University of Science and Technology of China

TECHNICAL REPORT:

The Latest Research Results on CVRP, 2L-CVRP, and 3L-CVRP

Yangguang Wang

Research Technologist & Research Assistant Intelligent Computing and Application Lab (ICA-LAB)

ygw@mail.ustc.edu.cn

Supervisor:

Professor of School of Management

Dean of School of Software Engineering

hpchen@.ustc.edu.cn

December 14, 2021

Abstract

Distributors are faced with loading constraints in their route planning, e.g.,multi-dimensional packing constraints, unloading sequence constraints, stability constraints and axle weight limits. Ignoring these constraints impairs planning and induces last-minute changes resulting in additional costs. Developing vehicle routing models incorporating loading constraints is critical to more efficient route planning. The research on 2L-CVRP and 3L-CVRP has received extensive attention from academia and industry in recent years due to its great application value. A vivid example is that China's largest logistics enterprises, like JD Logistics and SF Logistics, are trying to promote the integration of automatic planning of vehicle routes and unmanned loading of cargo, thus building more intelligent and integrated supply chain systems.

My contribution is twofold. First, I succeeded in designing sate-of-the-art metaheuristics called AMA-ENS to solve the well-known 2L-CVRP and 3L-CVRP. New best solutions are found on corresponding well-studied benchmark data sets. Second, I further considered time-dependent travel time on the original models, which are more complicated and practical. These two new models are called 2L-TDCVRP and 3L-TDCVRP. The metaheuristic methods designed for the original 2L-CVRP and 3L-CVRP can efficiently solve the new 2L-TDCVRP and 3L-TDCVRP problem.

Without considering loading constraints, AMA-ENS can be used to solve the capacitated vehicle routing problem (CVRP). Computational experiments indicates that AMA-ENS can compete with the state-of-the-art SISR algorithm (Christiaens et al. 2020. *Transportation Science*) and FILO algorithm (Accorsi at al.2021. *Transportation Science*) for the well-known CVRP problem.

Contents

1 Results of AMA-ENS for the 2L-CVRP Problem **1**

1.1 2L-CVRP under orientated loading 1

1.2 2L-CVRP under rotated loading 8

2 Results of AMA-ENS for the 3L-CVRP Problem **12**

3 Results of AMA-ENS for the CVRP problem **14**

List of Tables

1 Comparative results on the instances of Class 1 2

2 Results for the 2UOL version of 2L-CVRP 3

3 Comparison for the 2UOLversion of 2L-CVRP (averaged over Classes 2–5) 4

4 Results for the 2URLversion of 2L-CVRP 6

5 Comparison for the 2URLversion of 2L-CVRP (averaged over Classes 2–5) 7

6 Results for 2L-CVRP (2SOL) 8

7 Comparison for the 2SOL version of 2L-CVRP (averaged over Classes 2-5) 9

8 Results for the 2SRL version of 2L-CVRP 11

9 Comparison between AMA-ENS and existing approaches in 3L-CVRP set1 instances. All constraints are imposed. 13

10 Comparison of average solution quality for CVRP 15

11 Comparison of results of best solution quality for CVRP 16

1 Results of AMA-ENS for the 2L-CVRP Problem

We executed AMA-ENS ten times for each instance by setting the random seed from 1 to 10. We compare our AMA-ENS with some of the most efficient approaches for 2L-CVRP. All these approaches were also executed 10 times for each instance. All four versions of 2L-CVRP are solved in our study. In the following tables, the cost listed is the best cost achieved over 10 runs. We list the details of only the best-known solution (BKS) among all previous approaches and the three methods with excellent performance: PRMP, VNS, SA for the 2UOL and 2SOL versions, and ACO, MS-BR, and SA for the 2URL and 2ORL versions (only these three papers studied the rotation allowed versions).

- ACO (Fuellerer et al., 2009)
- SA1 (Leung et al., 2010), EGTS + LBFH (Leung et al., 2011)
- EGTS + LBFH (Leung et al., 2011)
- GRASPxELS (Duhamel et al., 2011)
- PRMP (Zachariadis et al., 2013)
- MS-BR (Dominguez et al., 2014; Dominguez et al., 2016)
- VNS (Wei et al., 2015)
- SA (Wei at al. 2018)
- **AMA-ENS**: the adaptive memetic algorithm with extended Neighbourhood search (Wang at al. 2021)

The charts and tables in this section are extracted from the following papers:

[1] **Wang Y.**, Liu C., Zhou S., Chen H. *, "An Adaptive Memetic Algorithm with Extended Neighbourhood Search for the Vehicle Routing Problem with Backhauls and Two-dimensional Loading Constraints" submitted to Annals of Operations Research.

[2] **Wang Y.**, Zhou S., Chen Z., Chen H.*, "A Metaheuristic Algorithm for the Time-dependent Capacitated Vehicle Routing Problem with Two-dimensional Loading Constraints" submitted to European Journal of Operational Research.

1.1 2L-CVRP under orientated loading

Table 1: Comparative results on the instances of Class 1

Inst.	BKS[1]	VNS		PRMP		ACO		BR-LNS		SA		AMA-ENS		
		Cost	Time (s)	Cost	Time (s)	Cost	Time (s)	Cost	Time (s)	Cost	Time (s)	Cost	Time (s)	Gap (%)[2]
1	278.73	278.73	0.00	278.73	0.00	278.73	0.10	278.73	0.01	278.73	0.90	278.73	0.00	0.00
2	334.96	334.96	0.00	334.96	0.00	334.96	0.10	334.96	0.00	334.96	0.30	334.96	0.00	0.00
3	358.40	358.40	0.10	358.40	0.00	358.40	0.20	358.40	0.00	358.40	1.00	358.40	0.00	0.00
4	430.88	430.89	0.00	430.88	0.00	430.88	0.30	430.88	0.00	430.89	0.90	430.89	0.00	0.00
5	375.28	375.28	0.00	375.28	0.00	375.28	0.30	375.28	0.00	375.28	0.00	375.28	0.00	0.00
6	495.85	495.85	0.10	495.85	0.00	495.85	0.30	495.85	0.06	495.85	2.50	495.85	0.01	0.00
7	568.56	568.56	0.00	568.56	0.00	568.56	0.20	568.56	0.00	568.56	0.00	568.56	0.00	0.00
8	568.56	568.56	0.00	568.56	0.00	568.56	0.20	568.56	0.00	568.56	0.00	568.56	0.00	0.00
9	607.65	607.65	0.10	607.65	0.00	607.65	0.60	607.65	0.00	607.65	1.10	607.65	0.00	0.00
10	535.74	535.80	0.10	535.80	0.10	535.80	2.30	535.80	5.18	535.80	5.80	535.80	0.01	0.01
11	505.01	505.01	0.00	505.01	0.00	505.01	0.80	505.01	0.18	505.01	0.60	505.01	0.00	0.00
12	610.00	610.00	0.90	610.00	0.20	610.00	1.60	610.00	0.46	610.00	5.40	610.00	0.32	0.00
13	2006.34	2006.34	0.10	2006.34	0.30	2006.34	1.30	2006.34	0.08	2006.34	0.00	2006.34	0.02	0.00
14	837.67	837.67	0.10	837.67	0.10	837.67	4.10	837.67	0.20	837.67	0.00	837.67	0.01	0.00
15	837.67	837.67	0.10	837.67	0.40	837.67	2.80	837.67	0.18	837.67	0.00	837.67	0.01	0.00
16	698.61	698.61	1.10	698.61	0.30	698.61	2.00	698.61	0.16	698.61	4.00	698.61	0.01	0.00
17	861.79	861.79	4.00	861.79	1.60	861.79	3.30	861.79	185.65	861.79	22.20	861.79	1.97	0.00
18	723.54	723.54	1.40	723.54	3.60	723.54	9.50	723.54	1.10	723.54	6.70	723.54	0.02	0.00
19	524.61	524.61	2.00	524.61	2.10	524.61	7.90	524.61	7.29	524.61	9.00	524.61	0.02	0.00
20	241.97	241.97	3.50	241.97	7.20	241.97	55.70	241.97	2.85	241.97	14.60	241.97	0.19	0.00
21	687.60	687.60	74.90	687.60	3.80	690.20	26.70	687.60	164.12	687.60	343.80	687.60	1.78	0.00
22	740.66	740.66	21.20	740.66	2.80	742.91	56.90	740.66	12.63	740.66	101.10	740.66	5.98	0.00
23	835.26	835.26	159.70	835.26	48.70	845.34	55.90	835.26	30.74	835.26	838.00	835.26	3.35	0.00
24	1024.69	1024.69	175.90	1024.69	38.10	1030.25	49.80	1024.69	490.50	1024.69	1250.20	1024.69	7.21	0.00
25	826.14	826.14	332.20	826.14	8.60	830.82	167.50	826.14	44.48	826.14	418.00	826.14	2.90	0.00
26	819.56	819.56	1.70	819.56	11.20	819.56	173.30	819.56	0.77	819.56	1.60	819.56	0.11	0.00
27	1082.65	1082.65	445.50	1082.65	172.30	1100.22	191.00	1082.65	9.50	1082.65	1306.00	1082.65	25.12	0.00
28	1040.70	1042.12	1021.50	1042.12	71.20	1062.23	252.20	1042.12	136.28	1042.12	24.60	1042.12	1.12	0.14
29	1162.96	1162.96	172.90	1162.96	121.90	1168.13	765.00	1162.96	147.85	1162.96	35.90	1162.96	10.25	0.00
30	1028.42	1028.42	1570.00	1028.42	267.50	1041.05	313.90	1028.42	371.68	1029.79	1435.80	1028.42	37.15	0.00
31	1299.21	1302.48	1813.80	1299.56	353.80	1341.89	517.80	1299.21	312.86	1301.03	1884.00	**1293.68**	97.61	**-0.45**
32	1296.18	1300.22	1976.10	1296.91	312.00	1334.26	519.70	1296.18	372.05	1300.30	2006.90	**1291.45**	116.56	**-0.42**
33	1296.13	1298.02	2204.10	1299.55	434.10	1331.69	479.20	1297.50	161.80	1296.13	1884.20	**1291.45**	197.53	**-0.36**
34	708.39	708.39	2125.20	709.82	328.20	712.32	621.40	709.08	554.20	708.66	1658.30	**707.57**	136.36	**-0.12**
35	862.79	865.39	2050.40	866.06	396.30	868.12	1468.20	864.63	382.43	862.79	1611.00	**857.19**	254.25	**-0.65**
36	583.98	586.49	2420.20	585.46	228.90	616.69	1589.80	590.16	560.74	583.98	1276.30	**579.71**	1106.82	**-0.73**
Avg.	769.37	769.80	460.53	769.70	78.20	776.04	203.94	769.69	109.89	769.62	448.63	768.69	55.74	-0.07

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

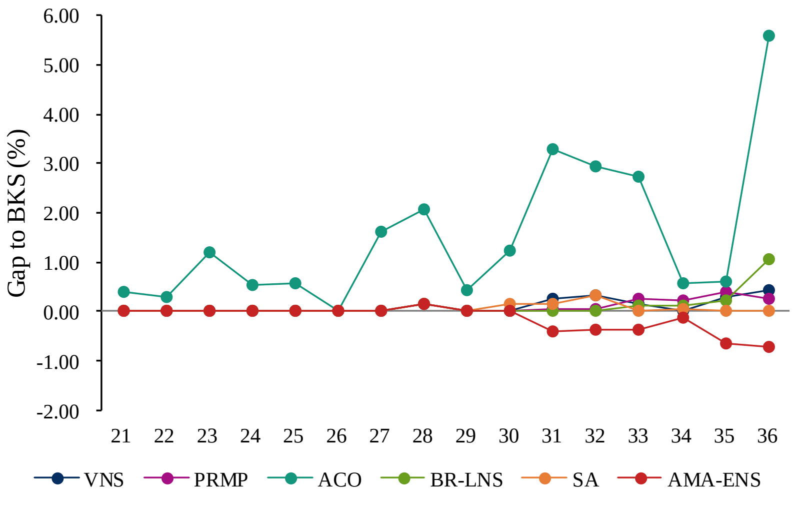

Figure 1: Gap to the BKS[1] on the instances of class 1

The X-axis represents the the current BKS level in the literature. The Lower, the better

[a] Gap to BKS (%): Percentage improvement between the solutions and BKS, Gap=100*(solution-BKS)/BKS.

Table 2: Results for the 2UOL version of 2L-CVRP

Inst.	Class 2			Class 3			Class 4			Class 5		
	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]
1	278.73	278.73	0.00	284.52	**279.49**	**-1.77**	282.95	282.95	0.00	278.73	278.73	0.00
2	334.96	334.96	0.00	352.16	**349.92**	**-0.64**	334.96	334.96	0.00	334.96	334.96	0.00
3	387.70	**379.77**	**-2.05**	394.72	**385.32**	**-2.38**	362.41	**358.40**	**-1.11**	358.40	358.40	0.00
4	430.88	430.89	0.00	430.88	430.89	0.00	447.37	447.37	0.00	430.88	430.89	0.00
5	375.28	375.28	0.00	381.69	**375.28**	**-1.68**	383.87	383.88	0.00	375.28	375.28	0.00
6	495.85	495.85	0.00	497.17	498.16	0.20	498.32	498.32	0.00	495.75	495.85	0.02
7	725.46	**708.61**	**-2.32**	678.75	**660.53**	**-2.68**	700.72	**686.26**	**-2.06**	657.77	657.77	0.00
8	674.55	**664.30**	**-1.52**	738.43	**724.16**	**-1.93**	692.47	**688.32**	**-0.60**	609.90	609.90	0.00
9	607.65	607.65	0.00	607.65	607.65	0.00	621.23	**607.65**	**-2.19**	607.65	607.65	0.00
10	689.68	**665.76**	**-3.47**	615.68	**611.54**	**-0.67**	710.87	**703.64**	**-1.02**	678.66	**678.62**	**-0.01**
11	684.21	**642.78**	**-6.06**	706.73	**698.30**	**-1.19**	784.88	**765.04**	**-2.53**	624.82	624.82	0.00
12	610.57	**610.00**	**-0.09**	610.00	610.00	0.00	614.23	**610.23**	**-0.65**	610.00	610.00	0.00
13	2585.72	**2512.14**	**-2.85**	2436.56	**2370.66**	**-2.70**	2548.06	**2544.09**	**-0.16**	2334.78	**2334.59**	**-0.01**
14	1038.09	**1028.80**	**-0.89**	996.25	**989.08**	**-0.72**	981.00	**954.06**	**-2.75**	871.22	871.22	0.00
15	1013.29	**1002.91**	**-1.02**	1149.99	**1096.97**	**-4.61**	1181.30	**1164.77**	**-1.40**	1159.94	1159.94	0.00
16	698.61	698.61	0.00	698.61	698.61	0.00	703.35	703.35	0.00	698.61	698.61	0.00
17	863.66	**861.79**	**-0.22**	861.79	861.79	0.00	861.79	861.79	0.00	861.79	861.79	0.00
18	1004.99	**983.06**	**-2.18**	1069.45	**1013.72**	**-5.21**	1116.45	**1095.30**	**-1.89**	917.94	917.94	0.00
19	754.53	**715.31**	**-5.20**	771.66	**747.39**	**-3.15**	775.87	**759.63**	**-2.09**	644.59	644.59	0.00
20	524.91	**488.68**	**-6.90**	521.31	**513.53**	**-1.49**	537.56	**533.58**	**-0.74**	470.33	**468.69**	**-0.35**
21	992.83	**965.43**	**-2.76**	1116.58	**1087.87**	**-2.57**	970.37	**959.84**	**-1.09**	873.25	**870.82**	**-0.28**
22	1035.66	**979.29**	**-5.44**	1052.98	**1025.12**	**-2.65**	1045.91	**1044.08**	**-0.17**	930.83	**929.08**	**-0.19**
23	1035.18	**977.37**	**-5.58**	1074.30	**1047.37**	**-2.51**	1071.30	**1045.71**	**-2.39**	930.09	**922.34**	**-0.83**
24	1178.07	**1135.03**	**-3.65**	1080.88	**1073.75**	**-0.66**	1100.76	**1093.55**	**-0.66**	1028.04	1042.37	1.39
25	1407.86	**1334.66**	**-5.20**	1365.37	**1326.00**	**-2.88**	1398.02	**1365.25**	**-2.34**	1150.04	1150.69	0.06
26	1272.87	**1234.91**	**-2.98**	1342.19	**1315.86**	**-1.96**	1390.99	**1375.88**	**-1.09**	1213.04	1216.90	0.32
27	1313.12	**1268.01**	**-3.44**	1369.44	**1341.79**	**-2.02**	1314.05	**1294.35**	**-1.50**	1240.32	**1236.52**	**-0.31**
28	2551.41	**2515.35**	**-1.41**	2592.73	**2557.44**	**-1.36**	2585.92	**2526.69**	**-2.29**	2294.40	2307.46	0.57
29	2196.00	**2134.77**	**-2.79**	2087.15	**2058.57**	**-1.37**	2240.18	**2203.36**	**-1.64**	2127.60	**2126.97**	**-0.03**
30	1803.26	**1726.50**	**-4.26**	1821.83	**1779.06**	**-2.35**	1820.46	**1802.24**	**-1.00**	1521.91	**1517.09**	**-0.32**
31	2254.47	**2188.87**	**-2.91**	2268.64	**2216.04**	**-2.32**	2366.80	**2335.26**	**-1.33**	1987.08	1989.38	0.12
32	2241.02	**2170.92**	**-3.13**	2227.66	**2195.11**	**-1.46**	2252.39	**2228.37**	**-1.07**	1949.34	**1944.97**	**-0.22**
33	2249.68	**2177.36**	**-3.21**	2348.25	**2304.74**	**-1.85**	2373.63	**2344.96**	**-1.21**	1975.14	**1969.26**	**-0.30**
34	1170.77	**1136.53**	**-2.92**	1196.20	**1169.77**	**-2.21**	1193.18	**1183.02**	**-0.85**	1014.76	1015.48	0.07
35	1364.35	**1323.39**	**-3.00**	1436.52	**1406.93**	**-2.06**	1486.29	**1470.64**	**-1.05**	1236.42	**1229.22**	**-0.58**
36	1681.82	**1650.36**	**-1.87**	1757.43	**1738.61**	**-1.07**	1638.66	**1621.28**	**-1.06**	1470.26	1478.07	0.53
Avg.	1125.77	1094.57	-2.48	1137.28	1115.75	-1.72	1149.68	1135.50	-1.11	1026.79	1026.86	-0.01

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

Table 3: Comparison for the 2UOLversion of 2L-CVRP (averaged over Classes 2–5)

Inst.	BKS[1]	PRMP			VNS			SA			AMA-ENS		
		Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]
1	281.23	281.23	0.40	0.00	281.23	1.20	0.00	281.23	5.70	0.00	**279.97**	1.09	**-0.45**
2	339.26	339.26	0.30	0.00	339.26	0.10	0.00	339.26	0.40	0.00	**338.70**	0.36	**-0.17**
3	375.81	376.32	0.40	0.14	376.32	0.90	0.14	375.81	0.70	0.00	**370.47**	2.17	**-1.42**
4	435.00	435.01	0.30	0.00	435.01	0.30	0.00	435.01	1.00	0.00	435.01	1.54	0.00
5	379.03	379.03	1.10	0.00	379.03	1.50	0.00	379.03	0.60	0.00	**377.43**	0.97	**-0.42**
6	496.77	497.04	0.30	0.05	497.04	1.00	0.05	497.04	1.80	0.05	497.04	1.01	0.05
7	690.67	690.67	1.60	0.00	690.67	2.50	0.00	690.67	1.90	0.00	**678.29**	1.47	**-1.79**
8	678.84	678.84	2.60	0.00	678.84	3.80	0.00	679.44	5.30	0.09	**671.67**	1.47	**-1.06**
9	611.05	612.01	1.60	0.16	612.01	1.30	0.16	612.01	2.40	0.16	**607.65**	2.64	**-0.56**
10	674.88	676.75	26.90	0.28	674.92	25.10	0.01	674.88	16.70	0.00	**664.89**	9.31	**-1.48**
11	701.07	703.22	27.20	0.31	702.47	59.90	0.20	701.07	23.70	0.00	**682.73**	3.83	**-2.62**
12	611.20	611.26	1.40	0.01	611.20	3.30	0.00	611.20	6.90	0.00	**610.06**	15.64	**-0.19**
13	2480.73	2491.18	52.70	0.42	2484.16	25.20	0.14	2480.73	22.00	0.00	**2440.37**	10.68	**-1.63**
14	973.23	975.88	164.30	0.27	975.06	295.50	0.19	973.23	53.40	0.00	**960.79**	99.31	**-1.28**
15	1128.18	1132.91	20.10	0.42	1128.60	246.30	0.04	1128.18	445.30	0.00	**1106.15**	100.01	**-1.95**
16	699.79	699.79	4.10	0.00	699.79	1.60	0.00	699.79	4.00	0.00	699.79	19.51	0.00
17	862.26	864.05	2.40	0.21	864.05	4.00	0.21	864.05	18.20	0.21	**861.79**	30.65	**-0.05**
18	1027.45	1031.95	33.00	0.44	1027.98	79.80	0.05	1027.45	160.50	0.00	**1002.50**	81.09	**-2.43**
19	737.40	741.78	24.30	0.59	737.73	250.50	0.04	737.40	206.60	0.00	**716.73**	91.38	**-2.80**
20	513.53	515.44	552.20	0.37	515.92	794.20	0.47	513.53	855.90	0.00	**501.12**	267.26	**-2.42**
21	988.30	992.78	241.50	0.45	991.63	751.10	0.34	988.30	1658.40	0.00	**970.99**	347.64	**-1.75**
22	1017.33	1023.01	166.60	0.56	1019.03	885.20	0.17	1017.56	1740.10	0.02	**994.39**	402.99	**-2.25**
23	1029.32	1032.36	336.80	0.30	1030.40	853.10	0.10	1029.32	1353.20	0.00	**998.20**	369.98	**-3.02**
24	1099.57	1104.64	319.60	0.46	1102.53	572.10	0.27	1100.64	923.10	0.10	**1086.18**	328.10	**-1.22**
25	1330.32	1341.26	921.70	0.82	1333.76	998.70	0.26	1330.32	1833.30	0.00	**1294.15**	490.37	**-2.72**
26	1306.59	1311.79	403.50	0.40	1306.60	1050.60	0.00	1306.59	1466.80	0.00	**1285.89**	503.69	**-1.58**
27	1309.92	1318.04	438.20	0.62	1311.27	874.50	0.10	1309.92	1696.00	0.00	**1285.17**	864.46	**-1.89**
28	2506.12	2530.46	3701.90	0.97	2519.35	2259.20	0.53	2506.12	2222.30	0.00	**2476.74**	2688.55	**-1.17**
29	2163.06	2173.02	1835.70	0.46	2166.14	2232.80	0.14	2163.06	2169.90	0.00	**2130.92**	2812.31	**-1.49**
30	1741.87	1760.59	2151.80	1.07	1746.82	2495.40	0.28	1741.87	1337.10	0.00	**1706.22**	2342.04	**-2.05**
31	2220.22	2244.13	2927.40	1.08	2227.79	2952.90	0.34	2220.22	2080.90	0.00	**2182.39**	2665.39	**-1.70**
32	2167.60	2196.85	3713.80	1.35	2177.66	2648.70	0.46	2167.60	1954.70	0.00	**2134.84**	2603.74	**-1.51**
33	2236.73	2261.68	1964.80	1.12	2239.91	2942.70	0.14	2236.73	1949.90	0.00	**2199.08**	2132.24	**-1.68**
34	1144.14	1157.22	3551.70	1.14	1147.67	2459.60	0.31	1144.14	2472.60	0.00	**1126.20**	3091.90	**-1.57**
35	1380.90	1401.17	2756.50	1.47	1388.55	2620.60	0.55	1380.90	2447.20	0.00	**1357.55**	3119.45	**-1.69**
36	1637.04	1669.44	4245.60	1.98	1656.00	3012.00	1.16	1637.04	2953.50	0.00	**1622.08**	2967.55	**-0.91**
Avg.	1110.46	1118.11	849.84	0.50	1113.23	872.42	0.19	1110.59	891.44	0.02	1093.17	790.88	-1.41

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

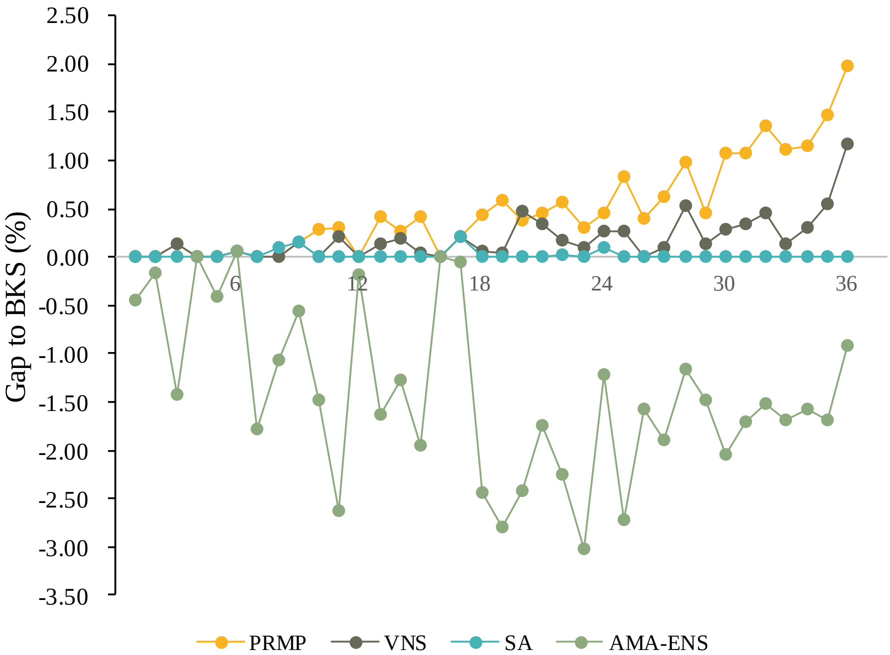

Figure 2: Gap to the BKS[1] for the $2|UO|L$ version of 2L-CVRP (averaged over Class 2–5)

The X-axis represents the the current BKS level in the literature. The Lower, the better

[a]Gap to BKS (%): Percentage improvement between the solutions and BKS, Gap=100*(solution-BKS)/BKS.

Table 4: Results for the 2URLversion of 2L-CVRP

Inst.	Class2			Class 3			Class 4			Class 5		
	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]
1	278.73	278.73	0.00	282.95	**279.49**	**-1.22**	282.95	282.95	0.00	278.73	278.73	0.00
2	334.96	334.96	0.00	352.16	**349.92**	**-0.64**	334.96	334.96	0.00	334.96	334.96	0.00
3	380.35	**371.72**	**-2.27**	385.32	385.32	0.00	358.40	358.40	0.00	358.40	358.40	0.00
4	430.88	430.89	0.00	430.88	430.89	0.00	447.37	447.37	0.00	430.88	430.89	0.00
5	375.28	375.28	0.00	379.94	**375.28**	**-1.23**	383.87	383.88	0.00	375.28	375.28	0.00
6	495.85	495.85	0.00	498.16	498.16	0.00	498.32	498.32	0.00	495.85	495.85	0.00
7	715.02	**699.52**	**-2.17**	664.96	**659.66**	**-0.80**	686.26	686.26	0.00	657.77	657.77	0.00
8	665.17	**664.30**	**-0.13**	738.43	**724.16**	**-1.93**	688.32	688.32	0.00	609.90	609.90	0.00
9	607.65	607.65	0.00	607.65	607.65	0.00	625.10	**607.65**	**-2.79**	607.65	607.65	0.00
10	667.42	**648.94**	**-2.77**	591.61	**584.80**	**-1.15**	703.64	703.64	0.00	678.62	678.62	0.00
11	664.48	**637.12**	**-4.12**	699.35	**685.80**	**-1.94**	771.93	**760.53**	**-1.48**	624.82	624.82	0.00
12	610.00	610.00	0.00	610.00	610.00	0.00	610.23	610.23	0.00	610.00	610.00	0.00
13	2502.65	**2463.55**	**-1.56**	2377.39	**2345.10**	**-1.36**	2533.79	**2500.85**	**-1.30**	2334.59	2334.59	0.00
14	1029.34	**1025.87**	**-0.34**	988.79	988.80	0.00	955.09	**954.06**	**-0.11**	871.22	871.22	0.00
15	1001.51	**1000.68**	**-0.08**	1116.07	**1096.97**	**-1.71**	1164.63	**1164.39**	**-0.02**	1159.94	1159.94	0.00
16	698.61	698.61	0.00	698.61	698.61	0.00	703.35	703.35	0.00	698.61	698.61	0.00
17	861.79	861.79	0.00	861.79	861.79	0.00	861.79	861.79	0.00	861.79	861.79	0.00
18	987.10	**971.48**	**-1.58**	986.30	**985.97**	**-0.03**	1100.52	**1095.12**	**-0.49**	917.94	917.94	0.00
19	723.93	**701.53**	**-3.09**	749.43	**742.27**	**-0.96**	747.03	**739.92**	**-0.95**	644.59	644.59	0.00
20	488.69	**483.60**	**-1.04**	511.46	**510.06**	**-0.27**	533.77	**528.33**	**-1.02**	466.79	466.79	0.00
21	964.49	**944.12**	**-2.11**	1086.72	**1071.20**	**-1.43**	959.82	**952.83**	**-0.73**	870.82	870.82	0.00
22	976.70	**957.04**	**-2.01**	1024.11	**1010.08**	**-1.37**	1041.80	**1033.58**	**-0.79**	928.02	928.02	0.00
23	984.00	**961.68**	**-2.27**	1041.60	**1031.44**	**-0.98**	1047.32	**1032.80**	**-1.39**	922.34	922.34	0.00
24	1140.13	**1112.35**	**-2.44**	1066.15	**1062.81**	**-0.31**	1086.09	**1081.90**	**-0.39**	1042.37	1042.37	0.00
25	1345.89	**1301.14**	**-3.32**	1333.64	**1314.75**	**-1.42**	1366.28	**1357.98**	**-0.61**	1149.66	1149.66	0.00
26	1257.00	**1220.09**	**-2.94**	1311.11	**1295.86**	**-1.16**	1362.22	**1359.75**	**-0.18**	1209.34	1209.34	0.00
27	1271.10	**1242.87**	**-2.22**	1329.33	**1315.87**	**-1.01**	1284.94	**1278.65**	**-0.49**	1231.52	**1222.66**	**-0.72**
28	2491.86	**2439.92**	**-2.08**	2541.02	**2522.66**	**-0.72**	2510.29	**2499.13**	**-0.44**	2276.71	2291.78	0.66
29	2129.10	**2081.81**	**-2.22**	2040.83	**2028.67**	**-0.60**	2199.79	**2193.98**	**-0.26**	2115.53	2116.51	0.05
30	1740.87	**1689.74**	**-2.94**	1767.72	**1753.16**	**-0.82**	1784.14	**1772.14**	**-0.67**	1512.71	1513.42	0.05
31	2162.88	**2120.38**	**-1.96**	2196.26	**2170.36**	**-1.18**	2314.76	**2302.72**	**-0.52**	1968.89	1974.17	0.27
32	2165.96	**2112.12**	**-2.49**	2166.18	**2149.86**	**-0.75**	2206.72	**2181.48**	**-1.14**	1938.96	**1938.42**	**-0.03**
33	2157.23	**2096.28**	**-2.83**	2276.31	**2235.41**	**-1.80**	2318.77	**2308.14**	**-0.46**	1946.51	1951.79	0.27
34	1121.67	**1091.89**	**-2.65**	1165.57	**1148.94**	**-1.43**	1163.96	**1160.03**	**-0.34**	1006.38	1012.15	0.57
35	1310.33	**1282.76**	**-2.10**	1393.90	**1374.65**	**-1.38**	1452.59	**1448.03**	**-0.31**	1224.21	**1218.27**	**-0.49**
36	1625.42	**1595.50**	**-1.84**	1708.05	**1678.23**	**-1.75**	1605.00	**1600.33**	**-0.29**	1457.05	1459.39	0.16
Avg.	1093.45	1072.55	-1.60	1110.55	1099.57	-0.87	1130.44	1124.27	-0.48	1022.76	1023.32	0.02

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

Table 5: Comparison for the 2URLversion of 2L-CVRP (averaged over Classes 2–5)

Inst.	BKS[1]	ACO			MS-BR			SA			AMA-ENS		
		Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]
1	280.84	281.16	–	0.11	280.84	3.30	0.00	281.13	0.70	0.10	**279.97**	0.48	**-0.31**
2	339.26	341.02	–	0.52	339.26	0.80	0.00	339.26	0.40	0.00	**338.70**	0.39	**-0.17**
3	370.62	372.93	–	0.62	370.62	34.80	0.00	371.62	2.10	0.27	**368.46**	0.91	**-0.58**
4	435.00	435.01	–	0.00	435.00	2.00	0.00	435.00	1.10	0.00	435.01	0.40	0.00
5	378.59	378.59	–	0.00	378.59	30.00	0.00	378.59	0.70	0.00	**377.43**	0.63	**-0.31**
6	497.04	497.04	–	0.00	497.05	3.80	0.00	497.04	1.70	0.00	497.04	0.25	0.00
7	681.00	688.50	–	1.10	681.00	20.30	0.00	681.00	1.20	0.00	**675.80**	0.64	**-0.76**
8	675.45	678.75	–	0.49	675.46	17.00	0.00	675.45	5.10	0.00	**671.67**	0.50	**-0.56**
9	612.01	612.02	–	0.00	612.01	32.30	0.00	612.01	2.80	0.00	**607.65**	1.44	**-0.71**
10	660.43	671.00	–	1.60	667.65	182.00	1.09	660.43	5.40	0.00	**654.00**	2.03	**-0.97**
11	690.56	698.25	–	1.11	690.56	146.50	0.00	690.56	5.20	0.00	**677.07**	4.72	**-1.95**
12	610.06	611.12	–	0.17	611.06	15.30	0.16	610.06	6.80	0.00	610.06	8.22	0.00
13	2437.15	2468.19	–	1.27	2437.15	114.50	0.00	2437.58	4.90	0.02	**2411.02**	5.16	**-1.07**
14	961.11	974.80	–	1.42	968.55	176.50	0.77	961.11	10.90	0.00	**959.99**	12.15	**-0.12**
15	1110.54	1132.49	–	1.98	1112.00	183.50	0.13	1110.54	46.40	0.00	**1105.50**	24.33	**-0.45**
16	699.79	699.79	–	0.00	699.80	26.50	0.00	699.79	5.10	0.00	699.79	8.49	0.00
17	861.79	862.36	–	0.07	861.79	12.50	0.00	861.79	15.40	0.00	861.79	14.34	0.00
18	997.97	1012.19	–	1.42	999.22	182.50	0.13	997.97	23.70	0.00	**992.63**	41.29	**-0.54**
19	716.24	726.96	–	1.50	722.17	268.80	0.83	716.24	168.40	0.00	**707.08**	39.72	**-1.28**
20	500.18	508.69	–	1.70	501.90	210.50	0.34	500.18	143.90	0.00	**497.19**	79.67	**-0.60**
21	971.45	989.24	–	1.83	977.03	348.80	0.57	971.45	1346.40	0.00	**959.74**	123.35	**-1.21**
22	994.77	1008.52	–	1.38	1001.75	297.30	0.70	994.77	1402.00	0.00	**982.18**	147.64	**-1.27**
23	998.81	1024.25	–	2.55	1011.19	420.50	1.24	998.81	903.80	0.00	**987.07**	197.71	**-1.18**
24	1083.69	1098.60	–	1.38	1092.90	213.50	0.85	1083.69	986.40	0.00	**1074.86**	160.60	**-0.81**
25	1298.87	1323.84	–	1.92	1320.27	362.50	1.65	1298.87	1389.20	0.00	**1280.88**	238.94	**-1.39**
26	1284.92	1314.34	–	2.29	1302.52	332.00	1.37	1284.92	1145.90	0.00	**1271.26**	267.51	**-1.06**
27	1279.22	1309.76	–	2.39	1304.14	362.00	1.95	1279.22	1529.90	0.00	**1265.01**	322.06	**-1.11**
28	2454.97	2526.81	–	2.93	2518.51	401.00	2.59	2454.97	1796.60	0.00	**2438.37**	2581.86	**-0.68**
29	2121.31	2175.33	–	2.55	2161.43	417.80	1.89	2121.31	1520.70	0.00	**2105.24**	1955.18	**-0.76**
30	1701.36	1742.15	–	2.40	1742.01	337.80	2.39	1701.36	1717.40	0.00	**1682.12**	893.57	**-1.13**
31	2160.70	2227.74	–	3.10	2204.44	472.80	2.02	2160.70	2244.60	0.00	**2141.91**	1820.12	**-0.87**
32	2119.46	2180.18	–	2.86	2167.61	394.00	2.27	2119.46	2036.50	0.00	**2095.47**	1441.45	**-1.13**
33	2174.71	2239.04	–	2.96	2222.42	459.50	2.19	2174.71	1925.10	0.00	**2147.91**	1732.20	**-1.23**
34	1114.40	1149.87	–	3.18	1142.25	458.00	2.50	1114.40	2399.10	0.00	**1103.25**	1992.90	**-1.00**
35	1345.26	1387.45	–	3.14	1392.05	471.80	3.48	1345.26	2376.00	0.00	**1330.93**	1979.94	**-1.07**
36	1598.88	1670.67	–	4.49	1653.05	375.30	3.39	1598.88	2646.50	0.00	**1583.36**	2754.05	**-0.97**
Avg.	1089.40	1111.63	–	1.57	1104.31	216.33	0.96	1089.45	772.72	0.01	1079.93	523.75	-0.76

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

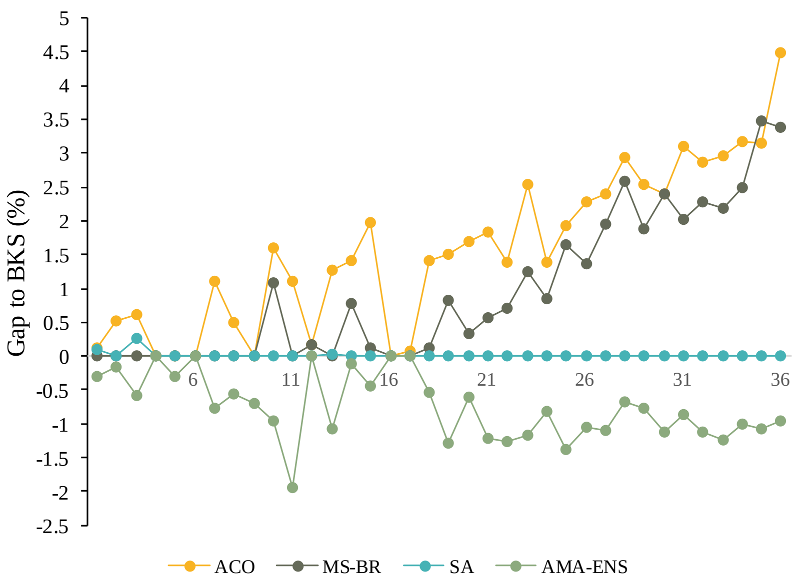

Figure 3: Gap to the BKS[1] for the 2URL version of 2L-CVRP (averaged over Class 2-5)

The X-axis represents the the current BKS level in the literature. The Lower, the better

[a]Gap to BKS (%): Percentage improvement between the solutions and BKS, Gap=100*(solution-BKS)/BKS.

1.2 2L-CVRP under rotated loading

Table 6: Results for 2L-CVRP (2SOL)

Inst.	Class 2			Class 3			Class 4			Class 5		
	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]
1	290.84	290.84	0.00	284.52	**280.80**	**-1.31**	280.80	**280.80**	**0.00**	278.73	278.73	0.00
2	347.73	347.73	0.00	352.16	**346.18**	**-1.70**	346.18	**338.40**	**-2.25**	334.96	334.96	0.00
3	403.93	**397.46**	**-1.60**	394.72	**389.95**	**-1.21**	389.95	**365.99**	**-6.14**	358.40	358.40	0.00
4	440.94	**436.32**	**-1.05**	440.68	**434.91**	**-1.31**	447.37	**442.95**	**-0.99**	430.88	430.88	0.00
5	388.72	**384.61**	**-1.06**	381.69	**376.64**	**-1.32**	383.87	**378.53**	**-1.39**	375.28	375.28	0.00
6	499.08	**490.71**	**-1.68**	504.68	**499.67**	**-0.99**	498.32	**491.27**	**-1.41**	495.85	495.85	0.00
7	734.65	**722.53**	**-1.65**	702.59	**691.59**	**-1.57**	703.49	**697.39**	**-0.87**	658.64	658.64	0.00
8	725.91	725.91	0.00	741.12	**728.70**	**-1.68**	697.92	**692.50**	**-0.78**	621.85	621.85	0.00
9	611.49	611.49	0.00	613.90	**604.77**	**-1.49**	625.10	**621.01**	**-0.65**	607.65	607.65	0.00
10	700.20	700.20	0.00	628.94	**618.20**	**-1.71**	715.82	**710.06**	**-0.80**	690.96	690.96	0.00
11	721.54	**713.24**	**-1.15**	717.37	**708.59**	**-1.22**	815.68	**807.27**	**-1.03**	624.82	624.82	0.00
12	619.63	**611.86**	**-1.25**	610.00	**601.42**	**-1.41**	618.23	**610.68**	**-1.22**	610.00	**608.88**	**-0.18**
13	2669.39	**2630.50**	**-1.46**	2486.44	2486.44	0.00	2609.36	**2587.07**	**-0.85**	2416.04	**2416.01**	**0.00**
14	1092.51	**1075.41**	**-1.57**	1039.06	1039.06	0.00	982.25	**970.08**	**-1.24**	922.75	**921.35**	**-0.15**
15	1041.75	**1032.38**	**-0.90**	1181.68	**1167.75**	**-1.18**	1246.49	**1235.93**	**-0.85**	1229.95	**1225.94**	**-0.33**
16	698.61	**689.32**	**-1.33**	698.61	**686.32**	**-1.76**	708.20	**700.83**	**-1.04**	698.61	698.61	0.00
17	870.86	**861.18**	**-1.11**	861.79	**853.50**	**-0.96**	861.79	**851.28**	**-1.22**	861.79	861.79	0.00
18	1053.09	**1043.18**	**-0.94**	1102.17	**1094.21**	**-0.72**	1134.11	**1120.10**	**-1.24**	926.34	926.34	0.00
19	792.07	**787.28**	**-0.60**	801.13	**790.09**	**-1.38**	801.21	**790.20**	**-1.37**	652.15	652.15	0.00
20	545.68	**536.18**	**-1.74**	541.58	**534.75**	**-1.26**	551.72	**547.37**	**-0.79**	478.15	478.15	0.00
21	1060.72	**1040.78**	**-1.88**	1149.90	**1141.63**	**-0.72**	1000.25	**988.56**	**-1.17**	886.00	886.00	0.00
22	1081.44	**1070.39**	**-1.02**	1094.66	**1083.73**	**-1.00**	1089.27	**1075.78**	**-1.24**	948.60	**944.99**	**-0.38**
23	1093.27	**1073.83**	**-1.78**	1117.54	**1100.87**	**-1.49**	1093.01	**1077.94**	**-1.38**	948.68	**946.57**	**-0.22**
24	1222.43	**1211.27**	**-0.91**	1118.44	**1106.84**	**-1.04**	1141.97	**1129.43**	**-1.10**	1046.08	1046.08	0.00
25	1453.98	**1439.77**	**-0.98**	1433.92	**1423.40**	**-0.73**	1435.18	**1423.98**	**-0.78**	1183.63	**1179.86**	**-0.32**
26	1323.23	**1309.63**	**-1.03**	1392.43	**1372.76**	**-1.41**	1447.03	**1437.92**	**-0.63**	1252.65	1252.65	0.00
27	1367.85	**1355.55**	**-0.90**	1423.74	**1396.75**	**-1.90**	1353.06	**1343.52**	**-0.71**	1259.17	1259.17	0.00
28	2632.55	**2615.47**	**-0.65**	2737.42	**2705.31**	**-1.17**	2690.69	**2669.67**	**-0.78**	2399.25	2399.25	0.00
29	2285.84	**2255.95**	**-1.31**	2150.35	**2134.91**	**-0.72**	2299.32	**2276.92**	**-0.97**	2179.12	2179.12	0.00
30	1875.38	**1841.07**	**-1.83**	1912.09	**1899.18**	**-0.68**	1904.42	**1879.27**	**-1.32**	1565.96	**1562.08**	**-0.25**
31	2341.08	**2308.28**	**-1.40**	2354.21	**2332.46**	**-0.92**	2459.59	**2425.00**	**-1.41**	2053.57	**2045.41**	**-0.40**
32	2365.99	**2348.70**	**-0.73**	2320.35	**2285.14**	**-1.52**	2343.29	**2310.29**	**-1.41**	2016.58	2016.58	0.00
33	2349.98	**2335.20**	**-0.63**	2447.20	**2407.80**	**-1.61**	2446.05	**2423.17**	**-0.94**	2044.88	**2039.12**	**-0.28**
34	1217.24	**1200.51**	**-1.37**	1249.07	**1235.21**	**-1.11**	1241.13	**1232.61**	**-0.69**	1062.18	**1060.09**	**-0.20**
35	1434.99	**1410.19**	**-1.73**	1511.66	**1497.24**	**-0.95**	1550.24	**1529.38**	**-1.35**	1278.90	**1275.19**	**-0.29**
36	1755.33	**1727.37**	**-1.59**	1833.97	**1813.94**	**-1.09**	1713.71	**1694.85**	**-1.10**	1541.07	**1533.39**	**-0.50**
Avg.	1169.72	1156.45	-1.08	1175.88	1163.08	-1.17	1184.06	1171.06	-1.20	1053.89	1052.58	-0.10

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

Table 7: Comparison for the 2SOL version of 2L-CVRP (averaged over Classes 2-5)

Inst.	BKS[1]	PRMP			VNS			SA			AMA-ENS		
		Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]	Cost	Time (s)	Gap (%)[2]
1	287.08	287.08	1.40	0.00	287.08	4.50	0.00	287.08	5.30	0.00	**282.79**	5.03	**-1.49**
2	344.21	344.21	1.00	0.00	344.21	0.50	0.00	347.21	0.60	0.87	**341.82**	0.52	**-0.69**
3	381.40	381.40	1.30	0.00	381.40	1.40	0.00	389.40	0.90	2.10	**377.95**	0.81	**-0.90**
4	439.97	439.97	1.60	0.00	439.97	0.90	0.00	439.97	1.30	0.00	**436.27**	1.16	**-0.84**
5	382.39	382.39	2.60	0.00	382.39	4.20	0.00	382.39	1.80	0.00	**378.77**	1.68	**-0.95**
6	499.48	499.48	5.60	0.00	499.48	1.70	0.00	499.48	2.50	0.00	**494.38**	2.04	**-1.02**
7	699.84	702.27	5.30	0.35	701.63	12.20	0.26	699.84	6.80	0.00	**692.54**	6.15	**-1.04**
8	696.70	699.54	7.00	0.41	696.70	21.30	0.00	696.70	45.80	0.00	**692.24**	37.29	**-0.64**
9	614.53	615.93	6.20	0.23	614.53	3.70	0.00	614.53	4.00	0.00	**611.23**	3.40	**-0.54**
10	686.09	688.48	55.00	0.35	686.09	115.60	0.00	686.52	294.80	0.06	**679.86**	240.73	**-0.91**
11	722.22	725.83	75.30	0.50	722.84	54.30	0.09	722.22	173.90	0.00	**713.48**	163.21	**-1.21**
12	614.47	614.52	7.10	0.01	614.52	7.50	0.01	614.47	130.90	0.00	**608.21**	115.32	**-1.02**
13	2545.31	2554.93	119.60	0.38	2546.77	53.40	0.06	2545.31	274.50	0.00	**2530.01**	228.06	**-0.60**
14	1009.14	1027.38	637.00	1.81	1026.21	416.70	1.69	1009.14	632.80	0.00	**1001.48**	521.66	**-0.76**
15	1175.08	1189.97	68.10	1.27	1175.08	298.50	0.00	1175.19	344.20	0.01	**1165.50**	306.14	**-0.82**
16	701.00	701.00	14.20	0.00	701.00	3.40	0.00	701.00	6.10	0.00	**693.77**	5.57	**-1.03**
17	864.05	864.05	40.90	0.00	864.05	4.40	0.00	864.05	19.40	0.00	**856.94**	18.25	**-0.82**
18	1054.29	1058.00	95.20	0.35	1054.29	396.20	0.00	1056.07	480.10	0.17	**1045.96**	397.52	**-0.79**
19	761.64	766.05	188.30	0.58	761.83	297.40	0.02	761.64	435.40	0.00	**754.93**	394.74	**-0.88**
20	529.91	534.87	1660.90	0.94	530.26	921.70	0.07	529.91	1541.70	0.00	**524.11**	1337.34	**-1.09**
21	1024.22	1041.77	420.20	1.71	1027.74	1003.00	0.34	1024.22	1850.20	0.00	**1014.24**	1725.56	**-0.97**
22	1053.49	1066.56	524.20	1.24	1053.49	1107.50	0.00	1055.62	1403.60	0.20	**1043.72**	1234.77	**-0.93**
23	1063.52	1076.19	519.50	1.19	1063.52	953.10	0.00	1064.15	1499.30	0.06	**1049.80**	1231.06	**-1.29**
24	1132.24	1139.12	1064.30	0.61	1132.88	841.40	0.06	1132.24	1339.60	0.00	**1123.41**	1116.31	**-0.78**
25	1378.55	1401.00	2319.50	1.63	1378.55	1306.10	0.00	1379.16	1716.90	0.04	**1366.75**	1551.94	**-0.86**
26	1354.05	1370.78	1491.20	1.24	1355.92	1240.30	0.14	1354.05	1550.00	0.00	**1343.24**	1398.38	**-0.80**
27	1352.11	1372.49	4163.80	1.51	1354.92	1242.50	0.21	1352.11	1795.20	0.00	**1338.75**	1606.14	**-0.99**
28	2615.65	2669.07	8640.10	2.04	2646.59	2423.00	1.18	2615.65	2206.80	0.00	**2597.43**	1999.53	**-0.70**
29	2228.66	2263.76	5484.30	1.57	2241.65	2672.80	0.58	2228.66	2281.90	0.00	**2211.73**	2164.88	**-0.76**
30	1814.92	1853.02	4676.90	2.10	1819.25	2502.10	0.24	1814.92	1583.80	0.00	**1795.40**	1439.26	**-1.08**
31	2302.11	2358.26	5845.40	2.44	2317.82	2760.60	0.68	2302.11	2406.80	0.00	**2277.79**	2224.63	**-1.06**
32	2261.55	2322.71	9433.20	2.70	2274.88	2664.00	0.59	2261.55	2704.20	0.00	**2240.18**	2455.73	**-0.94**
33	2322.03	2394.32	5662.50	3.11	2342.87	2614.50	0.90	2322.03	2864.50	0.00	**2301.32**	2448.45	**-0.89**
34	1192.59	1225.54	13141.80	2.76	1196.33	2825.70	0.31	1192.59	2568.80	0.00	**1182.11**	2157.23	**-0.88**
35	1443.95	1494.32	8989.60	3.49	1454.42	3052.90	0.73	1443.95	2809.40	0.00	**1428.00**	2354.17	**-1.10**
36	1711.02	1762.17	10059.60	2.99	1736.03	3282.60	1.46	1711.02	3282.20	0.00	**1692.39**	3017.78	**-1.09**
Avg.	1146.10	1163.57	2373.05	1.10	1150.76	975.32	0.27	1146.56	1062.94	0.10	1135.79	942.01	-0.92

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

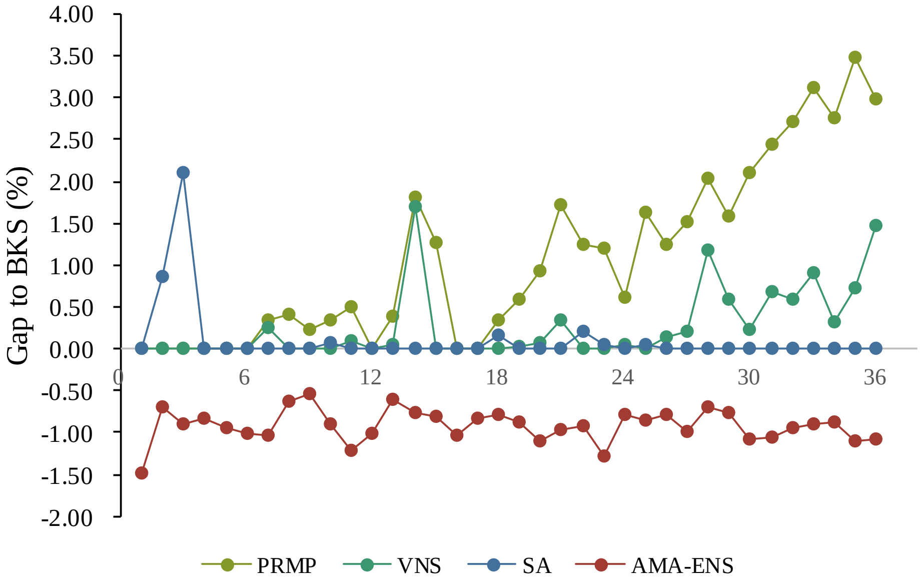

Figure 4: Gap to the BKS[1] for the 2SOL version of 2L-CVRP (averaged over Class 2–5)

The X-axis represents the the current BKS level in the literature. The Lower, the better

[a]Gap to BKS (%): Percentage improvement between the solutions and BKS, Gap=100*(solution- BKS)/BKS.

Table 8: Results for the 2SRL version of 2L-CVRP

Inst.	Class 2			Class 3			Class 4			Class 5		
	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]	BKS[1]	AMA-ENS	Gap (%)[2]
1	278.73	278.73	0.00	284.23	284.23	0.00	282.95	**278.49**	**-1.58**	278.73	278.73	0.00
2	334.96	334.96	0.00	352.16	352.16	0.00	334.96	**330.92**	**-1.21**	334.96	334.96	0.00
3	384.93	384.93	0.00	385.32	385.32	0.00	364.45	364.45	0.00	358.40	358.40	0.00
4	430.89	430.89	0.00	430.89	**423.39**	**-1.74**	447.37	447.37	0.00	430.89	430.89	0.00
5	375.28	**372.97**	**-0.62**	379.94	**372.96**	**-1.84**	383.88	383.88	0.00	375.28	375.28	0.00
6	498.16	**494.87**	**-0.66**	498.16	**491.77**	**-1.28**	498.32	498.32	0.00	495.85	495.85	0.00
7	716.82	**711.55**	**-0.74**	668.39	**657.27**	**-1.66**	686.26	686.26	0.00	657.77	657.77	0.00
8	674.20	**670.46**	**-0.55**	738.43	**733.86**	**-0.62**	692.47	**682.89**	**-1.38**	609.90	609.90	0.00
9	607.65	**602.65**	**-0.82**	607.65	607.65	0.00	625.10	**617.87**	**-1.16**	607.65	607.65	0.00
10	684.70	**672.10**	**-1.84**	615.68	615.68	0.00	710.87	**701.59**	**-1.31**	680.26	680.26	0.00
11	694.60	**687.12**	**-1.08**	704.77	704.77	0.00	776.69	**768.03**	**-1.12**	624.82	624.82	0.00
12	610.00	**599.59**	**-1.71**	610.00	**605.92**	**-0.67**	614.24	**608.38**	**-0.95**	610.00	610.00	0.00
13	2526.07	**2497.53**	**-1.13**	2436.41	**2423.89**	**-0.51**	2561.65	**2547.29**	**-0.56**	2334.78	**2314.73**	**-0.86**
14	1032.96	**1015.88**	**-1.65**	1006.69	**991.19**	**-1.54**	981.90	**976.41**	**-0.56**	921.45	**909.27**	**-1.32**
15	1005.26	**988.49**	**-1.67**	1146.66	**1128.40**	**-1.59**	1172.43	**1164.03**	**-0.72**	1160.96	**1142.64**	**-1.58**
16	698.61	**693.95**	**-0.67**	698.61	**688.15**	**-1.50**	703.35	**699.69**	**-0.52**	698.61	**685.64**	**-1.86**
17	861.79	**855.89**	**-0.68**	861.79	**850.62**	**-1.30**	861.79	**856.94**	**-0.56**	861.79	**846.64**	**-1.76**
18	988.37	**982.36**	**-0.61**	1031.49	**1023.47**	**-0.78**	1118.18	**1108.76**	**-0.84**	921.29	**921.29**	**0.00**
19	732.64	**726.17**	**-0.88**	757.59	**749.43**	**-1.08**	776.59	**771.34**	**-0.68**	651.97	**651.97**	**0.00**
20	495.01	**488.72**	**-1.27**	519.43	**516.21**	**-0.62**	541.17	**533.06**	**-1.50**	472.09	**468.52**	**-0.76**
21	986.35	**976.52**	**-1.00**	1104.72	**1098.40**	**-0.57**	977.00	**965.11**	**-1.22**	881.38	**869.11**	**-1.39**
22	1001.03	**993.70**	**-0.73**	1044.34	**1037.14**	**-0.69**	1061.43	**1054.24**	**-0.68**	935.74	**924.60**	**-1.19**
23	1001.74	**987.13**	**-1.46**	1064.72	**1055.25**	**-0.89**	1076.34	**1070.13**	**-0.58**	942.10	**925.20**	**-1.79**
24	1173.04	**1161.78**	**-0.96**	1076.30	**1056.79**	**-1.81**	1102.37	**1092.83**	**-0.87**	1042.43	**1033.30**	**-0.88**
25	1371.51	**1345.79**	**-1.88**	1364.61	**1350.86**	**-1.01**	1395.23	**1384.08**	**-0.80**	1173.55	**1163.71**	**-0.84**
26	1278.62	**1257.48**	**-1.65**	1341.01	**1321.63**	**-1.45**	1395.93	**1386.11**	**-0.70**	1226.01	**1202.74**	**-1.90**
27	1292.78	**1281.32**	**-0.89**	1367.12	**1341.89**	**-1.85**	1324.92	**1314.50**	**-0.79**	1250.91	**1240.92**	**-0.80**
28	2524.37	**2511.47**	**-0.51**	2588.78	**2564.20**	**-0.95**	2647.03	**2631.62**	**-0.58**	2368.67	**2327.12**	**-1.75**
29	2170.03	**2154.51**	**-0.72**	2089.73	**2060.72**	**-1.39**	2247.12	**2232.24**	**-0.66**	2152.16	**2130.54**	**-1.00**
30	1774.70	**1764.33**	**-0.58**	1821.19	**1804.82**	**-0.90**	1838.87	**1816.89**	**-1.20**	1541.85	**1517.39**	**-1.59**
31	2231.33	**2207.55**	**-1.07**	2260.59	**2244.64**	**-0.71**	2380.00	**2346.15**	**-1.42**	2025.75	**2006.04**	**-0.97**
32	2226.32	**2189.07**	**-1.67**	2234.74	**2216.97**	**-0.80**	2277.96	**2246.83**	**-1.37**	1986.14	**1954.86**	**-1.57**
33	2209.40	**2192.23**	**-0.78**	2350.43	**2306.24**	**-1.88**	2381.54	**2360.18**	**-0.90**	2010.55	**1984.73**	**-1.28**
34	1156.30	**1139.55**	**-1.45**	1195.80	**1186.40**	**-0.79**	1201.39	**1180.68**	**-1.72**	1041.41	**1022.70**	**-1.80**
35	1352.64	**1328.02**	**-1.82**	1430.28	**1415.07**	**-1.06**	1504.19	**1486.84**	**-1.15**	1261.97	**1253.09**	**-0.70**
36	1673.51	**1644.27**	**-1.75**	1759.82	**1744.59**	**-0.87**	1656.29	**1641.88**	**-0.87**	1511.25	**1490.66**	**-1.36**
Avg.	1112.65	1100.68	-0.99	1134.12	1122.55	-0.95	1155.62	1145.45	-0.84	1039.98	1029.22	-0.80

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

2 Results of AMA-ENS for the 3L-CVRP Problem

In the three-dimensional loading CVRP (3L-CVRP), the three dimensions of the vehicle are taken into account and the customer's demand also consists of three-dimensional items. Since the height dimension is considered, additional loading constraints concerning fragility and vertical stability of the cargo may be specified. This problem is frequently encountered in distribution logistics when items may be stacked on top of each other in a container. Examples of applications of the 3L-CVRP are found in the distribution of furniture, household appliances, soft drinks and staple goods (Ruan et al. 2013).

There are two sets of the 3L-CVRP benchmark data. The first set includes 27 instances and was introduced by Gendreau et al. (2006).The second set was proposed by Tarantilis et al. (2009); it contains 12 instances and has more variation in customer size and item dimensions. The first set was derived from classic CVRP data by introducing 3-D items for each customer. More precisely, the length L, width W, and height H of vehicles are set to 60, 25, and 30, respectively. The customer distribution and demand are the same as in the CVRP instance. However, for each customer, the item number is a random number within the [1, 3] interval, and the item dimensions are randomly generated in the interval between 20% and 60% of the corresponding vehicle edges. Each item is given a 20% probability of being fragile. The second set contains 50-125 customers located at (rcos (ϑ), rsin (ϑ)), and the depot location is (0,0); r and ϑ are randomly selected from [10, 100] and [0, 2π] respectively. The vehicle dimensions are set as L = 60, W = 30, and H = 30, respectively. There are three classes of items: Class 1 contains small items with dimensions equal to 20%-40% of the corresponding vehicle dimensions; Class 2 contains large items whose dimensions are within the interval [40%, 60%] of vehicle dimensions; and Class 3 contains diverse items by setting the factor interval as [10%, 70%]. Each item has a 20% probability of being fragile. The number of items required by each customer is randomly taken from the intervals [2, 4], [1, 2], and [1, 3] for classes 1, 2, and 3, respectively. The demand of each customer is randomly distributed in the interval [5, 35].

The charts and tables in this section are extracted from the following paper:

Wang Y., Zhou S., Chen H., Andrew Lim*, "Three-dimensional Capacitated Vehicle Routing Problem with Time-Dependent Travel Times", (Working paper), to be submitted to Transportation Research Part B: Methodological.

Table 9: Comparison between AMA-ENS and existing approaches in 3L-CVRP set1 instances. All constraints are imposed.

Id	Name	BKS	DMTS		VRLH1		HA		TS-ILA		ELS		AMA-ENS		
Id	Name	BKS[1]	Avg	time (s)	Avg	time (s)	Avg	time (s)	Avg	time (s)	Avg	time (s)	Avg	time (s)	Gap (%)[2]
1	E016-03m	302.02	302.23	85.10	302.02	72.30	303.21	98.85	302.02	53.50	302.02	3.20	302.02	3.15	0.00
2	E016-05m	334.96	334.96	3.50	334.96	0.90	334.96	4.55	334.96	6.30	334.96	0.18	334.96	0.17	0.00
3	E021-04m	381.37	409.44	450.10	401.44	182.00	398.05	93.86	381.37	116.20	385.53	365.61	381.37	355.83	0.00
4	E021-06m	437.19	439.98	51.20	437.54	16.10	440.68	46.75	437.19	14.00	437.19	20.26	437.19	19.95	0.00
5	E022-04g	436.79	447.36	287.80	451.03	182.60	452.56	63.98	436.79	149.30	443.17	151.91	436.79	149.93	0.00
6	E022-06m	498.32	499.99	130.60	498.38	23.60	498.56	130.60	498.32	31.60	501.06	3.44	498.32	3.35	0.00
7	E023-03g	768.94	773.31	421.00	772.49	133.10	790.23	317.02	768.94	84.90	771.07	19.54	768.94	19.06	0.00
8	E023-05s	805.77	807.59	548.20	821.35	139.10	820.67	98.90	805.77	120.40	813.13	325.20	805.77	317.97	0.00
9	E026-08m	630.13	630.13	95.50	645.81	24.30	635.50	353.07	631.68	13.70	630.13	6.26	630.13	6.11	0.00
10	E030-03g	824.69	839.75	601.50	827.29	175.10	836.21	410.90	828.99	258.60	824.69	473.48	824.69	463.50	0.00
11	E030-04s	776.19	790.47	434.40	815.62	136.40	825.75	197.76	780.61	278.90	776.19	220.54	**764.83**	214.96	**-1.46**
12	E031-09h	610.23	615.05	224.80	630.46	14.00	626.59	89.47	614.60	145.80	610.23	21.60	**602.09**	21.09	**-1.33**
13	E033-03n	2636.85	2732.85	654.60	2694.81	268.40	2739.80	319.78	2636.85	369.40	2656.72	494.99	**2600.00**	484.81	**-1.40**
14	E033-04g	1369.22	1460.34	2659.30	1413.59	311.60	1469.38	268.39	1398.77	588.10	1369.22	1079.37	**1338.71**	1055.49	**-2.23**
15	E033-05s	1338.35	1386.75	984.60	1355.50	311.50	1369.69	356.55	1352.76	615.90	1338.35	1295.01	**1312.97**	1265.43	**-1.90**
16	E036-11h	698.61	698.69	50.20	705.05	3.40	703.15	431.74	698.92	4.00	698.61	6.01	**683.21**	5.90	**-2.20**
17	E041-14h	866.40	869.96	177.20	917.96	2.50	872.05	374.84	866.40	9.50	866.40	17.30	**856.14**	16.86	**-1.18**
18	E045-04f	1223.64	1252.67	2258.60	1228.98	309.50	1250.86	325.74	1228.47	1634.10	1223.64	1104.38	**1212.02**	1083.64	**-0.95**
19	E051-05e	744.33	777.96	1407.20	753.87	416.50	780.37	1374.84	763.09	718.40	744.33	1494.95	**729.43**	1472.96	**-2.00**
20	E072-04f	570.82	600.82	7466.00	596.42	427.00	605.59	1336.97	590.99	2941.80	570.82	2441.63	**565.65**	2373.08	**-0.91**
21	E076-07s	1063.20	1140.11	2848.60	1107.00	443.40	1119.45	1247.86	1096.53	2301.40	1063.20	2510.78	**1052.77**	2441.71	**-0.98**
22	E076-08s	1140.54	1199.14	1890.00	1171.49	423.50	1167.28	1294.57	1155.81	1241.80	1140.54	2689.20	**1118.18**	2640.55	**-1.96**
23	E076-10e	1094.33	1176.07	2829.50	1135.46	425.80	1171.77	1105.74	1130.08	1924.90	1094.33	2887.94	**1087.41**	2826.04	**-0.63**
24	E076-14s	1101.67	1161.87	2391.60	1128.82	411.10	1136.27	2001.05	1122.80	2526.80	1101.67	2282.75	**1088.06**	2224.28	**-1.24**
25	E101-08e	1359.25	1442.62	3580.30	1428.80	453.00	1426.34	1458.80	1417.09	4536.20	1359.25	2846.14	**1347.16**	2769.55	**-0.89**
26	E101-10c	1545.67	1614.56	2968.70	1625.31	430.60	1585.46	3354.72	1605.11	3017.70	1545.67	2958.29	**1527.89**	2901.70	**-1.15**
27	E101-14s	1479.73	1571.38	2837.80	1550.85	435.00	1562.18	3140.18	1538.10	6025.70	1479.73	3065.46	**1453.82**	3018.86	**-1.75**
Avg.	-	927.38	962.08	1419.92	953.79	228.60	960.10	754.21	941.59	1101.07	928.96	1066.13	917.06	1042.81	-0.90

Bold type represents the new best solution values found.

[1] The best known solution in the literature.

[2] The percentage improvement (%) on the current BKS level. Lower numbers equate to better performance.

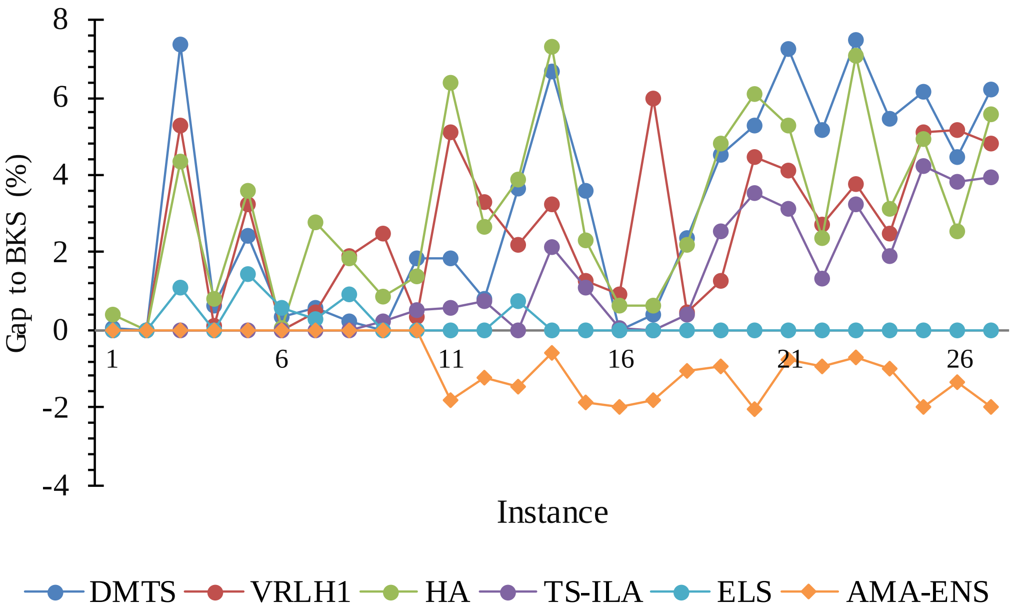

Figure 5: Gap to the BKS[1] for 3L-CVRP

The X-axis represents the the current BKS level in the literature. The Lower, the better

[a]Gap to BKS (%): Percentage improvement between the solutions and BKS, Gap=100*(solution-BKS)/BKS.

3 Results of AMA-ENS for the CVRP problem

CVRP is the cornerstone of VRP related research and has been widely used in the field of logistics. Since the CVRP benchmark data sets published earlier has many disadvantages, like becaming too easy for current algorithms, being too homogeneous, not covering the wide range of characteristics found in real applications, etc., we ran our algorithm on the newly published CVRP benchmark data set (Uchoa at al. 2017. EJOR), whose customer size ranges from 100 to 1000.

For comparison purposes, we consider recent state-of-the-art algorithms:

- Google OR: Google Operations Research (OR) Solver https://developers.google.com/optimization/
- HILS: Hybrid iterated local search (Subramanian at el. 2013)
- LKH-3: Lin-Kernighan-Helsgaun heuristic (Helsgaun at el. 2017)
- KGLS: Knowledge guided local search (Arnold et al. 2018)
- SISR: Slack induction by string removals (Christiaens at el. 2020. *Transportations Science*)
- FILO: Fast iterative localized optimization algorithm (Accorsi at al. 2021. *Transportations Science*)
- **AMA-ENS**: Adaptive memetic algorithm with extended neighborhood search (Wang at al. 2021.)

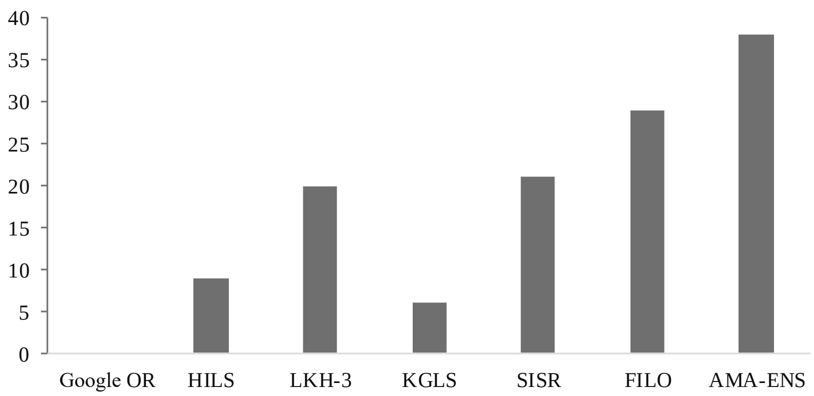

Figure 6: Number of Instances matching the BKS

AMA-ENS succeeds in matching 38 instances with its corresponding BKS value, and the number for SISR and FILO are 21 and 29, respectively. AMA-ENS performs better than SISR and FILO.

Table 10: Comparison of average solution quality for CVRP

Inst.	BKS	Google OR		LKH-3		HILS		KGLS		SISR		FILO		AMA-ENS	
		Avg Cost	Gap	Avg Cost	Gap	Avg Cost	Gap	Avg Cost	Gap	Avg Cost	Gap	Avg Cost	Gap	Avg Cost	Gap
X-n101-k25	27591	27977.2	1.40	27639.2	0.17	27591.0	0.00	27631.9	0.15	27593.3	0.01	27591.0	0.00	27591.0	0.00
X-n106-k14	26362	26757.5	1.50	26406.8	0.17	26391.1	0.11	26413.2	0.19	26380.9	0.07	26373.3	0.04	26380.9	0.07
X-n110-k13	14971	15099.8	0.86	14993.9	0.15	14971.0	0.00	14971.0	0.00	14972.1	0.01	14971.0	0.00	14971.0	0.00
X-n115-k10	12747	12808.3	0.48	12747.0	0.00	12747.0	0.00	12747.1	0.00	12747.0	0.00	12747.0	0.00	12747.0	0.00
X-n120-k6	13332	13501.9	1.27	13332.8	0.01	13333.7	0.01	13332.0	0.00	13332.0	0.00	13332.0	0.00	13332.0	0.00
X-n125-k30	55539	56853.4	2.37	55907.4	0.66	55846.5	0.55	55740.8	0.36	55559.8	0.04	55693.7	0.28	55539.0	0.00
X-n129-k18	28940	29722.3	2.70	29083.3	0.50	28972.1	0.11	28971.6	0.11	28948.9	0.03	28948.4	0.03	28948.9	0.03
X-n134-k13	10916	11171.0	2.34	10970.6	0.50	10947.5	0.29	10940.5	0.22	10937.7	0.20	10927.9	0.11	10937.7	0.20
X-n139-k10	13590	13741.2	1.11	13654.9	0.48	13591.2	0.01	13590.0	0.00	13590.4	0.00	13590.0	0.00	13590.0	0.00
X-n143-k7	15700	16135.6	2.77	15767.8	0.43	15735.7	0.23	15730.6	0.19	15727.8	0.18	15723.8	0.15	15700.0	0.00
X-n148-k46	43448	44598.5	2.65	43518.9	0.16	43448.0	0.00	43588.3	0.32	43464.1	0.04	43480.5	0.07	43448.0	0.00
X-n153-k22	21220	21789.3	2.68	21240.8	0.10	21452.3	1.09	21386.0	0.78	21228.6	0.04	21232.9	0.06	21225.0	0.02
X-n157-k13	16876	17137.7	1.55	16879.1	0.02	16876.0	0.00	16877.5	0.01	16878.2	0.01	16876.0	0.00	16876.0	0.00
X-n162-k11	14138	14262.2	0.88	14173.7	0.25	14152.4	0.10	14147.0	0.06	14159.0	0.15	14157.5	0.14	14138.0	0.00
X-n167-k10	20557	21176.4	3.01	20706.1	0.73	20603.7	0.23	20586.9	0.15	20558.6	0.01	20557.0	0.00	20557.0	0.00
X-n172-k51	45607	46874.9	2.78	45788.1	0.40	45665.3	0.13	45802.8	0.43	45622.6	0.03	45607.0	0.00	45607.0	0.00
X-n176-k26	47812	49260.2	3.03	48104.1	0.61	48218.5	0.85	47991.6	0.38	47823.7	0.02	47985.0	0.36	47823.7	0.02
X-n181-k23	25569	25935.6	1.43	25627.0	0.23	25572.1	0.01	25602.3	0.13	25575.1	0.02	25569.2	0.00	25575.1	0.02
X-n186-k15	24145	24908.0	3.16	24277.7	0.55	24170.7	0.11	24178.3	0.14	24166.2	0.09	24154.6	0.04	24166.2	0.09
X-n190-k8	16980	17421.9	2.60	17074.7	0.56	17108.0	0.75	17033.5	0.32	16982.8	0.02	16984.3	0.03	16983.3	0.02
X-n195-k51	44225	46151.1	4.36	44478.8	0.57	44305.0	0.18	44427.2	0.46	44292.0	0.15	44265.7	0.09	44225.0	0.00
X-n200-k36	58578	60447.9	3.19	58913.6	0.57	58784.0	0.35	58828.0	0.43	58635.6	0.10	58806.9	0.39	58578.0	0.00
X-n204-k19	19565	20348.4	4.00	19731.3	0.85	19617.6	0.27	19621.0	0.29	19653.2	0.45	19568.4	0.02	19565.0	0.00
X-n209-k16	30656	31775.5	3.65	30925.0	0.88	30739.0	0.27	30709.7	0.18	30661.7	0.02	30684.4	0.09	30656.0	0.00
X-n214-k11	10856	11374.0	4.77	11103.4	2.28	11077.2	2.04	10944.3	0.81	10894.4	0.35	10884.3	0.26	10860.5	0.04
X-n219-k73	117595	118038.0	0.38	117669.3	0.06	117595.0	0.00	117689.1	0.08	117623.7	0.02	117595.1	0.00	117596.1	0.00
X-n223-k34	40437	42046.6	3.98	40750.9	0.78	40549.8	0.28	40714.4	0.69	40535.5	0.24	40502.8	0.16	40437.0	0.00
X-n228-k23	25742	26613.4	3.39	25879.8	0.54	25803.7	0.24	25836.8	0.37	25814.3	0.28	25781.7	0.15	25742.8	0.00
X-n233-k16	19230	19883.9	3.40	19345.8	0.60	19296.0	0.34	19328.6	0.51	19285.7	0.29	19293.9	0.33	19230.0	0.00
X-n237-k14	27042	27927.5	3.27	27164.0	0.45	27068.8	0.10	27095.9	0.20	27081.1	0.14	27050.8	0.03	27081.1	0.14
X-n242-k48	82751	85518.0	3.34	83353.0	0.73	82867.9	0.14	83209.2	0.55	82885.6	0.16	82876.1	0.15	82885.6	0.16
X-n247-k50	37274	38282.8	2.71	37412.2	0.37	37502.3	0.61	37388.4	0.31	37379.6	0.28	37453.6	0.48	37379.6	0.28
X-n251-k28	38684	40087.6	3.63	38982.0	0.77	38859.4	0.45	38893.3	0.54	38765.2	0.21	38783.5	0.26	38765.2	0.21
X-n256-k16	18839	19294.5	2.42	19086.6	1.31	18880.8	0.22	18891.6	0.28	18887.3	0.26	18880.0	0.22	18887.3	0.26
X-n261-k13	26558	27920.6	5.13	27115.6	2.10	26808.2	0.94	26717.5	0.60	26595.8	0.14	26682.4	0.47	26558.2	0.00
X-n266-k58	75478	77660.8	2.89	76117.7	0.85	75611.4	0.18	75954.6	0.63	75609.2	0.17	75767.0	0.38	75564.7	0.11
X-n270-k35	35291	36700.5	3.99	35523.3	0.66	35352.9	0.18	35462.1	0.48	35364.4	0.21	35348.3	0.16	35303.0	0.03
X-n275-k28	21245	22087.3	3.96	21340.5	0.45	21262.4	0.08	21299.4	0.26	21250.5	0.03	21251.1	0.03	21245.0	0.00
X-n280-k17	33503	35055.6	4.63	33933.6	1.29	33803.4	0.90	33670.1	0.50	33648.6	0.43	33652.6	0.45	33543.2	0.12
X-n284-k15	20215	21137.9	4.57	20521.2	1.51	20415.9	0.99	20360.0	0.72	20287.6	0.36	20273.5	0.29	20245.5	0.15
X-n289-k60	95151	98560.9	3.58	96055.6	0.95	95515.0	0.38	95882.8	0.77	95345.8	0.20	95556.3	0.43	95300.9	0.16
X-n294-k50	47161	49301.8	4.54	47538.6	0.80	47262.0	0.21	47454.1	0.62	47251.9	0.19	47273.3	0.24	47184.1	0.05
X-n298-k31	34231	36970.5	8.00	34571.7	1.00	34383.7	0.45	34377.4	0.43	34267.8	0.11	34283.3	0.15	34267.8	0.11
X-n303-k21	21736	22573.7	3.85	22008.0	1.25	21900.7	0.76	21903.4	0.77	21772.9	0.17	21809.1	0.34	21772.9	0.17
X-n308-k13	25859	27141.4	4.96	26194.9	1.30	26058.6	0.77	26076.4	0.84	26281.0	1.63	25937.7	0.30	26281.0	1.63
X-n313-k71	94043	97497.4	3.67	94974.7	0.99	94290.3	0.26	94763.8	0.77	94155.7	0.12	94351.6	0.33	94112.2	0.07
X-n317-k53	78355	79211.0	1.09	78553.5	0.25	78355.0	0.00	78413.5	0.07	78386.1	0.04	78358.6	0.00	78355.4	0.00
X-n322-k28	29834	31488.5	5.55	30253.4	1.41	29996.5	0.54	30038.0	0.68	29892.5	0.20	29934.9	0.34	29848.7	0.05
X-n327-k20	27532	28777.6	4.52	27905.1	1.36	27815.8	1.03	27646.8	0.42	27644.7	0.41	27610.7	0.29	27540.8	0.03
X-n331-k15	31102	32648.2	4.97	31336.1	0.75	31227.4	0.40	31200.1	0.32	31124.5	0.07	31103.1	0.00	31103.0	0.00
X-n336-k84	139111	143294.8	3.01	140226.2	0.80	139560.0	0.32	140831.3	1.24	139429.8	0.23	139585.7	0.34	139273.5	0.12
X-n344-k43	42050	44036.4	4.72	42625.4	1.37	42307.5	0.61	42350.5	0.71	42122.7	0.17	42174.2	0.30	42075.6	0.06
X-n351-k40	25896	27433.6	5.94	26266.6	1.43	26134.7	0.92	26190.7	1.14	25976.5	0.31	25994.5	0.38	25943.6	0.18
X-n359-k29	51505	53858.4	4.57	52128.4	1.21	52089.2	1.13	51901.3	0.77	51549.8	0.09	51598.3	0.18	51549.8	0.09
X-n367-k17	22814	23874.0	4.65	23080.4	1.17	22985.5	0.75	22944.7	0.57	22836.1	0.10	22818.6	0.02	22836.1	0.10
X-n376-k94	147713	148775.7	0.72	147950.1	0.16	147713.4	0.00	147854.1	0.10	147763.5	0.03	147717.0	0.00	147763.5	0.03
X-n384-k52	65940	69022.0	4.67	66625.8	1.04	66407.8	0.71	66443.0	0.76	66113.6	0.26	66107.7	0.25	66113.6	0.26
X-n393-k38	38260	40785.6	6.60	38694.9	1.14	38515.7	0.67	38466.4	0.54	38384.5	0.33	38299.3	0.10	38384.5	0.33
X-n401-k29	66163	68249.2	3.15	66813.6	0.98	66729.5	0.86	66501.9	0.51	66239.5	0.12	66259.8	0.15	66239.5	0.12
X-n411-k19	19712	20810.6	5.57	20057.0	1.75	19970.8	1.31	19924.8	1.08	19776.7	0.33	19776.9	0.33	19720.3	0.04
X-n420-k130	107798	111594.0	3.52	108574.8	0.72	107838.0	0.04	108295.3	0.46	107853.4	0.05	107923.5	0.12	107839.8	0.04
X-n429-k61	65449	68858.4	5.21	66198.4	1.15	65786.8	0.52	65857.5	0.62	65539.3	0.14	65565.8	0.18	65502.7	0.08
X-n439-k37	36391	37655.3	3.47	36590.1	0.55	36448.5	0.16	36483.8	0.26	36457.7	0.18	36397.3	0.02	36395.5	0.01
X-n449-k29	55233	58427.1	5.78	56515.9	2.32	56272.8	1.88	55770.7	0.97	55388.8	0.28	55420.9	0.34	55368.5	0.25
X-n459-k26	24139	25834.9	7.03	24570.6	1.79	24479.3	1.41	24251.0	0.46	24228.3	0.37	24195.5	0.23	24163.8	0.10
X-n469-k138	221824	230963.3	4.12	223845.1	0.91	222189.0	0.16	223468.0	0.74	222253.9	0.19	222988.5	0.52	222170.1	0.16
X-n480-k70	89449	92923.0	3.88	90186.5	0.82	89857.0	0.46	89986.3	0.60	89515.1	0.07	89628.2	0.20	89524.4	0.08
X-n491-k59	66487	70817.2	6.51	67522.2	1.56	67238.7	1.13	67145.6	0.99	66606.9	0.18	66677.8	0.29	66641.5	0.23
X-n502-k39	69226	70166.5	1.36	69377.3	0.22	69380.4	0.22	69333.9	0.16	69271.4	0.07	69247.7	0.03	69239.5	0.02
X-n513-k21	24201	25845.9	6.80	24506.7	1.26	24406.9	0.85	24360.7	0.66	24293.9	0.38	24242.1	0.17	24201.0	0.00
X-n524-k153	154593	156897.0	1.49	154840.6	0.16	155176.6	0.38	155699.6	0.72	154894.6	0.20	154892.3	0.19	154747.6	0.10
X-n536-k96	94868	99575.6	4.96	96764.7	2.00	95713.0	0.89	95864.7	1.05	95145.9	0.29	95560.2	0.73	95091.9	0.24
X-n548-k50	86700	89382.6	3.09	87133.1	0.50	86976.2	0.32	86938.6	0.28	86789.1	0.10	86742.8	0.05	86778.4	0.09
X-n561-k42	42717	45758.6	7.12	43210.9	1.16	43095.7	0.89	43031.7	0.74	42875.0	0.37	42829.7	0.26	42742.7	0.06
X-n573-k30	50673	52436.5	3.48	51179.8	1.00	51203.9	1.05	50957.2	0.56	50842.6	0.33	50821.3	0.29	50813.0	0.28
X-n586-k159	190316	198347.2	4.22	191756.9	0.76	190835.6	0.27	191411.4	0.58	190640.1	0.17	190952.2	0.33	190588.1	0.14
X-n599-k92	108451	113380.7	4.55	110086.5	1.51	109460.7	0.93	109356.1	0.83	108684.8	0.22	108754.2	0.28	108656.0	0.19
X-n613-k62	59535	64073.6	7.62	60616.7	1.82	60457.8	1.55	60201.2	1.12	59705.6	0.29	59699.4	0.28	59696.3	0.27
X-n627-k43	62164	64897.9	4.40	63084.1	1.48	63052.4	1.43	62568.1	0.65	62291.8	0.21	62251.9	0.14	62371.6	0.33
X-n641-k35	63694	66862.3	4.97	64825.9	1.78	64709.8	1.59	64094.3	0.63	63851.8	0.25	63835.4	0.22	63874.2	0.28
X-n655-k131	106780	107815.9	0.97	107044.4	0.25	106785.7	0.01	106956.8	0.17	106841.6	0.06	106805.6	0.02	106808.8	0.03
X-n670-k130	146332	151874.1	3.79	147704.1	0.94	148272.8	1.33	147654.2	0.90	146961.5	0.43	147490.8	0.79	146777.7	0.30
X-n685-k75	68205	74085.5	8.62	69443.7	1.82	68988.4	1.15	68854.7	0.95	68379.6	0.26	68440.0	0.34	68343.1	0.20
X-n701-k44	81923	87060.3	6.27	83261.3	1.63	83159.4	1.51	82513.5	0.72	82053.9	0.16	82083.5	0.20	82237.3	0.38
X-n716-k35	43387	46012.9	6.05	44441.3	2.43	44264.0	2.02	43730.4	0.79	43492.0	0.24	43492.6	0.24	43505.8	0.27
X-n733-k159	136190	143829.1	5.61	137413.2	0.90	137014.7	0.61	137299.3	0.81	136445.2	0.19	136428.1	0.17	136426.9	0.17
X-n749-k98	77314	82813.4	7.11	78910.4	2.06	78323.3	1.31	78211.9	1.16	77534.9	0.29	77551.0	0.31	77655.4	0.44
X-n766-k71	114454	123106.2	7.56	116096.4	1.43	115858.3	1.23	115186.0	0.64	114836.0	0.33	114840.8	0.34	114764.5	0.27
X-n783-k48	72394	77518.9	7.08	73933.2	2.13	73765.3	1.89	73043.8	0.90	72637.3	0.34	72573.8	0.25	72790.7	0.55
X-n801-k40	73305	76428.2	4.26	74001.2	0.95	74141.6	1.14	73590.5	0.39	73412.0	0.15	73396.5	0.12	73500.4	0.27
X-n819-k171	158121	165074.0	4.40	160305.2	1.38	159363.2	0.79	159572.5	0.92	158424.5	0.19	158918.8	0.50	158511.6	0.25
X-n837-k142	193737	201836.8	4.18	195548.5	0.94	195053.8	0.68	195135.0	0.72	193946.6	0.11	194232.7	0.26	194231.3	0.26
X-n856-k95	88965	91613.9	2.98	89530.6	0.64	89266.2	0.34	89333.5	0.41	89111.1	0.16	89040.1	0.08	89037.5	0.08
X-n876-k59	99299	103576.1	4.31	100700.2	1.41	100487.3	1.20	100115.7	0.82	99484.5	0.19	99528.2	0.23	99682.7	0.39
X-n895-k37	53860	58191.7	8.04	56627.0	5.14	55023.1	2.16	54306.0	0.83	54072.3	0.39	54033.3	0.32	54070.6	0.39
X-n916-k207	329179	342127.2	3.93	331668.2	0.76	331158.4	0.60	331111.0	0.59	329584.3	0.12	330164.7	0.30	329852.0	0.20
X-n936-k151	132725	140479.3	5.84	134477.5	1.32	135052.1	1.75	133831.4	0.83	133497.1	0.58	133259.4	0.40	133369.9	0.49
X-n957-k87	85465	88603.0	3.67	86089.1	0.73	85979.8	0.60	85746.6	0.33	85559.8	0.11	85526.2	0.07	85550.1	0.10
X-n979-k58	118987	123885.2	4.12	121339.6	1.98	120569.7	1.33	119600.1	0.52	119108.2	0.10	119202.8	0.18	119247.5	0.22
X-n1001-k43	72359	78084.7	7.91	74151.1	2.48	74158.5	2.49	72998.9	0.88	72533.1	0.24	72518.9	0.22	72748.8	0.54
Avg	63108.61	65685.1	4.01	63751.7	1.00	63540.8	0.66	63493.4	0.53	63227.6	0.19	63266.1	0.20	63216.7	0.14

Table 11: Comparison of results of best solution quality for CVRP

Inst	BKS	Google OR		HILS		LKH-3		KGLS		SISR		FILO		AMA-ENS	
		Cost	Gap	Cost	Gap	Cost	Gap	Cost	Gap	Cost	Gap	Cost	Gap	Cost	Gap
X-n101-k25	27591	27865	0.99	27591	0.00	27591	0.00	27595	0.01	27591	0.00	27591	0.00	27591	0.00
X-n106-k14	26362	26747	1.46	26381	0.07	26381	0.07	26375	0.05	26368	0.02	26362	0.00	26364	0.01
X-n110-k13	14971	14986	0.10	14971	0.00	14971	0.00	14971	0.00	14971	0.00	14971	0.00	14971	0.00
X-n115-k10	12747	12768	0.16	12747	0.00	12747	0.00	12747	0.00	12747	0.00	12747	0.00	12747	0.00
X-n120-k6	13332	13458	0.95	13332	0.00	13332	0.00	13332	0.00	13332	0.00	13332	0.00	13332	0.00
X-n125-k30	55539	56601	1.91	55701	0.29	55713	0.31	55670	0.24	55539	0.00	55539	0.00	55539	0.00
X-n129-k18	28940	29668	2.52	28948	0.03	28954	0.05	28954	0.05	28940	0.00	28940	0.00	28940	0.00
X-n134-k13	10916	11096	1.65	10937	0.19	10929	0.12	10930	0.13	10918	0.02	10916	0.00	10916	0.00
X-n139-k10	13590	13693	0.76	13612	0.16	13590	0.00	13590	0.00	13590	0.00	13590	0.00	13590	0.00
X-n143-k7	15700	16019	2.03	15718	0.11	15723	0.15	15726	0.17	15700	0.00	15700	0.00	15700	0.00
X-n148-k46	43448	44334	2.04	43448	0.00	43448	0.00	43507	0.14	43448	0.00	43448	0.00	43448	0.00
X-n153-k22	21220	21605	1.81	21225	0.02	21225	0.02	21375	0.73	21225	0.02	21225	0.02	21225	0.02
X-n157-k13	16876	17086	1.24	16876	0.00	16876	0.00	16876	0.00	16876	0.00	16876	0.00	16876	0.00
X-n162-k11	14138	14238	0.71	14171	0.23	14138	0.00	14147	0.06	14138	0.00	14147	0.06	14138	0.00
X-n167-k10	20557	21158	2.92	20583	0.13	20557	0.00	20557	0.00	20557	0.00	20557	0.00	20557	0.00
X-n172-k51	45607	46695	2.39	45607	0.00	45607	0.00	45763	0.34	45607	0.00	45607	0.00	45607	0.00
X-n176-k26	47812	48986	2.46	47897	0.18	48140	0.69	47958	0.31	47812	0.00	47812	0.00	47812	0.00
X-n181-k23	25569	25787	0.85	25598	0.11	25569	0.00	25594	0.10	25569	0.00	25569	0.00	25569	0.00
X-n186-k15	24145	24908	3.16	24149	0.02	24147	0.01	24156	0.05	24151	0.02	24147	0.01	24151	0.02
X-n190-k8	16980	17380	2.36	16995	0.09	17029	0.29	17001	0.12	16980	0.00	16980	0.00	16980	0.00
X-n195-k51	44225	45757	3.46	44388	0.37	44225	0.00	44396	0.39	44241	0.04	44225	0.00	44241	0.04
X-n200-k36	58578	60338	3.00	58773	0.33	58617	0.07	58756	0.30	58587	0.02	58620	0.07	58578	0.00
X-n204-k19	19565	20212	3.31	19610	0.23	19565	0.00	19581	0.08	19565	0.00	19565	0.00	19565	0.00
X-n209-k16	30656	31740	3.54	30700	0.14	30702	0.15	30685	0.09	30656	0.00	30659	0.01	30656	0.00
X-n214-k11	10856	11228	3.43	11033	1.63	10917	0.56	10913	0.53	10874	0.17	10870	0.13	10856	0.00
X-n219-k73	117595	117924	0.28	117595	0.00	117595	0.00	117651	0.05	117596	0.00	117595	0.00	117595	0.00
X-n223-k34	40437	41794	3.36	40604	0.41	40490	0.13	40686	0.62	40504	0.17	40445	0.02	40437	0.00
X-n228-k23	25742	26396	2.54	25806	0.25	25745	0.01	25808	0.26	25782	0.16	25743	0.00	25742	0.00
X-n233-k16	19230	19682	2.35	19232	0.01	19276	0.24	19268	0.20	19232	0.01	19230	0.00	19232	0.01
X-n237-k14	27042	27809	2.84	27042	0.00	27042	0.00	27044	0.01	27043	0.00	27042	0.00	27043	0.00
X-n242-k48	82751	85518	3.34	83052	0.36	82809	0.07	83136	0.47	82805	0.07	82775	0.03	82805	0.07
X-n247-k50	37274	37853	1.55	37292	0.05	37300	0.07	37317	0.12	37274	0.00	37274	0.00	37274	0.00
X-n251-k28	38684	40007	3.42	38918	0.60	38798	0.29	38847	0.42	38687	0.01	38723	0.10	38687	0.01
X-n256-k16	18839	19067	1.21	18986	0.78	18880	0.22	18888	0.26	18880	0.22	18880	0.22	18839	0.00
X-n261-k13	26558	27760	4.53	26844	1.08	26692	0.50	26671	0.43	26558	0.00	26612	0.20	26558	0.00
X-n266-k58	75478	77275	2.38	75855	0.50	75478	0.00	75793	0.42	75549	0.09	75664	0.25	75478	0.00
X-n270-k35	35291	36401	3.15	35432	0.40	35324	0.09	35447	0.44	35325	0.10	35309	0.05	35303	0.03
X-n275-k28	21245	21918	3.17	21257	0.06	21245	0.00	21265	0.09	21245	0.00	21245	0.00	21245	0.00
X-n280-k17	33503	34859	4.05	33690	0.56	33725	0.66	33598	0.28	33545	0.13	33608	0.31	33506	0.01
X-n284-k15	20215	20872	3.25	20373	0.78	20325	0.54	20323	0.53	20261	0.23	20257	0.21	20231	0.08
X-n289-k60	95151	97868	2.86	95754	0.63	95401	0.26	95770	0.65	95245	0.10	95429	0.29	95242	0.10
X-n294-k50	47161	49010	3.92	47430	0.57	47240	0.17	47413	0.53	47199	0.08	47240	0.17	47167	0.01
X-n298-k31	34231	36296	6.03	34391	0.47	34318	0.25	34359	0.37	34234	0.01	34234	0.01	34231	0.00
X-n303-k21	21736	22376	2.94	21878	0.65	21806	0.32	21845	0.50	21753	0.08	21792	0.26	21739	0.01
X-n308-k13	25859	26934	4.16	25992	0.51	25989	0.50	25999	0.54	26224	1.41	25862	0.01	25862	0.01
X-n313-k71	94043	96958	3.10	94778	0.78	94216	0.18	94652	0.65	94098	0.06	94246	0.22	94045	0.00
X-n317-k53	78355	78863	0.65	78408	0.07	78355	0.00	78391	0.05	78361	0.01	78355	0.00	78355	0.00
X-n322-k28	29834	30932	3.68	30078	0.82	29923	0.30	30010	0.59	29861	0.09	29878	0.15	29834	0.00
X-n327-k20	27532	28592	3.85	27786	0.92	27767	0.85	27613	0.29	27611	0.29	27565	0.12	27532	0.00
X-n331-k15	31102	32493	4.47	31153	0.16	31136	0.11	31111	0.03	31122	0.06	31103	0.00	31102	0.00
X-n336-k84	139111	142905	2.73	139655	0.39	139351	0.17	140716	1.15	139272	0.12	139324	0.15	139205	0.07
X-n344-k43	42050	43560	3.59	42450	0.95	42190	0.33	42229	0.43	42081	0.07	42089	0.09	42061	0.03
X-n351-k40	25896	27093	4.62	26142	0.95	26050	0.59	26150	0.98	25965	0.27	25960	0.25	25924	0.11
X-n359-k29	51505	53541	3.95	51852	0.67	51820	0.61	51662	0.30	51514	0.02	51514	0.02	51566	0.12
X-n367-k17	22814	23597	3.43	22959	0.64	22956	0.62	22867	0.23	22821	0.03	22814	0.00	22814	0.00
X-n376-k94	147713	148630	0.62	147876	0.11	147713	0.00	147801	0.06	147736	0.02	147713	0.00	147713	0.00
X-n384-k52	65940	68550	3.96	66489	0.83	66351	0.62	66363	0.64	66046	0.16	66036	0.15	65997	0.09
X-n393-k38	38260	40303	5.34	38607	0.91	38360	0.26	38433	0.45	38338	0.20	38290	0.08	38260	0.00
X-n401-k29	66163	67913	2.64	66584	0.64	66597	0.66	66466	0.46	66222	0.09	66227	0.10	66209	0.07
X-n411-k19	19712	20571	4.36	19860	0.75	19834	0.62	19782	0.36	19757	0.23	19758	0.23	19716	0.02
X-n420-k130	107798	110857	2.84	108292	0.46	107801	0.00	108175	0.35	107809	0.01	107826	0.03	107810	0.01
X-n429-k61	65449	68113	4.07	65939	0.75	65689	0.37	65795	0.53	65494	0.07	65509	0.09	65494	0.07
X-n439-k37	36391	37171	2.14	36491	0.27	36402	0.03	36445	0.15	36402	0.03	36395	0.01	36402	0.03
X-n449-k29	55233	58066	5.13	56212	1.77	56154	1.67	55675	0.80	55296	0.11	55358	0.23	55296	0.11
X-n459-k26	24139	25435	5.37	24479	1.41	24363	0.93	24234	0.39	24187	0.20	24157	0.07	24187	0.20
X-n469-k138	221824	230460	3.89	223289	0.66	221939	0.05	223086	0.57	222090	0.12	222543	0.32	222090	0.12
X-n480-k70	89449	92457	3.36	90034	0.65	89629	0.20	89926	0.53	89458	0.01	89540	0.10	89458	0.01
X-n491-k59	66487	69944	5.20	67280	1.19	67098	0.92	67034	0.82	66502	0.02	66605	0.18	66502	0.02
X-n502-k39	69226	70032	1.16	69275	0.07	69340	0.16	69307	0.12	69238	0.02	69227	0.00	69238	0.02
X-n513-k21	24201	25295	4.52	24384	0.76	24316	0.48	24293	0.38	24237	0.15	24201	0.00	24201	0.00
X-n524-k153	154593	156322	1.12	154657	0.04	154656	0.04	155422	0.54	154758	0.11	154610	0.01	154646	0.03
X-n536-k96	94868	98815	4.16	96214	1.42	95663	0.84	95781	0.96	95071	0.21	95485	0.65	95040	0.18
X-n548-k50	86700	89066	2.73	87059	0.41	86813	0.13	86901	0.23	86710	0.01	86707	0.01	86710	0.01
X-n561-k42	42717	45330	6.12	43070	0.83	42918	0.47	42989	0.64	42799	0.19	42756	0.09	42726	0.02
X-n573-k30	50673	52080	2.78	51013	0.67	51102	0.85	50849	0.35	50777	0.21	50757	0.17	50757	0.17
X-n586-k159	190316	197853	3.96	191412	0.58	190695	0.20	191260	0.50	190454	0.07	190865	0.29	190470	0.08
X-n599-k92	108451	112831	4.04	109646	1.10	109119	0.62	109125	0.62	108598	0.14	108654	0.19	108605	0.14
X-n613-k62	59535	63561	6.76	60217	1.15	60333	1.34	60111	0.97	59609	0.12	59584	0.08	59636	0.17
X-n627-k43	62164	64590	3.90	62755	0.95	62928	1.23	62486	0.52	62221	0.09	62228	0.10	62238	0.12
X-n641-k35	63694	66652	4.64	64638	1.48	64591	1.41	63952	0.41	63802	0.17	63769	0.12	63782	0.14
X-n655-k131	106780	107710	0.87	106970	0.18	106780	0.00	106936	0.15	106808	0.03	106780	0.00	106785	0.00
X-n670-k130	146332	151071	3.24	147139	0.55	147974	1.12	147477	0.78	146676	0.24	147247	0.63	146640	0.21
X-n685-k75	68205	73090	7.16	69234	1.51	68843	0.94	68628	0.62	68271	0.10	68355	0.22	68288	0.12
X-n701-k44	81923	86604	5.71	82863	1.15	82982	1.29	82447	0.64	82007	0.10	82006	0.10	82075	0.19
X-n716-k35	43387	45704	5.34	44074	1.58	44058	1.55	43627	0.55	43449	0.14	43461	0.17	43459	0.17
X-n733-k159	136190	142650	4.74	137172	0.72	136848	0.48	137185	0.73	136344	0.11	136317	0.09	136323	0.10
X-n749-k98	77314	82083	6.17	78612	1.68	78213	1.16	78109	1.03	77399	0.11	77467	0.20	77563	0.32
X-n766-k71	114454	121645	6.28	115732	1.12	115396	0.82	115011	0.49	114751	0.26	114703	0.22	114679	0.20
X-n783-k48	72394	76764	6.04	73718	1.83	73512	1.54	72974	0.80	72544	0.21	72486	0.13	72665	0.37
X-n801-k40	73305	76262	4.03	73849	0.74	73970	0.91	73500	0.27	73362	0.08	73322	0.02	73396	0.12
X-n819-k171	158121	164377	3.96	159697	1.00	159261	0.72	159396	0.81	158344	0.14	158661	0.34	158391	0.17
X-n837-k142	193737	201518	4.02	195308	0.81	194857	0.58	194988	0.65	193868	0.07	194142	0.21	194103	0.19
X-n856-k95	88965	91109	2.41	89327	0.41	89082	0.13	89218	0.28	89042	0.09	88996	0.03	88986	0.02
X-n876-k59	99299	103017	3.74	100539	1.25	100418	1.13	100048	0.75	99405	0.11	99421	0.12	99526	0.23
X-n895-k37	53860	57607	6.96	56334	4.59	54856	1.85	54240	0.71	53982	0.23	53966	0.20	54029	0.31
X-n916-k207	329179	340947	3.57	331018	0.56	330920	0.53	331006	0.56	329418	0.07	329882	0.21	329572	0.12
X-n936-k151	132725	139456	5.07	133944	0.92	134732	1.51	133713	0.74	133190	0.35	132999	0.21	133129	0.30
X-n957-k87	85465	88222	3.23	85893	0.50	85864	0.47	85656	0.22	85493	0.03	85493	0.03	85506	0.05
X-n979-k58	118987	123379	3.69	120791	1.52	120142	0.97	119559	0.48	119065	0.07	119145	0.13	119120	0.11
X-n1001-k43	72359	77117	6.58	73994	2.26	73749	1.92	72882	0.72	72414	0.08	72443	0.12	72528	0.23
Max Gap	-	-	7.162232	-	4.59339	-	1.920977	-	1.153755	-	1.411501	-	0.650377	-	0.37434
Min Gap	-	-	0.100194	-	0	-	0	-	0	-	0	-	0	-	0
Average Gap	-	-	3.322353	-	0.641092	-	0.443209	-	0.40076	-	0.095248	-	0.101099	-	0.061363
NB BKS found	-	0	-	9	-	20	-	6	-	21	-	29	-	38	-

The gray cell indicates that the current solution matches the known best solution (BKS).

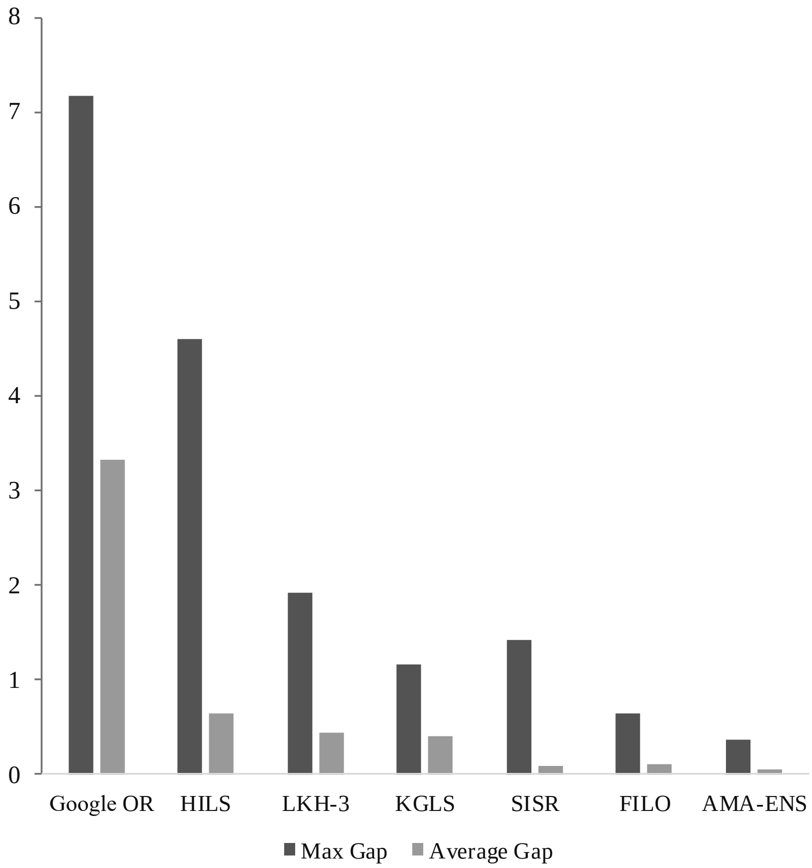

Figure 7: Average Gap[1] and Max Gap[2] for CVRP

[a]Average Gap(%): average gap between the solution and BKS for all the instances. The smaller, the better.

[b]Max Gap(%): the maximal gap between the solution and BKS among all the instances. The smaller, the better.

The average gap and max gap of AMA-ENS are the smallest among the compared algorithms, indicating that AMA-ENS performs the best.