Effective Recombination Operators for the family of Vehicle Routing Problems

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ABSTRACT

We propose two new or modified recombination operators for the family of vehicle routing problems, i.e. the Capacitated Vehicle Routing Problem (CVRPTW), Pickup and Delivery Problem (PDPTW), and Team Orienteering Problem (TOPTW), with Time Windows. Starting with fitness landscape analysis we propose a new Order-based recombination operator, we extend the Selective Route Exchange Crossover (SREX) recombination operator, and we adapt the state-of-the-art Edge Assembly Crossover (EAX) operator to PDPTW and TOPTW. The proposed recombination operators are competitive to EAX and the best results may be achieved by combining different operators. Furthermore, a memetic algorithm using the proposed operators is capable of providing results competitive to state-of-the-art dedicated methods.

CCS CONCEPTS

• **Applied computing → Transportation**; • **Computing methodologies → Discrete space search**.

KEYWORDS

Recombination operators, Vehicle Routing Problem, Pickup and Delivery Problem, Team Orienteering Problem, Time Windows

ACM Reference Format:

Piotr Cybula, Marek Rogalski, Piotr Sielski, Andrzej Jaszkiewicz, and Przemysław Pełka. 2021. Effective Recombination Operators for the family of Vehicle Routing Problems. In *2021 Genetic and Evolutionary Computation Conference Companion (GECCO '21 Companion), July 10–14, 2021, Lille, France.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3449726.3459574

1 INTRODUCTION

The family of vehicle routing problems (VRP) comprises NP-hard combinatorial optimization problems with high practical importance in transportation and logistics[1]. CVRPTW is defined by a depot node and a set of customer nodes with defined demands, service times, and time windows. For each pair of nodes (*edge*), a travel time and a travel distance are defined. A fleet of homogeneous vehicles with limited capacity is available. The goal is to find a set of routes that start and end at the depot minimizing lexicographically the number of routes and the total travel distance. In PDPTW customer nodes are organized into pairs of pickup and delivery nodes which need to be visited in an appropriate order. The objectives are the same as in CVRPTW. In TOPTW instead of demands, customer nodes are associated with profits. No capacity constraints are considered and the distance impacts only travel times. The goal is to find a fixed number of routes serving a subset of customer nodes with the largest sum of profits.

2 FITNESS LANDSCAPE ANALYSIS

We use *fitness distance correlation (FDC)* to measure how closely the distance/similarity to a set of other good solutions and the solution quality are related. We consider the following types of features and corresponding similarity measures: number of common pairs of nodes assigned in both solutions to a single route - s_1, number of common edges - s_2, number of common arcs - s_3, number of common pairs of unconnected nodes - s_4, number of common pairs of edges - s_5, sum of differences of relative positions of nodes - s_6, number of common ordered pairs of unconnected nodes - s_7. We use a number of instances selected from commonly used benchmarks, i.e. Gehring and Homberger instances [4] for CVRPTW, instances of Li and Lim [6] for PDPTW, and Cordeau et al. instances [2] for TOPTW.

Table 1 presents average correlations of solutions quality with the average similarity to all other local optima. In majority of cases, relatively strong correlations with the expected sign are observed. These results may suggest that effective recombination operators could be obtained by preserving common and combining uncommon features from both parents. However, due to multiple constraints in the VRP family, it may be difficult to construct a feasible, or nearly feasible solution in this way. Thus, dedicated recombination operators taking into account specifics of the family of problems are needed.

Table 1: FDC results - values of correlations

	s_1	s_2	s_3	s_4	s_5	s_6	s_7
CVRPTW	-0.64	-0.36	-0.38	-0.63	-0.51	-0.47	-0.22
PDPTW	-0.56	-0.45	-0.42	-0.55	-0.50	-0.17	-0.26
TOPTW	0.84	0.93	0.90	0.82	0.88	0.56	0.84

[1]This research was funded by NCBR grant POIR.01.01.01-00-0012/19

GECCO '21 Companion, July 10–14, 2021, Lille, France

ACM ISBN 978-1-4503-8351-6/21/07.
https://doi.org/10.1145/3449726.3459574

3 PROPOSED RECOMBINATION OPERATORS

Order-based recombination is a new operator introduced in this paper. It is motivated by the comparison of values of similarity measures used in the fitness landscape analysis. Lower values of the numbers of common ordered pairs of nodes compared to the the numbers of all common pairs suggest that new interesting solutions may be obtained by inverting the order of pairs of nodes that have different order in the parents. The general idea of this operator is to find pairs of nodes in one of the parents that are present in a single route also in the other parent, but with a different order of nodes and to apply to all or some of these pairs the order from the other parent.

Modified SREX operator. The original Selective Route Exchange Crossover (SREX) proposed for PDPTW [8] generates offspring solutions by combining routes from two parents through a local search procedure minimizing the number of unserved nodes. We modified the original SREX operator in the following ways. We adapted it also to other VRP problems considered in this paper. To solve the Maximum Coverage Problem (MCP), instead of repeated local search proposed in [8], we use a simple memetic algorithm (MA) with local and global Tabu lists. We use lexicographic objective function in MCP minimizing the number of unserved nodes and the sum of travel distances. After solving MCP, the redundant nodes are removed from a route selected randomly from either parent.

Edge Assembly Crossover (EAX) [7] was proposed for CVRPTW, but it can also be directly applied to PDPTW. In order to apply it to TOPTW problem, we ensure that both A and B constitute of the same set of nodes by adding nodes present only in B to A and then vice versa. The nodes are added in a greedy manner.

4 COMPUTATIONAL EXPERIMENT

To evaluate the proposed recombination operators we use them within a steady-state memetic algorithm with elite population, clearing as diversity preservation mechanism, and random initial solutions, implemented as a general purpose solver in C++[2]. We use the sets of instances described in Section 2. We used PCs with Intel Xeon E5-2697 v3 and AMD EPYC 7352. We compare the obtained results also to state-of-the-art results presented in [9] (VCGP) and [7] (NBD) for CVRPTW, LS+AGES+LNS (CLS) method [3] for PDPTW, and SAILS [5] and MS-ILS [1] methods for TOPTW.

For TOPTW, we report in Table 2 results obtained with each combination of the operators. Furthermore, in an additional experiment in which each combination of operators was run for 60 minutes our method generated 18 new best known solutions compared to [1].

For PDPTW in a similar manner to [3], we report in Table 3 the total number of routes and the total distance for all instances for each version V. The lack of values for version S (SREX operator) is caused by the fact that this version failed to produce any feasible solutions for 26 instances of size 800 and 1000.

The results for CVRPTW are presented in Table 4 with running times set to the value used in [9].

Table 2: TOPTW results in 10 minutes runs

m V	2	3	4	Grand mean
S	882.2	1215.42	1468.73	1188.78
O	870.95	1203.81	1461.11	1178.62
E	870.11	1200.93	1460.51	1177.18
SO	876.68	1215.58	1471.03	1187.76
SE	876.39	1215.96	**1472.17**	1188.17
OE	869.73	1204.63	1461.65	1178.67
SOE	874.16	1214.36	1471.48	1186.67
SAILS	872.20	1172.89	1402.84	1149.31
MS-ILS	**898.71**	**1216.78**	1469.51	**1195.00**

Table 3: PDPTW results in 3 hours runs

size	V	distance	routes	V	distance	routes	V	distance	routes
ALL	S			SO	5116736.7	8154	SOE	**5086694.7**	**8154**
	O	5118714.2	8173	SE	5103974.9	8172			
	E	5085393.0	8184	OE	5099695.6	8165	CLS	5432060.1	8166

Table 4: CVRPTW results in 349 minutes runs

inst	V	distance	routes	V	distance	routes	V	distance	routes
ALL	S	2054927	3420	SO	2043208	3420	SOE	2041895	3420
	O	2054881	3420	SE	2052743	3420	NBD	2040661	3424
	E	2061174	3420	OE	2060516	3420	VCGP	**2036700**	3420

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[2] Full results available at https://www.math.uni.lodz.pl//~cybula/gecco2021/paper512.pdf