COOPERATIVE VARIABLE NEIGHBORHOOD SEARCH FOR THE VEHICLE ROUTING PROBLEM WITH SIMULTANEOUS PICKUP AND DELIVERY

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Abstract— The vehicle routing problem with simultaneous pickup and delivery (VRPSDP) is a common transportation problem where a fleet of vehicles deliver goods from the depot to line haul customers and pick up goods from backhaul customers to the depot. This problem variation allows vehicles to make the delivery and pickup operations on same time by visiting all clients once with the aim of minimization of total travel distance. In this study, a very efficient cooperative variable neighborhood search (CVNS) is proposed to solve the problem. In this parallel search approach, variable neighborhood search (VNS), savings heuristic and perturbation mechanism are combined with the help of parallelization strategies. The proposed approach is able to solve a number of well-known benchmark instances by providing superior solutions compare to those reported in the literature.

Index Terms— Vehicle routing problem, simultaneous deliveries and pickups, parallel computing, variable neighborhood search.

I. INTRODUCTION

In general, the vehicle routing problem (VRP) aims to serve a set of customers with a fleet of vehicles from the central depot. The routes, which start and endin a central depot, commonly demonstrated in order to minimize the total distance traveled by the vehicles. See Toth and Vigo [1] and Braekers, et al. [2] for a comprehensive introduction to VRP variants. While in the classical VRP, the vehicles deliver the goods from the central depot to customers, in some extensions, the vehicles may also collect the goods from the customers and deliver them to the depot. This VRP extension is categorized as VRP with backhauls (VRPB).

The VRPB can be basically classified into four classes:

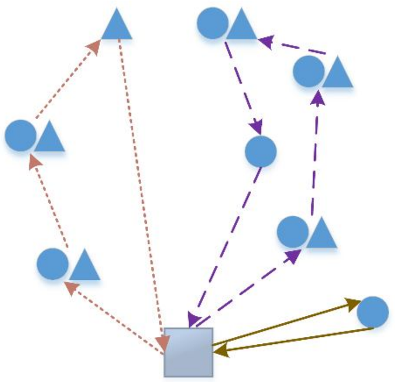
- VRP with clustered backhauls (VRPCB): the vehicles first deliver all goods to customers, then start to collect goods from customersby visiting each customer once.
- VRP with mixed linehauls and backhauls (VRPMB): the vehicles make delivery goods to customers or collect goods from customers in any sequence by visiting each customer once.
- VRP with simultaneous pickup and delivery (VRPSPD): the vehicles may serve customers both delivery and collects purposes simultaneously by visiting each customer once.
- VRP with divisible delivery and pickup (VRPDDP): In addition to VRPSPD case, the vehicles are allowed to visit customers twice by delivery and collect purposes.

Please see Desaulniers, et al. [3], Berbeglia, et al. [4], Parragh, et al. [5] and Wassan and Nagy [6] for detailed classifications and literature surveys on pickup and delivery problems. The VRPSPD is firstly presented byMin [7] in order to transport books between a depot and a number of libraries whorequire simultaneous consideration of both pickup and delivery operations. In order to solve this problem, the author provided a first cluster, then route algorithm. Later, Salhi and Nagy [8] and Dethloff [9] proposed mathematical formulations of the problem and offered insertion based approaches to solve the problem. In recent twenty-five years, a number of authors provided heuristic and meta-heuristic variations for solving VRPSPD. Please see Avci and Topaloglu [10] and Polat, et al. [11] for recent studies on this subject.

The main contribution of this study is proposing an efficient algorithm that employs“ asynchronous cooperation with centralized information exchange strategy” in VNS. Cooperative variable neighborhood search (CVNS) algorithm effectively solves a number of well-known VRPSDP benchmark instances and significantly improves the best known solutions. The remainder of this study is as follows. The problem environment is presented in Section II. Section III defines the details of the proposed methodology. Section IV presents numerical results and Section V points out the conclusions and future research directions.

II. THE VEHICLE ROUTING PROBLEM WITH DIVISIBLE DELIVERY AND PICKUP

The problem considered in this study is to design the service network of the vehicles in which the customer may demand line haul and/or backhaul goods from/to a central depot. This problem commonly might be seen on dispatching/collecting cargo parcelsto/from customers to a regional post station with trucks or containers to/from feeder ports to a hub port with ships, etc. **Fig.I** shows an example configuration for the VRPSPD where the square, circle and triangular present central depot, delivery goods and pickup goods, respectively. In this view, the VRPSPD could be described as follows. A number of customersin a service network demand delivery and/or pickup operations simultaneously. Each customer has to be visited once.The service has to be given with anumber of homogenousand capacitated vehicles. Each route starts and ends in a central depot. There is no transfer between customers. The loads cannot be divided into smaller loads and known in advance.Vehicle departures from the central depot with the total loads that has to deliver and arrives to the central depot with the total loads it has to pick up.



FigureI: Representation of VRPSPD

III. THE PROPOSED METHODOLOGY

Because of the NP-hard nature of the problem, exact solution methods on the VRP variants are not generallypractical for solving large-sizedproblem instances[12].The variable neighborhood search (VNS) approach[13-15] is one of the powerful metaheuristic methodology used on solving a set of combinatorial optimization problems including VRP variants[16-22]. The advantage of VNSalgorithm is assembled on the systematic investigation of a set of neighborhood structuresused in *shaking* and *local search* steps.It uses the following idea “a solution of one neighborhood structure does not have to be a local optimum of another neighborhood structure”. It uses the incumbent solutions obtained in shaking step as starting point of local search operations withthe aimof gettingabetter solution. In order to decide whether to move or not, the temporary solution is compared with the global solution after the shaking and local search operators are applied. Please see Hansen and Mladenović [13] for the details of the approach.

Parallel computing aims to explore variousareas of the solution space anddecrease the run time by letting numerous processors to work simultaneously [23]. Various parallelization strategies have been developed for VNS approach in the literature[24-26]. In this study, “Asynchronous cooperation with centralized information exchange strategy”[24] is used for parallelization of the VNS approach. The strategy could be detailed by taxonomy of Crainic and Hail [27] as pC/C/MPSS where *pC*showsseveral processes are distributively controlsthe global search, *C*showsthe data exchanged as asynchronously collegial and *MPSS* represents the approach start from various initial points by using same neighborhood sequence. In our adaptation, the initial solution, constructed with savings heuristic, is refined with the basic VNS during a number of iterations in addition to the perturbation mechanism for the search diversification as it suggested by Polat, et al. [11].

IV. NUMERICAL INVESTIGATION

The developed approach is coded by using MATLAB R2013b and executed on a workstation computer which has Intel Xeon E5420-2.50 GHz CPU and 8 GB RAM. The parallelization of the CVNS algorithm implemented on six core processors and one interface processor. The parameters of the basic VNS approach are used as suggested by Polat, et al. [11].

The performance of the algorithm is tested on the VRPSPD benchmark data set of Salhi and Nagy [8] which consists of 28 test problems involving from 50 to 200 customers and a central depot. While CMT 1-2-3-4-5-11-12 X&Y instances do not consider time limit on the total route duration, the remaining 14 instances consider time limit (TL) restriction. In the literature, the test data related to this benchmark instances configured by using different formulations. Some authors used rounded values when calculating the distance between customersand some authors also rounded the demands of the customers. Additionally, there is also a difference on formulating the CMT Y instances from X instances.While some authors swapped the delivery and pickup values for every customer, others exchanged the delivery and pickup values for every other customer. Since rounding the values enable more correct comparisons, rounded demand and distance values are used in the content of this study. The CMT Y instances are also formulated by using exchange strategy. Therefore, the performance of the proposed approach compared with the studies that use same configurations.

Salhi and Nagy [8]proposed Cluster Insertion Heuristic (CIH) for single and multi-depot VRPSPD. Dethloff [9]offered a construction based heuristic which is called as Insertion Based Heuristics (IBH) for the problem. Crispim [28]developed a hybrid metaheuristic algorithm (TS-VND) by integrating the tabu search (TS) and the variable neighbourhood descent (VND) for solving VRPSPD and VRPMB variants without considering time limits.Tang Montané and Galvão [29]proposed a TS algorithm by combing a variety of a neighbourhood movements and search strategies for VRPSPD without lime limit. Wassan, et al. [30]presented a reactive tabu search (RTS) metaheuristic which checks the feasibility of alternative moves before the movements.This approach (RTS2) later adapted by Nagy, et al. [31] for solving the VRPSPD and VRPDDP. Later, Polat, et al. [11] offered a very efficient perturbation based VNS (PVNS) approachfor solving VRPSPD variants. Since the authors used unrounded values in formulating test instances, in this study, we recoded the PVNS approach by using same configurations presented by the authors to solve the instances with rounded values. Please note that our parallel approach CVNS is structured by enhancing PVNS presented by Polat, et al. [11]. The performance of existing approaches and the proposed CVNS approach is compared in **Table I** in which *#v* shows the total number of vehicles and *D* show the total distance of the network. The bold values show the best values for each problem instance.

The results indicate that CVNS approach outperforms the solution approaches exiting in the literature in terms of solution quality. The CVNS approach provides better or same results for 27 of 28 test instances. Considering without time limit instances, CVNS provides a 19.57% improvement over CIH, 18.00% over IBH, 10.27% over TS-VND, 4.26% over TS,4.70% over RTS and 0.11% over PVNS. On the other hand, CVNS provides a 2.56% improvement over CIH, 7.82% over IBH, 4.38% over RTS and 0.16% over the PVNS when the limit constraint is implemented.

Table I: Performance compression between CVNS and other heuristics

	CIH		IBH		TS-VND		TS		RTS2		PVNS		CVNS	
Instance	#v	D	#v	D	#v	D	#v	D	#v	D	#v	D	#v	D
1X	5	525	3	501	3	477	3	472	3	478	3	**470**	3	**470**
1Y	5	525	3	501	3	485	3	470	3	476	3	**459**	3	**459**
2X	10	841	7	782	6	710	7	695	7	713	6	**685**	6	**685**
2Y	10	839	7	782	6	715	7	700	7	694	6	**651**	6	**651**
3X	8	829	5	847	5	744	5	721	5	727	5	715	5	**714**
3Y	8	829	5	847	5	742	5	719	5	723	5	709	5	**705**
4X	12	1053	7	1050	7	915	7	880	8	901	7	866	7	**862**
4Y	12	1047	7	1050	7	996	7	878	7	859	7	**831**	7	**831**
5X	16	1334	11	1348	10	1136	11	1098	11	1090	10	**1063**	10	**1063**
5Y	16	1334	11	1348	10	1129	10	1083	10	1053	9	985	9	**982**
6X	6	555	6	584	-	-	-	-	6	555	6	**548**	6	**548**
6Y	5	555	6	584	-	-	-	-	6	556	6	**548**	6	**548**
7X	11	910	11	961	-	-	-	-	11	899	11	**897**	11	**897**
7Y	11	910	11	961	-	-	-	-	11	902	11	**897**	11	**897**
8X	9	873	9	928	-	-	-	-	9	874	9	863	9	**856**
8Y	9	867	9	936	-	-	-	-	9	867	9	863	9	**856**
9X	14	1188	15	1299	-	-	-	-	15	1200	14	**1143**	14	**1143**
9Y	14	1188	15	1299	-	-	-	-	15	1215	14	**1143**	14	**1143**
10X	18	1420	19	1571	-	-	-	-	19	1439	18	1374	18	**1373**
10Y	17	1420	19	1571	-	-	-	-	19	1467	18	1369	18	**1366**
11X	7	1087	4	959	4	944	4	900	5	1009	4	**874**	4	**874**
11Y	7	1075	4	1070	4	1035	5	910	4	905	4	**826**	4	**826**
12X	10	820	6	804	5	731	6	675	6	680	6	**672**	6	**672**
12Y	10	825	5	825	5	860	6	689	5	**632**	5	**632**	5	**632**
13X	11	1557	11	1576	-	-	-	-	11	1647	11	1555	11	**1551**
13Y	11	**1546**	11	1576	-	-	-	-	12	1710	11	1550	11	1549
14X	11	879	10	871	-	-	-	-	10	842	9	**821**	9	**821**
14Y	11	879	10	871	-	-	-		11	854	9	**821**	9	**821**
Total average		989,64		1010,79		-		-		927,39		886,76		885,54
Without TL Avg.		925,93		908,14		829,93		777,86		781,43		745,57		744,71
With TL Avg.		1053,36		1113,43		-		-		1073,36		1028		1026,36

CONCLUSION

In this paper, we proposed a parallel variable neighborhood search approachCVNS to solve VRPSDP. The performance of the proposed approach is compared with the existing six approaches that usingSalhi and Nagy [8]'s data sets with rounded value. The results indicate that the CVNS approach provides very efficient solutions in an acceptable solution time. According to the best of our knowledge, the parallel VNS has been applied first time to the VRPclasses in the literature. The performance of the proposedapproachcan be enhanced by integrating memory. It could be adaptedto solve a variety of vehicle routing problem applications including vehicle routing problem with divisible pickup and delivery.

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