Detailed performance evaluation of EHSA-MTRPP over 470 benchmark instances

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Abstract

The multiple traveling repairman problem with profits consists of multiple repairmen serving a subset of all customers to maximize the revenues collected through the visited customers. To address this problem, an effective hybrid search algorithm based on the memetic framework is proposed. In the proposed method, two features are integrated: a dedicated arc-based crossover to generate high-quality offspring solutions and a fast evaluation technique to reduce the complexity of navigating classical neighborhoods. The performance of the algorithm on 470 benchmark instances were compared with those of the leading reference algorithms. The results show that the proposed algorithm outperforms the state-of-the-art algorithms by setting new records for 137 instances and matching the best-known results for 330 instances. The importance of the key search components of the algorithm was investigated.

Key words: Combinatorial optimization; Multiple traveling repairman problem with profits; Arc-based crossover; Variable neighborhood search; Heuristics.

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1 Detailed performance evaluation over the 470 benchmark instances between EHSA-MTRPP and the reference algorithms.

This appendix presents the detailed results of the proposed MA-MTRPP algorithm compared to the reference algorithms (ALNS-MTRPP (Avci & Avci, 2019) and MA-MTRPP (Lu et al., 2019)) over the 470 benchmark instances. Table 1 summarizes detailed comparison between ALNS-MTRPP and EHSA-MTRPP for the 230 Ins_Avci instances. The first three columns 'Instance' [1], 'UB' and 'Bestsofar' describe respectively the name for each instance, the upper bound and the best found result reported in Avci & Avci (2019). Then columns 'Best', 'Average' and 'Tavg' present the best found result, the average found result and the average running time to obtain the best found result of ALNS-MTRPP for each instance. The following three columns list the same information for our EHSA-MTRPP algorithm. The last column 'imp' gives the improvement of EHSA-MTRPP over ALNS-MTRPP in terms of the best found solution. (Better results are indicated in bold.) Using similar column headings to Table 1 (excluding column 'Bestsofar'), Table 2 gives the detailed comparison between MA-MTRPP and EHSA-MTRPP for each of the 240 Ins_Lu instances. (Better results are also marked in bold.)

Table 1: Detailed results obtained by the reference algorithm ALNS-MTRPP (Avci & Avci, 2019) and our algorithm EHSA-MTRPP over the 230 Ins_Avci instances, where each instance was solved 5 times according to Avci & Avci (2019). The optimal solutions of the instances for $Size = 10$ are known but their timing information for ALNS-MTRPP is not available. Improved results are indicated in bold.

Instance	UB	Bestsofar	ALNS-MTRPP			EHSA-MTRPP			imp
			Best	Average	Tavg	Best	Average	Tavg	
10_1_2	2975	2975	2975	2975.00	*	2975	2975.00	0.03	0
10_2_2	2319	2319	2319	2319.00	*	2319	2319.00	0.02	0
10_3_2	1997	1997	1997	1997.00	*	1997	1997.00	0.03	0
10_4_2	2688	2688	2688	2688.00	*	2688	2688.00	0.02	0
10_5_2	2644	2644	2644	2644.00	*	2644	2644.00	0.03	0
10_6_2	2207	2207	2207	2207.00	*	2207	2207.00	0.02	0
10_7_2	1483	1483	1483	1483.00	*	1483	1483.00	0.03	0
10_8_2	2060	2060	2060	2060.00	*	2060	2060.00	0.02	0
10_9_2	1800	1800	1800	1800.00	*	1800	1800.00	0.03	0
10_10_2	1318	1318	1318	1318.00	*	1318	1318.00	0.02	0
10_11_2	1616	1616	1616	1616.00	*	1616	1616.00	0.02	0
10_12_2	2100	2100	2100	2100.00	*	2100	2100.00	0.03	0
10_13_2	2054	2054	2054	2054.00	*	2054	2054.00	0.03	0
10_14_2	2517	2517	2517	2517.00	*	2517	2517.00	0.03	0
10_15_2	2023	2023	2023	2023.00	*	2023	2023.00	0.03	0
10_16_2	1984	1984	1984	1984.00	*	1984	1984.00	0.03	0
10_17_2	2383	2383	2383	2383.00	*	2383	2383.00	0.03	0
10_18_2	1972	1972	1972	1972.00	*	1972	1972.00	0.03	0
10_19_2	2264	2264	2264	2264.00	*	2264	2264.00	0.02	0
10_20_2	1893	1893	1893	1893.00	*	1893	1893.00	0.03	0
10_1_3	3069	3069	3069	3069.00	*	3069	3069.00	0.03	0
10_2_3	2458	2458	2458	2458.00	*	2458	2458.00	0.03	0

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[1] The name 'Size_index_k' for each instance indicates respectively the number of customers, the instance index and the number of servers.

Table 1 – Continued from previous page

Instance	UB	Bestsofar	ALNS-MTRPP			EHSA-MTRPP			imp
			Best	Average	Tavg	Best	Average	Tavg	
10_3_3	2151	2151	2151	2151.00	*	2151	2151.00	0.03	0
10_4_3	2818	2818	2818	2818.00	*	2818	2818.00	0.03	0
10_5_3	2728	2728	2728	2728.00	*	2728	2728.00	0.03	0
10_6_3	2324	2324	2324	2324.00	*	2324	2324.00	0.03	0
10_7_3	1543	1543	1543	1543.00	*	1543	1543.00	0.03	0
10_8_3	2206	2206	2206	2206.00	*	2206	2206.00	0.03	0
10_9_3	1950	1950	1950	1950.00	*	1950	1950.00	0.03	0
10_10_3	1508	1508	1508	1508.00	*	1508	1508.00	0.03	0
10_11_3	1692	1692	1692	1692.00	*	1692	1692.00	0.02	0
10_12_3	2208	2208	2208	2208.00	*	2208	2208.00	0.03	0
10_13_3	2225	2225	2225	2225.00	*	2225	2225.00	0.03	0
10_14_3	2642	2642	2642	2642.00	*	2642	2642.00	0.03	0
10_15_3	2059	2059	2059	2059.00	*	2059	2059.00	0.03	0
10_16_3	2136	2136	2136	2136.00	*	2136	2136.00	0.03	0
10_17_3	2468	2468	2468	2468.00	*	2468	2468.00	0.03	0
10_18_3	2075	2075	2075	2075.00	*	2075	2075.00	0.03	0
10_19_3	2397	2397	2397	2397.00	*	2397	2397.00	0.03	0
10_20_3	1955	1955	1955	1955.00	*	1955	1955.00	0.03	0
20_1_2	10619	9793	9793	9793.00	4.0	9793	9793.00	0.05	0
20_2_2	11953	11619	11619	11619.00	4.0	11619	11619.00	0.06	0
20_3_2	9594	9140	9140	9140.00	3.0	9140	9140.00	0.06	0
20_4_2	9695	8869	8869	8869.00	3.0	8869	8869.00	0.06	0
20_5_2	9891	9110	9110	9110.00	3.0	9110	9110.00	0.06	0
20_6_2	9141	8587	8587	8587.00	3.0	8587	8587.00	0.05	0
20_7_2	11077	10661	10661	10661.00	3.0	10661	10661.00	0.06	0
20_8_2	10041	9389	9389	9389.00	3.0	9389	9389.00	0.07	0
20_9_2	8476	7785	7785	7785.00	3.0	7785	7785.00	0.06	0
20_10_2	10480	9861	9861	9861.00	3.0	9861	9861.00	0.05	0
20_11_2	8908	8385	8385	8385.00	3.0	8385	8385.00	0.06	0
20_12_2	8558	7737	7737	7737.00	3.0	7737	7737.00	0.07	0
20_13_2	8809	8235	8235	8235.00	3.0	8235	8235.00	0.06	0
20_14_2	8598	8197	8197	8197.00	2.0	8197	8197.00	0.06	0
20_15_2	7954	7102	7102	7102.00	3.0	7102	7102.00	0.06	0
20_16_2	9646	9110	9110	9110.00	4.0	9110	9110.00	0.05	0
20_17_2	11798	11439	11439	11439.00	4.0	11439	11439.00	0.08	0
20_18_2	9371	8864	8864	8864.00	3.0	8864	8864.00	0.06	0
20_19_2	9841	9125	9125	9125.00	3.0	9125	9125.00	0.05	0
20_20_2	9167	8484	8484	8484.00	3.0	8484	8484.00	0.06	0
20_1_3	10917	10197	10197	10197.00	3.0	10197	10197.00	0.06	0
20_2_3	12307	11930	11930	11930.00	3.0	11930	11930.00	0.06	0
20_3_3	10001	9512	9512	9512.00	3.0	9512	9512.00	0.06	0
20_4_3	9940	9221	9221	9221.00	4.0	9221	9221.00	0.06	0
20_5_3	10132	9530	9530	9530.00	3.0	9530	9530.00	0.06	0
20_6_3	9442	8980	8980	8980.00	3.0	8980	8980.00	0.06	0
20_7_3	11418	11103	11103	11103.00	3.0	11103	11103.00	0.07	0
20_8_3	10432	9891	9891	9891.00	3.0	9891	9891.00	0.06	0
20_9_3	8734	8140	8140	8140.00	3.0	8140	8140.00	0.06	0
20_10_3	10857	10218	10218	10218.00	3.0	10218	10218.00	0.06	0
20_11_3	9207	8735	8735	8735.00	4.0	8735	8735.00	0.06	0
20_12_3	8861	8125	8125	8125.00	3.0	8125	8125.00	0.07	0
20_13_3	9118	8615	8615	8615.00	3.0	8615	8615.00	0.06	0
20_14_3	8980	8594	8594	8594.00	3.0	8594	8594.00	0.06	0
20_15_3	8182	7394	7394	7394.00	4.0	7394	7394.00	0.06	0
20_16_3	9973	9491	9491	9491.00	3.0	9491	9491.00	0.06	0
20_17_3	12166	11860	11860	11860.00	3.0	11860	11860.00	0.06	0
20_18_3	9658	9271	9271	9271.00	3.0	9271	9271.00	0.06	0
20_19_3	10135	9428	9428	9428.00	3.0	9428	9428.00	0.06	0
20_20_3	9437	8774	8774	8774.00	2.0	8774	8774.00	0.06	0
50_1_2	57860	56113	56113	56113.00	39.0	56113	56113.00	0.47	0
50_2_2	58966	57322	57322	57322.00	34.0	57322	57322.00	0.38	0
50_3_2	58782	57158	57158	57158.00	40.0	57158	57158.00	0.88	0
50_4_2	53119	51258	51258	51258.00	37.0	51258	51258.00	1.07	0
50_5_2	52476	50503	50503	50503.00	33.0	50503	50503.00	0.62	0
50_6_2	63105	60847	60847	60847.00	41.0	60847	60847.00	2.03	0
50_7_2	51207	49219	49219	49219.00	35.0	49219	49219.00	0.36	0
50_8_2	63233	61552	61552	61552.00	31.0	61552	61552.00	0.65	0
50_9_2	52277	49863	49863	49863.00	33.0	49863	49863.00	1.15	0
50_10_2	54481	52252	52252	52252.00	42.0	52252	52252.00	0.95	0
50_11_2	59171	56665	56665	56653.00	33.0	56665	56665.00	0.72	0
50_12_2	59866	57864	57864	57864.00	30.0	57864	57864.00	0.34	0

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Table 1 – Continued from previous page

Instance	UB	Bestsofar	ALNS-MTRPP			EHSA-MTRPP			imp
			Best	Average	Tavg	Best	Average	Tavg	
50_13_2	53863	51880	51880	51880.00	29.0	51880	51880.00	0.59	0
50_14_2	60574	58742	58742	58742.00	42.0	58742	58742.00	1.38	0
50_15_2	66959	64310	64310	64310.00	26.0	64310	64310.00	0.42	0
50_16_2	57024	54516	54516	54516.00	35.0	54516	54516.00	1.20	0
50_17_2	49697	47459	47459	47459.00	36.0	47459	47459.00	0.42	0
50_18_2	47759	45477	45477	45477.00	35.0	45477	45477.00	1.17	0
50_19_2	63094	60607	60607	60607.00	41.0	60607	60607.00	0.56	0
50_20_2	68242	65776	65776	65776.00	38.0	65776	65776.00	1.04	0
50_1_3	59195	57877	57877	57877.00	31.0	57877	57877.00	0.38	0
50_2_3	60011	58688	58688	58688.00	28.0	58688	58688.00	0.37	0
50_3_3	60134	58930	58930	58930.00	32.0	58930	58930.00	2.72	0
50_4_3	54607	53220	53220	53220.00	31.0	53220	53220.00	0.87	0
50_5_3	53820	52079	52079	52071.00	34.0	52079	52079.00	0.73	0
50_6_3	64397	62879	62879	62879.00	33.0	62879	62879.00	1.22	0
50_7_3	52129	50655	50655	50655.00	27.0	50655	50655.00	1.06	0
50_8_3	64649	63184	63184	63184.00	29.0	63184	63184.00	0.39	0
50_9_3	53613	51743	51743	51743.00	31.0	51743	51743.00	0.64	0
50_10_3	55763	54012	54012	54012.00	32.0	54012	54012.00	0.74	0
50_11_3	60307	58447	58447	58447.00	25.00	**58457**	58457.00	1.01	**10**
50_12_3	60907	59193	59193	59193.00	32.0	59193	59193.00	1.09	0
50_13_3	55077	53658	53658	53658.00	30.0	53658	53658.00	0.43	0
50_14_3	62020	60870	60870	60870.00	28.0	60870	60870.00	0.38	0
50_15_3	68241	65899	65899	65899.00	38.0	65899	65899.00	0.41	0
50_16_3	58103	56288	56288	56288.00	28.0	56288	56288.00	0.80	0
50_17_3	50992	49180	49180	49180.00	27.0	49180	49180.00	0.52	0
50_18_3	48998	47349	47349	47349.00	31.0	47349	47349.00	0.37	0
50_19_3	64203	62162	62162	62162.00	37.0	62162	62162.00	0.95	0
50_20_3	69269	67384	67384	67384.00	33.0	67384	67384.00	0.48	0
100_1_2	229981	225406	225406	225399.00	517.0	225406	225406.00	35.34	0
100_2_2	217789	211472	211469	211469.00	304.0	211472	211468.00	30.98	0
100_3_2	232219	227079	227076	227076.00	384.0	227079	227079.00	23.64	0
100_4_2	239016	232774	232774	232740.00	372.0	232774	232774.00	25.75	0
100_5_2	235762	230168	230168	230168.00	320.0	230168	230168.00	18.82	0
100_6_2	250035	244980	244980	244975.00	367.0	244980	244980.00	21.14	0
100_7_2	221367	215606	215606	215601.00	378.0	215606	215600.40	28.92	0
100_8_2	225137	219545	219545	219545.00	359.0	219545	219545.00	12.89	0
100_9_2	246039	240882	240882	240882.00	250.0	240882	240882.00	8.73	0
100_10_2	237973	232974	232974	232974.00	319.0	232974	232974.00	12.14	0
100_11_2	234360	228708	228708	228708.00	364.0	228708	228708.00	22.30	0
100_12_2	241798	236177	236163	236158.00	271.0	236177	236177.00	58.24	0
100_13_2	226918	220525	220525	220525.00	319.0	220525	220525.00	53.72	0
100_14_2	234877	230132	230132	230132.00	327.0	230132	230132.00	7.55	0
100_15_2	233848	229139	229139	229139.00	358.0	229139	229139.00	16.35	0
100_16_2	235605	229617	229617	229617.00	358.0	229617	229617.00	15.75	0
100_17_2	243819	238811	238811	238790.00	369.0	238811	238811.00	20.86	0
100_18_2	211467	206714	206714	206711.00	361.0	206714	206714.00	20.89	0
100_19_2	228173	222901	222901	222901.00	327.0	222901	222901.00	10.00	0
100_20_2	220840	214409	214409	214406.00	305.0	214409	214409.00	15.11	0
100_1_3	233697	230077	230077	230071.00	456.0	230077	230073.20	59.15	0
100_2_3	221078	216707	216707	216707.00	524.0	216707	216707.00	14.48	0
100_3_3	235747	232313	232313	232313.00	544.0	232313	232313.00	9.71	0
100_4_3	242386	237753	237753	237751.00	569.0	237753	237753.00	21.94	0
100_5_3	239196	235397	235397	235397.00	535.0	235397	235397.00	16.32	0
100_6_3	254152	250399	250399	250392.00	591.0	250399	250399.00	17.29	0
100_7_3	225198	220956	220956	220951.00	642.0	220956	220956.00	18.63	0
100_8_3	228537	224616	224616	224552.00	592.0	224616	224616.00	13.98	0
100_9_3	249375	245634	245561	245561.00	575.0	245634	245634.00	10.97	0
100_10_3	241311	238030	238030	238030.00	415.0	238030	238019.20	15.88	0
100_11_3	237872	233922	233922	233922.00	572.00	**233942**	233942.00	19.15	**20**
100_12_3	245396	241462	241462	241462.00	669.0	241462	241425.00	13.64	0
100_13_3	230427	225281	225281	225267.00	537.0	225281	225255.80	51.36	0
100_14_3	238655	234946	234946	234946.00	419.0	234946	234946.00	8.55	0
100_15_3	237523	234060	234060	234060.00	539.0	234060	234060.00	55.51	0
100_16_3	239534	234809	234809	234782.00	548.0	234809	234796.40	119.21	0
100_17_3	247720	244245	244245	244235.00	643.0	244245	244245.00	71.87	0
100_18_3	214949	211550	211550	211550.00	556.0	211550	211550.00	20.84	0
100_19_3	232104	227826	227826	227826.00	538.0	227826	227826.00	24.03	0
100_20_3	224264	219171	219171	219171.00	557.0	219171	219171.00	13.55	0
200_1_2	932657	918426	918426	918370.00	3600.00	**918614**	918522.60	301.41	**188**
200_2_2	956771	941481	941481	941206.00	3600.00	**941554**	941463.60	267.72	**73**

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Instance	UB	Bestsofar	ALNS-MTRPP			EHSA-MTRPP			imp
			Best	Average	Tavg	Best	Average	Tavg	
200_3_2	943174	928676	928676	928191.00	3600.00	**929451**	929206.20	177.35	**775**
200_4_2	930799	917373	917373	917306.00	3600.00	**917770**	917626.00	280.79	**397**
200_5_2	905588	890510	890510	890144.00	3600.00	**890981**	890724.80	302.61	**471**
200_6_2	872034	858745	858745	858550.00	3600.00	**859212**	858805.00	296.03	**467**
200_7_2	839455	826310	826310	825826.00	3600.00	**826451**	826263.60	284.28	**141**
200_8_2	894462	879960	**879960**	879444.00	3600.00	879908	879685.20	245.09	-52
200_9_2	946226	931708	931708	931063.00	3600.00	**932063**	931987.40	192.16	**355**
200_10_2	905235	889624	889624	889405.00	3600.00	**889969**	889934.60	264.57	**345**
200_11_2	863633	849608	849608	849135.00	3600.00	**850316**	850282.80	280.36	**708**
200_12_2	864027	851353	851353	850709.00	3600.00	**851746**	851639.20	275.42	**393**
200_13_2	915688	903213	903213	902856.00	3600.00	**903372**	903325.00	274.70	**159**
200_14_2	908605	894623	894623	894365.00	3600.00	**894654**	894615.60	257.49	**31**
200_15_2	903031	888853	888853	888489.00	3600.00	**889076**	888914.60	287.23	**223**
200_16_2	908778	894601	894310	894236.00	3600.00	**895114**	895006.20	299.99	**513**
200_17_2	917911	904383	904383	904115.00	3600.00	**904987**	904919.20	224.91	**604**
200_18_2	899074	884741	884741	884502.00	3600.00	**885001**	884878.20	246.31	**260**
200_19_2	878239	863938	863938	863731.00	3600.00	**864054**	863862.40	245.38	**116**
200_20_2	959616	945832	945832	945646.00	3600.00	**945984**	945835.40	260.89	**152**
200_1_3	943383	933400	933400	933196.00	3600.00	**933493**	933264.80	303.33	**93**
200_2_3	966977	955807	955807	955557.00	3600.00	**955974**	955830.00	206.40	**167**
200_3_3	953298	943719	943719	943626.00	3600.00	**943727**	943707.20	245.29	**8**
200_4_3	941907	932363	932363	932285.00	3600.00	**932564**	932442.40	302.15	**201**
200_5_3	915558	905729	905729	905621.00	3600.00	**905994**	905832.60	243.12	**265**
200_6_3	882480	873075	873075	872989.00	3600.00	**873552**	873444.80	224.46	**477**
200_7_3	850082	840962	840962	840690.00	3600.00	**840967**	840880.00	311.54	**5**
200_8_3	904436	894255	894255	894021.00	3600.00	**894388**	894348.80	290.93	**133**
200_9_3	956011	945496	945496	945423.00	3600.00	**945893**	945716.00	195.23	**397**
200_10_3	915657	905137	905137	904949.00	3600.00	**905263**	905089.60	233.59	**126**
200_11_3	874750	865083	865083	864883.00	3600.00	**865176**	865135.60	260.61	**93**
200_12_3	874547	865242	865242	865083.00	3600.00	**865485**	865381.80	226.44	**243**
200_13_3	925772	916790	916790	916563.00	3600.00	**916852**	916802.80	234.55	**62**
200_14_3	919487	908876	908876	908768.00	3600.00	**909222**	909031.60	324.63	**346**
200_15_3	913028	903591	903591	903493.00	3600.00	**903731**	903637.20	264.09	**140**
200_16_3	918892	908510	908510	908430.00	3600.00	**908790**	908713.80	282.01	**280**
200_17_3	928066	919329	919329	918940.00	3600.00	**919401**	919367.80	253.26	**72**
200_18_3	909861	899639	899639	899562.00	3600.00	**899678**	899637.20	280.80	**39**
200_19_3	888472	878495	878495	878316.00	3600.00	**878521**	878347.00	245.60	**26**
200_20_3	970003	960009	960009	959836.00	3600.00	**960336**	960219.00	250.82	**327**
500_1_10	1540232	1455646	1455646	1450904.00	10800.00	**1465487**	1464784.80	949.72	**9841**
500_2_10	1493557	1391485	1391485	1386346.00	10800.00	**1400406**	1399388.00	856.19	**8921**
500_3_10	1483427	1384634	1384634	1378319.00	10800.00	**1392639**	1391237.00	931.19	**8005**
500_4_10	1534357	1444182	1444182	1438537.00	10800.00	**1452232**	1451622.80	904.74	**8050**
500_5_10	1576081	1491372	1491372	1484236.00	10800.00	**1498882**	1497917.00	820.96	**7510**
500_6_10	1432875	1330017	1329885	1324838.00	10800.00	**1341915**	1340896.80	962.32	**11898**
500_7_10	1569249	1476662	1476662	1470998.00	10800.00	**1483606**	1483109.60	884.38	**6944**
500_8_10	1524396	1422831	1422831	1417807.00	10800.00	**1429915**	1428878.80	883.22	**7084**
500_9_10	1522589	1435589	1435589	1425589.00	10800.00	**1444757**	1443367.80	893.36	**9168**
500_10_10	1554106	1454877	1454877	1446037.00	10800.00	**1462725**	1461455.00	903.66	**7848**
500_11_20	776959	707561	707561	702652.00	10800.00	**711554**	711231.60	870.24	**3993**
500_12_20	750028	687615	687615	683130.00	10800.00	**690071**	689512.00	901.21	**2456**
500_13_20	745248	684758	684758	682071.00	10800.00	**687498**	687162.80	896.88	**2740**
500_14_20	778525	710573	709061	705387.00	10800.00	**712445**	712126.80	849.57	**1872**
500_15_20	782275	720736	720736	717572.00	10800.00	**721856**	721647.40	852.07	**1120**
500_16_20	761474	661704	661704	659807.00	10800.00	**662405**	662169.60	949.46	**701**
500_17_20	768591	696260	696260	694075.00	10800.00	**699431**	699048.20	871.09	**3171**
500_18_20	762094	695045	695045	691853.00	10800.00	**698370**	698075.40	951.44	**3325**
500_19_20	766907	675514	675514	672667.00	10800.00	**676709**	676636.60	945.73	**1195**
500_20_20	769990	682489	682489	678832.00	10800.00	**683727**	683533.60	889.32	**1238**
750_1_100	4228241	4088551	4088551	4057817.00	43200.00	**4088685**	4088633.40	1457.98	**134**
750_2_100	4241250	4076244	4076244	4050407.00	43200.00	**4076454**	4076407.20	1220.98	**210**
750_3_100	4110388	3952579	3951848	3912082.00	43200.00	**3952708**	3952666.40	1365.20	**129**
750_4_100	4091437	3925597	3925597	3888261.00	43200.00	**3925662**	3925633.20	1257.79	**65**
750_5_100	4082626	3959146	3958755	3922355.00	43200.00	**3959419**	3959367.80	1461.04	**273**
1000_1_50	5477463	5238853	5238853	5119098.00	43200.00	**5239719**	5239458.00	1632.56	**866**
1000_2_50	5340073	5135418	5127116	5041220.00	43200.00	**5137547**	5137334.60	1811.08	**2129**
1000_3_50	5465097	5302530	5302530	5180878.00	43200.00	**5308690**	5308534.00	1778.12	**6160**
1000_4_50	5420077	5218614	5218614	5102997.00	43200.00	**5221360**	5221105.00	1761.50	**2746**
1000_5_50	5310584	5050205	5046116	4888644.00	43200.00	**5051316**	5051207.20	1804.74	**1111**
Avg.	518837.49	500280.07	500212.50	496401.17	3527.83	500848.55	500765.52	195.88	

Table 2: Detailed results obtained by the reference algorithm MA-MTRPP (Lu et al., 2019) and our algorithm MA-MTRPP over the 240 Ins_Lu instances, where each instance was solved 10 times according to Lu et al. (2019). The optimal solutions of the instances for $Size = 20$ are known. Improved results are indicated in bold.

Instance	UB	MA-MTRPP			EHSA-MTRPP			imp
		Best	Average	Tavg	Best	Average	Tavg	
20_21_2	4041	4041	4041.00	1.30	4041	4041.00	0.06	0
20_22_2	4309	4309	4309.00	1.30	4309	4309.00	0.06	0
20_23_2	4800	4800	4800.00	1.50	4800	4800.00	0.05	0
20_24_2	2442	2442	2442.00	1.40	2442	2442.00	0.05	0
20_25_2	3872	3872	3872.00	1.20	3872	3872.00	0.04	0
20_26_2	4067	4067	4067.00	1.40	4067	4067.00	0.05	0
20_27_2	3410	3410	3410.00	1.30	3410	3410.00	0.05	0
20_28_2	3721	3721	3721.00	1.30	3721	3721.00	0.05	0
20_29_2	3479	3479	3479.00	1.10	3479	3479.00	0.05	0
20_30_2	4173	4173	4173.00	1.40	4173	4173.00	0.05	0
20_31_2	3408	3408	3408.00	1.30	3408	3408.00	0.05	0
20_32_2	5155	5155	5155.00	1.30	5155	5155.00	0.06	0
20_33_2	4407	4407	4407.00	1.50	4407	4407.00	0.06	0
20_34_2	3794	3794	3794.00	1.20	3794	3794.00	0.04	0
20_35_2	3852	3852	3852.00	1.30	3852	3852.00	0.07	0
20_36_2	4092	4092	4092.00	1.20	4092	4092.00	0.04	0
20_37_2	4281	4281	4281.00	1.30	4281	4281.00	0.05	0
20_38_2	3258	3258	3258.00	1.40	3258	3258.00	0.05	0
20_39_2	2940	2940	2940.00	1.30	2940	2940.00	0.05	0
20_40_2	5251	5251	5251.00	1.20	5251	5251.00	0.05	0
20_21_3	2292	2292	2292.00	1.50	2292	2292.00	0.05	0
20_22_3	1674	1674	1674.00	1.30	1674	1674.00	0.05	0
20_23_3	2710	2710	2710.00	1.30	2710	2710.00	0.06	0
20_24_3	1620	1620	1620.00	1.20	1620	1620.00	0.05	0
20_25_3	2623	2623	2623.00	1.10	2623	2623.00	0.05	0
20_26_3	2645	2645	2645.00	1.40	2645	2645.00	0.06	0
20_27_3	1913	1913	1913.00	1.40	1913	1913.00	0.06	0
20_28_3	1851	1851	1851.00	1.30	1851	1851.00	0.05	0
20_29_3	2959	2959	2959.00	1.00	2959	2959.00	0.05	0
20_30_3	2770	2770	2770.00	1.60	2770	2770.00	0.06	0
20_31_3	2410	2410	2410.00	1.20	2410	2410.00	0.05	0
20_32_3	2704	2704	2704.00	1.10	2704	2704.00	0.05	0
20_33_3	2081	2081	2081.00	1.20	2081	2081.00	0.05	0
20_34_3	1736	1736	1736.00	1.20	1736	1736.00	0.05	0
20_35_3	1910	1910	1910.00	1.60	1910	1910.00	0.05	0
20_36_3	2877	2877	2877.00	1.30	2877	2877.00	0.06	0
20_37_3	2659	2659	2659.00	1.40	2659	2659.00	0.05	0
20_38_3	2942	2942	2942.00	1.40	2942	2942.00	0.07	0
20_39_3	2720	2720	2720.00	1.10	2720	2720.00	0.06	0
20_40_3	2888	2888	2888.00	1.20	2888	2888.00	0.06	0
20_21_4	2048	2048	2048.00	1.10	2048	2048.00	0.05	0
20_22_4	1581	1581	1581.00	1.30	1581	1581.00	0.05	0
20_23_4	1547	1547	1547.00	1.20	1547	1547.00	0.06	0
20_24_4	1101	1101	1101.00	1.10	1101	1101.00	0.05	0
20_25_4	2252	2252	2252.00	1.00	2252	2252.00	0.06	0
20_26_4	1807	1807	1807.00	1.10	1807	1807.00	0.05	0
20_27_4	1505	1505	1505.00	1.30	1505	1505.00	0.05	0
20_28_4	1352	1352	1352.00	1.10	1352	1352.00	0.05	0
20_29_4	2189	2189	2189.00	1.60	2189	2189.00	0.13	0
20_30_4	1729	1729	1729.00	1.10	1729	1729.00	0.05	0
20_31_4	1723	1723	1723.00	1.50	1723	1723.00	0.07	0
20_32_4	1974	1974	1974.00	1.30	1974	1974.00	0.06	0
20_33_4	1841	1841	1841.00	1.20	1841	1841.00	0.06	0
20_34_4	1604	1604	1604.00	1.20	1604	1604.00	0.06	0
20_35_4	1246	1246	1246.00	1.30	1246	1246.00	0.07	0
20_36_4	1646	1646	1646.00	1.40	1646	1646.00	0.05	0
20_37_4	2147	2147	2147.00	1.10	2147	2147.00	0.06	0
20_38_4	2040	2040	2040.00	1.20	2040	2040.00	0.05	0
20_39_4	1844	1844	1844.00	1.30	1844	1844.00	0.06	0
20_40_4	1492	1492	1492.00	1.10	1492	1492.00	0.05	0

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Table 2 – Continued from previous page

Instance	UB	MA-MTRPP			EHSA-MTRPP			imp
		Best	Average	Tavg	Best	Average	Tavg	
50_21_2	26893	24674	24674.00	7.90	**24678**	24678.00	4.79	**4**
50_22_2	28678	26552	26552.00	7.40	26552	26552.00	0.31	0
50_23_2	29659	27501	27501.00	8.50	27501	27501.00	1.07	0
50_24_2	31353	29416	29416.00	7.80	**29424**	29424.00	1.53	**8**
50_25_2	29843	27605	27605.00	8.40	27605	27605.00	0.46	0
50_26_2	30696	28251	28251.00	7.90	28251	28251.00	0.40	0
50_27_2	30456	27501	27501.00	6.30	27501	27501.00	0.35	0
50_28_2	29888	27386	27386.00	7.90	27386	27386.00	0.96	0
50_29_2	28225	25634	25634.00	6.80	25634	25634.00	1.19	0
50_30_2	31784	29046	29046.00	7.60	**29062**	29062.00	0.87	**16**
50_31_2	28369	25557	25557.00	7.90	25557	25557.00	1.11	0
50_32_2	25319	22982	22982.00	6.60	22982	22982.00	0.44	0
50_33_2	33668	31418	31418.00	7.80	31418	31418.00	0.75	0
50_34_2	33629	31471	31471.00	7.50	31471	31471.00	0.98	0
50_35_2	28983	26040	26040.00	5.50	26040	26040.00	0.30	0
50_36_2	24032	21355	21355.00	7.50	21355	21355.00	1.91	0
50_37_2	33583	31077	31077.00	7.70	31077	31077.00	0.90	0
50_38_2	30737	27656	27656.00	7.50	27656	27656.00	1.09	0
50_39_2	31972	29320	29320.00	6.00	29320	29320.00	0.32	0
50_40_2	25782	23001	23001.00	7.20	23001	23001.00	0.58	0
50_21_3	19069	17318	17318.00	7.20	17318	17318.00	0.60	0
50_22_3	19106	17375	17375.00	7.40	17375	17375.00	0.93	0
50_23_3	17173	15708	15708.00	5.80	15708	15708.00	0.33	0
50_24_3	21965	20274	20274.00	6.10	20274	20274.00	0.75	0
50_25_3	22294	20428	20428.00	6.70	20428	20428.00	0.67	0
50_26_3	21828	19963	19963.00	7.40	19963	19963.00	2.04	0
50_27_3	17592	15637	15637.00	6.50	15637	15637.00	0.52	0
50_28_3	19234	17233	17233.00	6.10	17233	17233.00	0.33	0
50_29_3	20663	18343	18343.00	6.80	18343	18343.00	1.25	0
50_30_3	18412	16351	16351.00	7.00	16351	16351.00	0.43	0
50_31_3	16221	14143	14143.00	5.40	14143	14143.00	0.35	0
50_32_3	19646	17510	17510.00	6.40	17510	17510.00	0.88	0
50_33_3	18228	16622	16622.00	5.60	16622	16622.00	0.25	0
50_34_3	19220	17802	17802.00	6.10	17802	17802.00	0.35	0
50_35_3	20230	17711	17711.00	4.20	17711	17711.00	0.32	0
50_36_3	19940	17848	17848.00	6.60	17848	17848.00	0.66	0
50_37_3	17875	15909	15909.00	5.20	15909	15909.00	0.31	0
50_38_3	21369	19326	19326.00	6.10	19326	19326.00	0.52	0
50_39_3	19205	17077	17077.00	6.60	17077	17077.00	1.02	0
50_40_3	20022	17893	17893.00	6.00	17893	17893.00	0.61	0
50_21_4	15144	13483	13483.00	6.00	13483	13483.00	0.35	0
50_22_4	15137	13656	13656.00	5.90	13656	13656.00	0.72	0
50_23_4	13805	12676	12676.00	5.80	12676	12676.00	0.49	0
50_24_4	15063	13545	13545.00	5.90	13545	13545.00	0.39	0
50_25_4	16196	14397	14397.00	6.10	14397	14397.00	0.77	0
50_26_4	13931	12291	12291.00	6.90	12291	12291.00	0.81	0
50_27_4	14201	12416	12416.00	6.80	12416	12416.00	3.81	0
50_28_4	14297	12544	12544.00	5.20	12544	12544.00	0.33	0
50_29_4	15228	13071	13071.00	4.60	13071	13071.00	0.42	0
50_30_4	13882	12119	12119.00	5.60	12119	12119.00	0.65	0
50_31_4	15477	13670	13670.00	4.80	13670	13670.00	0.52	0
50_32_4	13845	11829	11829.00	5.90	11829	11829.00	0.70	0
50_33_4	14237	12649	12649.00	5.70	12649	12649.00	0.35	0
50_34_4	13049	11646	11646.00	6.00	11646	11646.00	0.77	0
50_35_4	15194	12694	12694.00	4.80	12694	12694.00	0.37	0
50_36_4	14888	13190	13190.00	5.90	**13191**	13191.00	1.44	**1**
50_37_4	15091	13325	13325.00	6.30	13325	13325.00	0.50	0
50_38_4	16998	15087	15087.00	6.00	15087	15087.00	0.55	0
50_39_4	16504	14535	14535.00	5.30	**14538**	14538.00	0.49	**3**
50_40_4	13935	12158	12158.00	4.90	12158	12158.00	0.51	0
100_21_2	121094	114595	114581.60	46.20	114595	114595.00	25.13	0
100_22_2	125258	118043	118042.00	48.40	118043	118037.90	21.74	0
100_23_2	128166	122713	122712.30	45.20	122713	122713.00	16.59	0
100_24_2	121826	114752	114744.80	44.60	114752	114752.00	16.08	0
100_25_2	121825	115229	115225.80	47.70	115229	115229.00	8.22	0
100_26_2	116378	110146	110131.90	46.30	110146	110146.00	26.09	0
100_27_2	122095	115008	115005.40	47.80	115008	115008.00	13.54	0
100_28_2	118966	113088	113083.40	46.80	113088	113083.50	44.11	0
100_29_2	118212	111843	111842.80	48.70	**111847**	111847.00	15.37	**4**
100_30_2	117149	111240	111230.50	46.50	111240	111240.00	21.50	0

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Table 2 – Continued from previous page

Instance	UB	MA-MTRPP			EHSA-MTRPP			imp
		Best	Average	Tavg	Best	Average	Tavg	
100_31_2	132132	126202	126187.10	45.60	126202	126202.00	13.00	0
100_32_2	122030	115322	115322.00	46.20	115322	115322.00	8.21	0
100_33_2	115486	107507	107503.30	49.80	107507	107506.60	55.53	0
100_34_2	112245	106227	106225.80	44.10	106227	106227.00	12.66	0
100_35_2	99604	94066	94066.00	47.70	94066	94066.00	11.95	0
100_36_2	134081	126764	126751.00	44.00	**126775**	126775.00	16.67	**11**
100_37_2	120618	114951	114949.30	44.20	114951	114951.00	37.74	0
100_38_2	112715	106831	106829.00	46.10	106831	106831.00	35.12	0
100_39_2	127564	120931	120912.10	45.50	120931	120931.00	24.96	0
100_40_2	114206	105869	105869.00	41.10	105869	105869.00	4.65	0
100_21_3	79809	74941	74930.40	38.30	74941	74938.50	51.27	0
100_22_3	85111	80730	80730.00	37.80	**80736**	80736.00	8.08	**6**
100_23_3	81031	77306	77306.00	38.90	77306	77306.00	14.76	0
100_24_3	82717	77574	77572.40	37.50	77574	77574.00	12.78	0
100_25_3	79624	74913	74906.40	40.90	74913	74913.00	5.23	0
100_26_3	91830	87548	87548.00	36.00	87548	87548.00	11.33	0
100_27_3	81906	77001	77000.80	36.20	77001	77001.00	10.40	0
100_28_3	87253	82694	82693.70	36.40	82694	82694.00	17.40	0
100_29_3	77065	72632	72627.00	39.30	72632	72632.00	19.15	0
100_30_3	77992	74179	74179.00	36.00	74179	74179.00	5.82	0
100_31_3	78291	73707	73706.50	39.10	73707	73707.00	23.17	0
100_32_3	74732	69562	69560.50	36.50	69562	69562.00	65.70	0
100_33_3	78388	72666	72653.40	39.50	72666	72666.00	26.83	0
100_34_3	81873	77526	77526.00	41.00	77526	77526.00	2.28	0
100_35_3	73068	68980	68978.90	37.20	68980	68980.00	52.41	0
100_36_3	87473	81724	81723.30	41.40	81724	81720.60	34.77	0
100_37_3	84976	80524	80493.50	40.20	80524	80521.70	67.99	0
100_38_3	85900	82069	82069.00	36.80	82069	82069.00	9.66	0
100_39_3	81813	76473	76466.80	36.10	76473	76473.00	20.23	0
100_40_3	83224	76778	76778.00	31.80	76778	76778.00	7.01	0
100_21_4	60509	56403	56403.00	31.00	56403	56403.00	13.49	0
100_22_4	63856	59726	59726.00	32.20	59726	59726.00	8.66	0
100_23_4	61739	58571	58571.00	33.80	58571	58571.00	3.89	0
100_24_4	65214	60395	60393.30	32.40	60395	60395.00	46.16	0
100_25_4	60292	56721	56721.00	31.10	56721	56721.00	3.88	0
100_26_4	61150	57427	57426.50	31.60	57427	57427.00	27.89	0
100_27_4	58704	54315	54315.00	32.80	54315	54315.00	7.88	0
100_28_4	64654	61017	61015.90	34.90	61017	61017.00	21.99	0
100_29_4	59880	56292	56292.00	30.60	56292	56292.00	9.28	0
100_30_4	61997	58708	58707.90	34.30	58708	58707.50	47.22	0
100_31_4	59088	55230	55227.10	32.80	55230	55230.00	22.76	0
100_32_4	62552	58165	58163.50	32.70	58165	58165.00	14.95	0
100_33_4	58994	53723	53715.10	32.10	53723	53723.00	33.19	0
100_34_4	70355	66128	66128.00	33.90	**66131**	66131.00	42.19	**3**
100_35_4	55795	52381	52380.00	31.80	52381	52381.00	14.88	0
100_36_4	60413	55657	55657.00	33.90	55657	55657.00	8.32	0
100_37_4	57135	53850	53839.00	32.90	53850	53850.00	51.93	0
100_38_4	59511	56026	56023.40	32.10	56026	56026.00	19.59	0
100_39_4	59288	54714	54714.00	32.30	54714	54714.00	12.36	0
100_40_4	64191	58319	58315.20	31.80	58319	58319.00	10.82	0
200_21_2	485794	**468522**	468150.20	417.70	468503	468380.90	257.49	-19
200_22_2	527280	508582	508269.40	431.10	**508845**	508543.30	204.87	**263**
200_23_2	482458	465900	465643.60	443.40	**466134**	466054.30	241.59	**234**
200_24_2	458565	443298	443129.90	417.80	**443497**	443404.10	293.87	**199**
200_25_2	491163	473518	473325.90	437.20	**473713**	473596.40	181.13	**195**
200_26_2	470996	455004	454816.30	450.40	**455583**	455266.00	275.97	**579**
200_27_2	520146	504749	504356.30	448.80	**504811**	504623.50	271.20	**62**
200_28_2	512202	494996	494670.00	480.30	**495119**	494998.60	222.68	**123**
200_29_2	473107	454543	454213.80	512.10	**454866**	454680.40	213.46	**323**
200_30_2	515128	495476	494997.20	508.40	**495542**	495467.50	321.14	**66**
200_31_2	512317	496105	495797.50	495.80	**496265**	496179.00	298.34	**160**
200_32_2	502157	486354	485922.10	508.00	**486510**	486329.50	297.20	**156**
200_33_2	382389	367202	366924.70	477.80	**367251**	367239.30	192.56	**49**
200_34_2	535925	518895	518734.20	490.60	**519166**	518984.60	262.31	**271**
200_35_2	496792	479742	479391.80	501.60	**479879**	479810.50	277.26	**137**
200_36_2	479295	462639	462325.90	466.30	**462679**	462605.20	258.96	**40**
200_37_2	471186	455547	455356.70	390.00	**455802**	455665.10	290.46	**255**
200_38_2	476610	461059	460816.60	402.40	**461244**	461149.90	234.72	**185**
200_39_2	528763	510921	510638.70	414.10	**511526**	511205.40	228.81	**605**
200_40_2	460515	442976	442560.80	413.90	**443050**	442915.30	259.27	**74**

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Table 2 – Continued from previous page

Instance	UB	MA-MTRPP			EHSA-MTRPP			imp
		Best	Average	Tavg	Best	Average	Tavg	
200_21_3	325604	313483	313109.70	351.90	**313652**	313483.80	247.92	**169**
200_22_3	367158	353283	353092.10	321.60	**353481**	353272.30	205.44	**198**
200_23_3	348401	337139	336901.40	316.10	**337264**	337076.60	251.51	**125**
200_24_3	315674	304754	304445.60	326.50	**304826**	304717.80	193.13	**72**
200_25_3	333824	321516	321255.80	342.70	**321593**	321516.50	209.57	**77**
200_26_3	309521	298559	298276.00	339.20	**298744**	298563.10	252.28	**185**
200_27_3	330091	319365	319098.50	342.20	**319501**	319394.40	233.62	**136**
200_28_3	335136	323076	322882.50	318.30	**323260**	323187.20	267.11	**184**
200_29_3	346526	333553	333331.20	340.80	**333765**	333627.00	267.39	**212**
200_30_3	341513	327898	327666.00	326.20	**327982**	327944.80	276.72	**84**
200_31_3	333974	321798	321728.20	360.90	**321938**	321897.70	263.67	**140**
200_32_3	347987	335874	335722.90	395.60	**336042**	335951.10	253.59	**168**
200_33_3	341538	330200	329993.90	368.80	**330372**	330307.60	203.15	**172**
200_34_3	340028	327067	326876.70	390.30	**327300**	327236.60	269.81	**233**
200_35_3	320156	308516	308348.50	391.00	**308758**	308639.70	231.41	**242**
200_36_3	342026	330356	330157.80	367.90	**330368**	330317.00	259.60	**12**
200_37_3	317460	306781	306676.00	380.60	**306841**	306795.20	257.85	**60**
200_38_3	344352	332126	331900.40	415.50	**332318**	332186.70	278.33	**192**
200_39_3	306594	294425	294145.40	398.70	**294539**	294420.60	276.93	**114**
200_40_3	315269	302962	302635.60	370.60	**303031**	302975.70	214.06	**69**
200_21_4	235424	225768	225613.10	261.00	**225864**	225838.30	217.08	**96**
200_22_4	259926	248421	248297.00	258.80	**248550**	248501.30	163.66	**129**
200_23_4	261918	**252434**	252255.40	260.90	252424	252299.20	171.12	-10
200_24_4	262981	253674	253506.10	267.30	**253927**	253806.60	243.32	**253**
200_25_4	232468	223149	223074.00	245.70	**223163**	223134.50	210.10	**14**
200_26_4	242970	234401	234177.30	261.10	**234635**	234414.50	259.58	**234**
200_27_4	231468	222973	222875.30	270.10	**223095**	223030.20	258.13	**122**
200_28_4	247738	237875	237658.30	256.30	**237937**	237864.20	281.88	**62**
200_29_4	248605	238234	238065.30	252.40	**238257**	238189.70	232.20	**23**
200_30_4	255496	244401	244293.40	259.40	**244554**	244510.30	194.84	**153**
200_31_4	259277	249045	248899.70	268.90	**249171**	249046.10	273.47	**126**
200_32_4	248284	238982	238820.70	273.30	**239118**	238964.50	268.17	**136**
200_33_4	253318	244230	244111.10	269.10	**244393**	244375.60	242.84	**163**
200_34_4	246745	236155	235931.00	304.20	**236262**	236149.10	215.00	**107**
200_35_4	257955	249014	248885.80	301.60	**249070**	249023.40	168.41	**56**
200_36_4	224650	214670	214591.20	304.10	**214817**	214708.20	221.23	**147**
200_37_4	268362	260318	260148.70	298.30	260318	260313.20	261.78	0
200_38_4	209484	199311	199151.50	315.70	**199392**	199293.00	284.17	**81**
200_39_4	245192	235030	234851.40	325.90	**235257**	235125.60	240.69	**227**
200_40_4	236360	225798	225575.50	313.30	**225900**	225831.20	176.66	**102**
Avg.	116981.80	111973.18	111915.69	102.64	112011.00	111983.28	66.45	

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