Online Supplement

Appendix A. Instance Generation

Following the general practice, we generate 14 new large-sized instances by adapting the existing capacitated vehicle routing problem (CVRP) instances. For a given CVRP instance with n vertices, the number of clusters is calculated as $l = \lceil (n+1)/\theta \rceil$ and $\theta = 5$. The clustering method chooses l seed vertices by selecting vertices that are as far from each other as possible. The assignment of each non-seed vertex to a cluster is performed using the clustering procedure. For each cluster, its demand is calculated by $q_k = \sum_{i \in V_k} \omega_i$, where ω_i denotes the vertex demand in the original CVRP instances and $V_k \subseteq V$ is the set of vertices in the k-th cluster. In cases where q_k exceeds the total available capacity of the vehicle fleet, excess demand is "cut off". The original vehicle count is not used because it often results in a number that is too high relative to the number of clusters. Instead, for each instance the number of vehicles is computed as $m = \sum_{k=1}^{l} q_k * 1.5/Q$, where Q is the vehicle capacity provided in the original CVRP instances.

Appendix B. Parameter Sensitivity Analysis

In this work, we propose an effective bi-population collaborative memetic search (BCMS) approach for both soft-clustered and hard-clustered vehicle routing problems. The weight coefficient α and the similarity coefficient β are two main parameters of BCMS, which greatly affect the convergence speed and the solution quality. To study the effect of each parameter value, we compare the performance of BCMS algorithms under different parameter values. For each parameter, we consider its "Tested Values" while fixing other parameters to their "Best Value". Our sensitivity analysis experiments are conducted on 12 most challenging Li instances in the literature. For each instance, we run it ten times within the given time limit. Detailed comparative results of BCMS algorithms with different α and β values are summarized in Tables B.1 and B.2.

Appendix B.1. Sensitivity of BCMS to α

To study the effect of α on the performance of BCMS, we consider $\alpha \in \{0.1, 0.3, 0.5, 0.7, 0.9\}$ and fix β to 0.7 and η to 10. For each parameter setting, we run BCMS on each instance 10 times, and then record the best solution value ($\hat{f}$) found across the 10 runs, the average solution value ($\bar{f}$), and the average computation time ($\bar{t}$) in seconds required to obtain the best result.

Table B.1: Comparisons of BCMS Algorithms with Different α Values

	$\alpha = 0.1$			$\alpha = 0.3$			$\alpha = 0.5$			$\alpha = 0.7$			$\alpha = 0.9$		
Instance	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$
560.vrp-C113-R5	**27188**	27192.40	254.52	**27188**	27191.80	373.59	**27188**	**27189.70**	231.54	27237	27259.70	479.30	27235	27277.70	390.55
600.vrp-C121-R5	28680	28682.60	376.54	28676	28685.50	511.78	**28669**	**28680.30**	361.01	28743	28761.30	433.57	28719	28741.60	376.11
640.vrp-C129-R5	**19785**	19817.50	223.29	**19785**	19811.50	296.36	**19785**	**19804.00**	251.08	20082	20191.10	502.30	20074	20202.30	431.18
720.vrp-C145-R5	22872	22942.40	395.29	22871	22925.80	409.83	**22868**	**22908.30**	444.22	23425	23529.50	369.86	23450	23525.40	206.63
760.vrp-C153-R5	35026	35045.70	482.71	35028	35047.80	447.59	**34995**	**35039.00**	278.17	35160	35216.00	385.89	35145	35178.90	477.40
800.vrp-C161-R5	25430	25521.00	388.20	**25412**	25448.00	303.48	**25412**	**25430.70**	322.37	25943	26345.50	407.40	26073	26350.60	502.76
840.vrp-C169-R5	37736	37756.00	1455.41	37699	37744.30	977.47	**37699**	**37718.70**	1217.77	37808	37817.60	1356.01	37819	37847.90	1079.99
880.vrp-C177-R5	28246	28375.30	489.55	28345	28463.60	557.58	**28228**	**28290.30**	1192.52	28914	29413.80	876.65	28904	29507.10	799.38
960.vrp-C193-R5	**30593**	**30638.00**	890.62	**30593**	30734.00	762.45	**30593**	30689.70	1583.57	31515	31609.10	1395.80	31504	31704.30	1225.25
1040.vrp-C209-R5	**33503**	33739.80	722.74	**33503**	**33526.70**	949.40	**33503**	33532.00	1100.67	34532	35193.70	978.67	35097	35352.30	1599.38
1120.vrp-C225-R5	**36214**	36406.00	1018.95	36302	36533.10	640.44	**36214**	**36320.50**	1062.82	37607	38145.10	1641.45	38093	38307.90	1333.69
1200.vrp-C241-R5	38793	39318.20	1149.86	**38778**	38895.90	810.39	**38778**	**38865.20**	1319.26	40902	41205.70	1257.42	40292	41155.10	1475.54
avg.value	30338.83	30452.91	653.97	30348.33	30417.33	586.70	**30327.67**	**30372.37**	780.42	30989.00	31224.01	840.36	31033.75	31262.59	824.82
avg.rank	2.38	2.50	–	2.13	2.33	–	**1.50**	**1.17**	–	4.58	4.33	–	4.42	4.67	–

Table B.2 summarizes the results of BCMS for different α values, i.e., $\alpha \in \{0.1, 0.3, 0.5, 0.7, 0.9\}$. In the last rows, we give the average value and the average rank of each performance indicator. One can clearly observe that BCMS with $\alpha = 0.5$ achieves excellent performance. In particular, it achieves the smallest average values of both $\hat{f}$ and $\bar{f}$. Similar observations can also be found in terms of the average rank of both $\hat{f}$ and $\bar{f}$. Hence, the best performance with BCMS is achieved when $\alpha = 0.5$.

Appendix B.2. Sensitivity of BCMS to β

The similarity coefficient β is another important parameter of BCMS. To investigate its performance impact, we fix α to 0.5, and consider $\beta \in \{0.5, 0.6, 0.7, 0.8, 0.9\}$. Table B.2 presents the detailed comparative results of BCMS with different β values. The last rows provide the average value and the average rank for each performance indicator.

Table B.2: Comparisons of BCMS Algorithms with Different β Values

	$\beta = 0.5$			$\beta = 0.6$			$\beta = 0.7$			$\beta = 0.8$			$\beta = 0.9$		
Instance	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$	$\hat{f}$	$\bar{f}$	$\bar{t}$
560.vrp-C113-R5	**27188**	27191.90	415.59	**27188**	27191.80	190.09	**27188**	**27189.70**	231.54	**27188**	27191.10	411.27	27192	27192.70	424.76
600.vrp-C121-R5	28681	28686.10	446.89	28680	28684.80	377.63	**28669**	**28680.30**	361.01	28679	28685.20	486.97	28679	28683.80	354.97
640.vrp-C129-R5	**19785**	19799.70	367.09	**19785**	19809.50	380.88	**19785**	19804.00	251.08	19810	19831.00	286.43	**19785**	**19799.20**	466.96
720.vrp-C145-R5	22872	22911.90	450.23	22874	22907.10	466.18	**22868**	22908.30	444.22	22878	**22900.60**	466.14	22874	22935.20	273.62
760.vrp-C153-R5	35018	35042.70	562.08	35034	35054.60	493.17	**34995**	35039.00	278.17	35030	35062.70	391.11	**34995**	**35023.60**	458.96
800.vrp-C161-R5	25426	25452.60	405.93	25430	25448.90	442.00	**25412**	25430.70	322.37	**25412**	25428.40	430.21	**25412**	**25423.10**	350.04
840.vrp-C169-R5	37737	37755.20	1757.54	37723	37756.20	1027.95	**37699**	**37718.70**	1217.77	**37699**	37766.60	963.96	37705	37751.50	959.74
880.vrp-C177-R5	**28228**	28310.10	796.68	28246	28315.30	1200.28	**28228**	**28290.30**	1192.52	28246	28292.10	985.95	**28228**	28346.70	1090.87
960.vrp-C193-R5	**30593**	30656.80	632.92	**30593**	30740.80	529.57	**30593**	30689.70	1583.57	**30593**	30678.30	672.59	**30593**	**30643.80**	678.78
1040.vrp-C209-R5	**33503**	33642.60	993.38	**33503**	33613.80	803.81	**33503**	**33532.00**	1100.67	**33503**	33687.40	950.36	33529	33578.50	943.04
1120.vrp-C225-R5	**36214**	36247.20	820.11	**36214**	**36244.40**	1098.11	36214	36320.50	1062.82	**36214**	36304.50	863.34	**36214**	36261.50	722.02
1200.vrp-C241-R5	**38778**	38872.30	1017.97	**38778**	38928.00	822.45	**38778**	38865.20	1319.26	38794	39050.40	1280.65	**38778**	**38849.30**	839.01
avg.value	30335.25	30380.76	722.20	30337.33	30391.27	652.68	**30327.67**	**30372.37**	780.42	30337.17	30406.53	682.41	30332.00	30374.08	630.23
avg.rank	3.08	3.17	–	3.50	3.33	–	**2.08**	2.58	–	3.38	3.42	–	2.96	**2.50**	–

From Table B.2, it is evident that BCMS achieves the best performance in terms of both $\hat{f}$ and $\bar{f}$ when $\beta = 0.7$. It also achieves the smallest average rank value of $\hat{f}$. It finds the second-smallest average rank value of $\bar{f}$, which is only slightly worse than BCMS with $\beta = 0.9$. Therefore, we set the parameter value of β to 0.7.