be visited before backhaul customers, nodes from the set N^{40+} must be compared with the edges in TSP cycle from the set N^{20-}, but route must visit nodes in N^{20-} first. In case of the set N^{40-} and the edges in TSP cycle from the set N^{20-}, nodes in the set N^{40-} must be visited first. However, matchings TSP cycles from the set N^{20-} with nodes from the set N^{40-}, as well as matchings TSP cycles from the set N^{20+}, with nodes from the set N^{40+} has no any sense.

Let explain ISO-DC1 heuristics in more details by using following example. If network consists of 10 nodes as it is shown in the Figure 3, then ISO-DC1 may be applied as it is shown below.

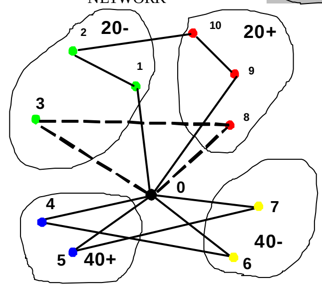
POSSIBLE SEQUENCES OF NODES WHILE MATCHING EDGES (1,2)-(8,9)



BEST NODES' SEQUENCE

Largest savings for matching edges (1,2)-(8,9)

DISTRIBUTION – COLLECTING NETWORK



dij	0	1	2	3	4	5	6	7	8	9	10
0	-	55	80	57	56	51	52	53	53	70	80
1		-	30	50	78	90	97	80	52	55	32
2			-	48	79	94	-	-	53	51	50
3				-	49	52	-	-	54	57	54
4					-	24	52	55	-	-	-
5						-	53	54	-	-	-
6							-	30	50	58	81
7								-	56	54	61
8									-	26	50
9										-	29
10											-

$N^{20-}=\{(1,2);(2,3);(3,1)\}$ $N^{20+}=\{(8,9);(9,10);(10,8)\}$

$N^{40-}=\{6,7\}$ $N^{40+}=\{4,5\}$

DISTANCES AND SETS

1,2	8,9	**301**	8,9	7	186
1,2	9,10	336	9,10	7	193
1,2	10,8	324	10,8	7	155
1,2	4	108	8,9	6	
1,2	5	98	9,10	6	
2,3	8,9	266	10,8	6	
2,3	9,10	320	7	4	54
2,3	10,8	335	7	5	50
2,3	4	153	6	4	56
2,3	5	155	6	5	50
3,1	8,9	229			
3,1	9,10	286			
3,1	10,8	248			
3,1	4	95			
3,1	5	88			

POSIBLE MATCHINGS

Figure 3 Example of ISO-DC1 heuristics application

Possible and the best matchings, and corresponding savings are shown in the Figure 3, as well as solution obtained by the heuristics proposed. The largest savings are obtained by joining nodes 0-1-2-10-9-0, and this route is inserted first. Finally, after all "full" matchings are exausted, route 0-3-8-0 when vehicle is loaded only with the one 20ft container is also inserted.

4. COMPUTATIONAL EXPERIENCE

Performances of heuristics DC1 are well explored and reported in literature. Namely, previous research shows that DC1 gives lengths of routes approx. 3-4% larger than the lower bound (Gendreau, 1996), and cca 20% larger than the best solution (Renaud at al, 2000).

In this paper, authors' effort was concentrated on practical application of proposed solution procedure. To provide test problems, and to analyze heuristics behavior in more realistic environment, close to real container distribution problems, authors analyze processes in Port of Izmir, Turkey.

Izmir is the third largely populated city in Turkey, and its port is situated in the western coast of Aegean Sea (Figure 4). The port has a vast agricultural and industrial hinterland. The annual capacity of the Izmir Port is 11 million tons with the total area of 902,000m^2. The capacity of container terminal is 226,000 TEU/year, and Port of Izmir is the largest container port in Turkey.

Based of data given by ARKAS, container distribution – collecting processes include in average 70 – 80 deliveries of import containers, and 60 – 70 pick ups of export containers every day. In case of import flows, 30% deliveries are 40ft, and 70% 20ft containers. Export flows comprise 40% of 40ft, and 60% 20ft containers. In the same time there are about 150-200 requirements for empty container repositioning, but those flows were not analyzed here, although make important transportation demand that may also be considered. Containers' pickup and delivery is realized in the Port of Izmir gravity zone which comprises customers which are up to 50 km from the port. However, because most of customers don't have handling equipment, vehicles mostly wait at the customer site until container is loaded or unloaded. Therefore, only 10% of nodes currently may be considered as a potential for matching and routes construction.

Figure 4 Port of Izmir gravity zone

Having in mind above mentioned distribution system characteristics, to analyze performances of ISO-DC1 appropriate problem generation software had been developed. In our numerical experiments, to find TSP tours in the network, LOGWARE software was used (Ballou, 1998). Size of test problems analyzed were up to 50 nodes in sets N^{20+}, N^{20-}, and up to 25 nodes in sets N^{40-}, N^{40+}. Also, to provide practical application of ISO-DC1 heuristics an VB program written in nonoptimized code has been developed, but the software itself now is in test phase. Network is randomly generated in the area similar to the Izmir port gravity zone. In our test examples, fact that only 10% of customers have container handling equipment was neglected, and it was assumed that routes could be constructed through all network nodes.

Because VB software is still in the test phase, the heuristics performances were analyzed on limited number of problem instances, and results obtained are encouraging.

5. CONCLUSION

In this paper solution procedure for the ISO containers' distribution/collection problem has been proposed. To define matchings of nodes, adopted Double Cycle 1 heuristic has been proposed. For the practical application, VB software, currently in the test phase has been developed.

Having in mind all previously mentioned, several interesting directions remain for the future research: adoption other heuristics to ISOVRPB, particularly with aim of making comparison with ISO-DC1. Here, the most important direction is connected to genetic algorithm approach proposed by Nishimura at al (2005), and making comparison with those two concepts. Also, other interesting extensions are related to empty containers flows, which mean joining repositioning and loaded flows, or in other words integration of forward and reverse logistics.

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