Appendix of the paper "Hybrid evolutionary computation methods for quay crane scheduling problems"

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1. Complete experimental results

This section provides detailed results for all sets of benchmark instances introduced by Meisel [1]. The notations of problems characteristics are the same as ones used in Meisel [1]. *Loc* indicates the distributions of tasks on the vessel, f indicates the the handling rate, d is the precedence density, q is the number of QCs, and s is the safety distance. The signs * and $^\blacktriangle$ respectively indicate that the proposed methods are able to find the optimal solutions or improve the best known solutions (BKS) as compared to CPLEX and UDS. Here, *best*, *avg.*, and t_{best} denote the best and average makespans and the average time in seconds (from the five independent runs) to find the best solution in a run with HGA and HGP.

References

[1] F. Meisel, C. Bierwirth, A unified approach for the evaluation of quay crane scheduling models and algorithms, Computers & Operations Research 38 (2011) 683–693.

[2] C. Bierwirth, F. Meisel, A fast heuristic for quay crane scheduling with interference constraints, Journal of Scheduling 12 (2009) 345–360.

[3] N. Kaveshgar, N. Huynh, S. K. Rahimian, An efficient genetic algorithm for solving the quay crane scheduling problem, Expert Systems with Applications (2012) (online).

Table 1: Comparison of HGA and HGP with other methods (Set A, $n = 10 - 20$)

Class / Instance	CPLEX	UDS [2]	GA [3]		HGA			HGP		
	lw. bound	*obj.*	*obj.*	*time*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$n = 10$										
1	520	520	520	4	520*	520	<1	520*	520	<1
2	508	508	508	4	508*	508	<1	508*	508	<1
3	513	513	513	4	513*	513	<1	513*	513	<1
4	510	510	510	4	510*	510	<1	510*	510	<1
5	514	515	515	4	514*▲	514	<1	514*▲	514	<1
6	513	513	513	4	513*	513	<1	513*	513	<1
7	511	511	511	4	511*	511	<1	511*	511	<1
8	513	513	513	4	513*	513	<1	513*	513	<1
9	512	512	512	4	512*	512	<1	512*	512	<1
10	549	549	549	4	549*	549	<1	549*	549	<1
$n = 15$										
1	513	514	514	5	513*▲	513	<1	513*▲	513	<1
2	507	507	507	5	507*	507	<1	507*	507	<1
3	513	515	515	5	513*▲	513	<1	513*▲	513	<1
4	513	513	516	6	513*	513	<1	513*	513	<1
5	507	507	507	5	507*	507	<1	507*	507	<1
6	508	508	513	5	508*	508	<1	508*	508	<1
7	507	507	508	6	507*	507.2	<1	507*	507	<1
8	508	508	513	6	508*	508	<1	508*	508	<1
9	507	507	507	7	507*	507	<1	507*	507	<1
10	513	513	514	6	513*	513	<1	513*	513	<1
$n = 20$										
1	506	508	509	7	508	508	<1	508	508	<1
2	507	509	514	7	511	511	<1	511	511	<1
3	507	509	509	6	509	509	<1	509	509	<1
4	507	509	513	7	509	509	1.6	509	509	<1
5	506	506	507	7	506*	506	<1	506*	506	<1
6	507	508	508	7	508	508	<1	508	508	<1
7	506	507	507	7	507	507	<1	507	507	<1
8	508	510	510	6	510	510	<1	510	510	<1
9	507	508	508	7	508	508	<1	508	508	<1
10	507	507	511	6	507*	507	1.6	507*	507	<1

Table 2: Comparison of HGA and HGP with other methods (Set A, $n = 25 - 40$)

Class / Instance	CPLEX	UDS [2]	GA [3]		HGA			HGP		
	lw. bound	*obj.*	*obj.*	*time*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$n = 25$										
1	506	508	513	9	508	508	<1	508	508	<1
2	507	507	513	8	507*	507	<1	507*	507	<1
3	506	507	507	8	507	507	<1	507	507	<1
4	507	507	507	9	507*	507	<1	507*	507	<1
5	506	507	507	9	507	507	1.6	507	507	<1
6	506	507	507	8	507	507	2.4	507	507.6	2.8
7	506	508	508	8	508	508	<1	508	508	<1
8	507	507	507	8	507*	507	2.2	507*	507	<1
9	506	506	507	9	506*	506	3	506*	506	<1
10	506	506	513	8	506*	506	2.6	506*	506	1.8
$n = 30$										
1	505	506	507	10	506	506.2	6	506	506	<1
2	507	508	508	10	508	508	<1	508	508	<1
3	506	507	507	10	507	507.8	3.4	507	507	2.4
4	506	507	507	9	507	507	<1	507	507	<1
5	506	506	506	10	507	507.2	4.6	506*	506	1.8
6	505	506	513	9	506	506	<1	506	506	<1
7	507	508	514	9	509	509	<1	509	509	<1
8	506	508	508	9	508	508	1.4	508	508	<1
9	506	506	506	10	506*	506	2.4	506*	506	<1
10	506	506	506	10	506*	506	<1	506*	506	<1
$n = 35$										
1	506	506	506	11	506*	506	5.4	506*	506	<1
2	506	507	507	11	507	507	<1	507	507	<1
3	506	506	506	11	507	508.8	4	506*	506.4	4.2
4	506	507	507	10	507	507.6	6.6	507	507	2
5	506	507	508	11	507	507.6	3.8	507	507	<1
6	505	511	511	11	511	511	2.4	511	511	1.4
7	506	507	512	10	507	507	6.4	507	507	2.4
8	505	506	506	11	506	506	4.6	506	506	1.4
9	505	506	506	11	506	506	1.2	506	506	<1
10	506	508	513	11	508	508	<1	508	508	1.4
$n = 40$										
1	505	506	506	12	506	507.4	4	506	506	1
2	506	506	506	12	506*	506	1	506*	506	<1
3	505	505	512	12	505*	507	4.6	505*	505	2.4
4	506	507	507	11	507	507	<1	507	507	<1
5	506	506	507	12	507	507	4.2	506*	506	1
6	505	507	513	11	507	508.4	3.6	507	507	1.8
7	507	507	507	15	507*	507	1.2	507*	507	<1
8	506	506	514	12	506*	506.4	4.4	506*	506	5.6
9	506	506	506	12	506*	506.2	2	506*	506.4	2.8
10	506	507	514	11	507	507	<1	507	507	<1

Table 3: Comparison of HGA and HGP with other methods (Set B, $n = 45 - 55$)

Class / Instance	CPLEX	UDS [2]	HGA			HGP		
	lw. bound	*obj.*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$n = 45$								
1	755	758	758	758.6	88.2	758	759.4	145.2
2	754	759	759	759.2	45	759	759	13
3	754	759	761	763.6	65.8	762	763.2	204.4
4	755	789	788▲	788.8	63	788▲	788	66.4
5	754	758	762	767.2	91.4	758	760.4	114
6	754	789	787▲	790.4	73.6	775▲	778.8	204
7	754	798	798	798.8	45.4	798	798	59.4
8	755	759	766	766.6	98.4	763	766.2	53.6
9	754	797	797	797.2	20.6	797	797	11
10	754	792	792	792	55.6	792	792	77.6
$n = 50$								
1	753	774	774	774	36.4	774	774	21.6
2	754	771	772	777.6	74.6	775	775.6	124.6
3	754	772	772	774.2	92	772	772	128.6
4	753	765	768	768.6	187.2	765	769.6	122
5	753	762	766	767.2	87.8	769	770.6	81.2
6	753	765	769	769	25.8	769	769	27.4
7	754	782	782	782	<1	782	782	2.2
8	753	761	761	762.6	43	762	763	127.2
9	754	798	798	798	13.6	798	798	7.4
10	753	759	759	763	104.2	759	762	161.6
$n = 55$								
1	754	758	762	763.6	160.4	763	763.4	172.4
2	754	783	785	786.4	86.2	785	785.4	71
3	753	779	779	779	15.6	779	779	3.4
4	753	759	760	765.4	120	761	762.6	198.4
5	754	758	765	767.2	132.2	761	763.8	183
6	754	789	789	789	59.8	789	789	35.4
7	754	768	769	771	82.4	769	775.2	110
8	753	767	769	770.8	114.6	771	772.2	184
9	753	801	801	801	10.6	801	801	6.4
10	754	757	765	766.6	214.6	760	763.4	150.2

Table 4: Comparison of HGA and HGP with other methods (Set B, $n = 60 - 70$)

Class / Instance	CPLEX	UDS [2]	HGA			HGP		
	lw. bound	*obj.*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$n = 60$								
1	753	781	782	788.6	160.8	781	782.2	158.2
2	753	756	759	762.6	222.2	759	761.4	154
3	753	758	761	764.4	233	764	767.2	163
4	754	765	771	771	65.8	770	770.8	44.8
5	753	760	768	768	93.2	761	766	159.2
6	753	758	759	761.6	266.2	760	761.8	254.2
7	753	786	786	786	46.4	786	786	56.4
8	753	757	766	766	140.6	765	766	180.8
9	753	785	785	785	27.2	785	785	17.4
10	753	805	805	805	26.2	805	805	21.6
$n = 65$								
1	753	758	761	761.6	200	759	760.6	160.4
2	753	799	799	799	13.4	799	799	8.2
3	753	803	803	803	37.8	803	803	20.6
4	753	758	765	766	203.8	764	765	167.6
5	753	758	762	765.8	136.4	761	765	150.2
6	754	757	763	763.4	162.2	761	762	156.2
7	754	757	761	762.6	227.6	760	760.8	186.2
8	754	756	764	764.4	251.2	759	761.4	163.2
9	754	758	762	764.6	182	764	767.2	168.4
10	754	786	786	789.2	261.8	787	788	109.8
$n = 70$								
1	753	766	766	767.4	162	761▲	767.4	184.2
2	753	764	769	769.4	113.2	765	767.6	164.6
3	753	760	767	768.4	163.2	764	765.4	86
4	753	760	774	775.6	201.8	769	772.6	192.8
5	753	757	759	763.2	263	762	765	205.6
6	753	761	762	762.4	145.4	762	763.4	234.4
7	754	759	762	764.8	146.4	762	765	221.4
8	753	758	766	767	150.4	763	766.6	129
9	753	757	766	767.2	149.8	766	767.6	201.4
10	753	779	779	779.8	192.2	779	780	217

Table 5: Comparison of HGA and HGP with other methods (Set C, $n = 75 - 85$)

Class / Instance	CPLEX	UDS [2]	HGA			HGP		
	lw. bound	*obj.*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$n = 75$								
1	1003	1178	1179	1179	29.2	1178	1178	221
2	1003	1011	1022	1031.6	491	1022	1028.2	445
3	1003	1182	1180▲	1180.8	299.8	1181▲	1181.2	283
4	1003	1107	1107	1107	116.4	1107	1107	43.6
5	1003	1192	1192	1192	62.4	1192	1192	17.8
6	1003	1123	1123	1123.4	167.2	1123	1123	96.8
7	1003	1200	1199▲	1199.4	204	1199▲	1199.2	370.4
8	1003	1174	1173▲	1173.8	88.2	1173▲	1173.4	242.4
9	1003	1074	1073▲	1073.8	212.8	1074	1074	144.4
10	1003	1188	1187▲	1187	130.6	1187▲	1187	54.6
$n = 80$								
1	1003	1173	1173	1173.4	73.6	1173	1173	245
2	1003	1023	1023	1031.4	449.2	1023	1028.6	402.8
3	1003	1013	1038	1054.8	414.6	1026	1034.8	443
4	1003	1202	1201▲	1201.2	394.2	1201▲	1201	199.4
5	1002	1036	1037	1037.4	438	1036	1038.2	293.6
6	1004	1117	1117	1117.8	289.2	1117	1117	148.2
7	1002	1201	1199▲	1199.6	374.4	1199▲	1199.6	292.6
8	1003	1040	1025▲	1038	491.8	1035▲	1047.2	452.8
9	1004	1192	1190▲	1190	260.2	1190▲	1190	81
10	1003	1207	1206▲	1206	115	1206▲	1206	72.6
$n = 85$								
1	1004	1049	1049	1050.4	370.8	1049	1049.4	327.2
2	1003	1017	1027	1036	492.6	1027	1033.6	492
3	1003	1027	1033	1038.4	444	1032	1038.8	361.8
4	1003	1186	1185▲	1185.2	351.6	1184▲	1184.2	368.8
5	1003	1082	1082	1082.6	491.8	1082	1082.6	410.6
6	1003	1010	1016	1019.6	569	1019	1020.6	362
7	1003	1195	1195	1195	137.2	1195	1195	26.6
8	1003	1105	1105	1105	130.4	1104▲	1104.8	212.4
9	1003	1010	1037	1040.8	487.4	1022	1033.2	456.4
10	1003	1166	1166	1166	70.6	1166	1166	8.6

Table 6: Comparison of HGA and HGP with other methods (Set C, $n = 90 - 100$)

Class / Instance	CPLEX	UDS [2]	HGA			HGP		
	lw. bound	*obj.*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$n = 90$								
1	1003	1014	1020	1022.8	492	1022	1029	437.6
2	1003	1020	1034	1041.6	540.8	1034	1041.6	398
3	1003	1011	1027	1035.8	433.6	1021	1034.8	489.6
4	1003	1063	1063	1063	273.8	1063	1063.6	322.4
5	1003	1062	1062	1062.2	364.4	1062	1062.2	206.8
6	1003	1193	1192▲	1194.4	81.4	1191▲	1192.8	270.4
7	1003	1108	1108	1108.2	165	1108	1108.2	275
8	1003	1094	1094	1094.4	100	1094	1094	124.4
9	1003	1075	1075	1075.2	126.2	1075	1075	207
10	1003	1049	1049	1049.4	325.2	1049	1049.6	320.4
$n = 95$								
1	1003	1174	1172▲	1173.2	361.4	1174	1174	53
2	1003	1090	1090	1090.2	255.8	1090	1090	189.2
3	1003	1014	1025	1029	471.6	1028	1032.8	460.6
4	1003	1138	1135▲	1136.2	426	1136▲	1136.8	355.2
5	1003	1144	1142▲	1142.6	345.6	1142▲	1142.2	316.4
6	1003	1055	1055	1055.4	370	1055	1055	324.8
7	1003	1173	1172▲	1172	48.2	1171▲	1171.8	146.8
8	1003	1015	1027	1031.2	498.4	1030	1038	531.8
9	1003	1019	1022	1028.6	453.4	1020	1021.6	468
10	1003	1011	1025	1028.8	482.4	1017	1030.6	481.4
$n = 100$								
1	1003	1014	1030	1037.2	483	1027	1032.8	453.6
2	1003	1104	1104	1104.6	445.2	1104	1107	210.6
3	1003	1107	1106▲	1106.8	288.4	1106▲	1106.8	175.6
4	1003	1202	1201▲	1201.6	371.8	1202	1202	183.2
5	1003	1015	1030	1036.2	559.4	1030	1032.6	434.6
6	1003	1136	1135▲	1136	286.4	1134▲	1134.8	295.8
7	1003	1098	1098	1098.8	238	1098	1098	123.8
8	1003	1151	1151	1151	212.6	1151	1151	93.2
9	1003	1023	1032	1036.8	561.8	1029	1033.6	482.4
10	1003	1015	1040	1044.4	506	1027	1034.8	534

Table 7: Comparison of HGA and HGP with other methods (Set D, $f = 0.2$)

Class / Instance	UDS [2]	HGA			HGP		
	obj.	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$Loc = cl1$							
1	544	543▲	543	1.8	543▲	543	<1
2	556	556	556	3.6	556	556	4
3	680	680	680	<1	680	680	<1
4	578	578	578	<1	578	578	<1
5	356	356	356	3	356	356	4.6
6	414	413▲	413	<1	413▲	413	<1
7	439	439	439	<1	439	439	<1
8	383	383	383	<1	383	383	<1
9	420	420	420	2	420	420	<1
10	380	380	380	3.6	380	380	<1
$Loc = cl2$							
1	453	453	453	<1	453	453	<1
2	430	429▲	429	10.2	429▲	429	3
3	439	438▲	438.4	22.2	438▲	438	44.6
4	312	312	312.2	42.2	313	313.2	137.2
5	349	348▲	348.4	58.8	349	349	28.4
6	307	308	309.4	85.8	308	309.8	149.6
7	373	372▲	372	11.2	372▲	372	12.8
8	308	308	310.6	110.2	308	308	93.8
9	308	308	309.4	152.8	310	310.4	107.4
10	397	397	397	6	396▲	396	46
$Loc = uni$							
1	415	414▲	414	84	414▲	414	46.2
2	307	308	308	82.6	307	307.2	150.8
3	426	426	426	17.2	426	426	10.6
4	324	324	324	17	324	324	18.2
5	309	313	315.4	59	309	312.6	81
6	307	307	309	110.6	307	310.4	124
7	325	325	325	20.4	325	325	11.2
8	349	349	349	1.6	349	349	<1
9	387	386▲	386	32.2	386▲	386	40.4
10	346	347	349.4	189.2	346	348	161.2

Table 8: Comparison of HGA and HGP with other methods (Set D, $f = 0.8$)

Class / Instance	UDS [2]	HGA			HGP		
	obj.	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$Loc = cl1$							
1	1214	1214	1214	26.8	1214	1214	40
2	1206	1209	1211	67.2	1208	1209.8	68
3	1222	1220▲	1223.4	65.6	1222	1223	115.4
4	1221	1222	1224.6	103.2	1221	1221.8	94.8
5	1210	1214	1214.8	29	1214	1214.8	13
6	1213	1217	1217.6	114.4	1216	1216.8	224.4
7	1217	1216▲	1216.4	73.6	1216▲	1217.2	62.4
8	1213	1213	1213.8	71.4	1213	1213.8	108.2
9	1209	1209	1211.4	78.4	1209	1211.2	86.4
10	1212	1216	1217	32.4	1215	1215.6	122.4
$Loc = cl2$							
1	1207	1215	1216.2	182.8	1209	1211.8	131.6
2	1208	1211	1213.4	120.4	1212	1214.8	65
3	1211	1214	1216.6	102.2	1214	1217	130.4
4	1209	1213	1214	153.2	1212	1213.6	98.6
5	1210	1213	1216.2	55.8	1215	1217.2	165.6
6	1212	1214	1214	84.6	1214	1214.4	185.4
7	1211	1211	1212.2	73.6	1211	1211.4	41.4
8	1208	1210	1211.4	132	1210	1210.8	167.2
9	1207	1207	1210	139.6	1207	1207.8	130.6
10	1208	1213	1215.2	152.8	1211	1213.8	199.8
$Loc = uni$							
1	1207	1214	1215.6	158.6	1209	1210.4	156
2	1209	1210	1213.6	232.8	1214	1216.8	154.8
3	1216	1216	1217.8	109.2	1212▲	1219.2	127
4	1210	1210	1212	105	1210	1210	111.8
5	1207	1207	1210	177.6	1207	1209.4	222
6	1207	1215	1220	118.6	1209	1213.4	110.2
7	1208	1213	1213.2	154	1209	1211.6	94.4
8	1208	1209	1211.2	120.6	1213	1215.4	189.4
9	1208	1214	1216.6	124.8	1214	1216	113
10	1210	1216	1217.6	165.2	1215	1218.4	128

Table 9: Comparison of HGA and HGP with other methods (Set E)

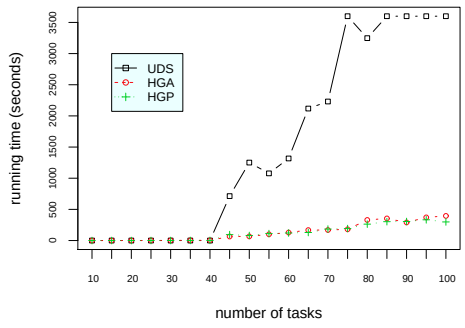
Class / Instance	UDS [2]	HGA			HGP		
	obj.	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$d = 0.80$							
1	774	774	774	39.4	774	774	20.6
2	771	772	773.8	136.8	773	773.6	138
3	772	774	775.6	44.8	772	773.6	114.6
4	758	767	768	165.6	760	762.4	221.6
5	761	762	763.4	256.8	763	764.8	192.4
6	757	759	759	110.2	759	759.6	66.8
7	782	782	782	2.4	782	782	2.4
8	758	761	761.8	160.8	761	762.8	104.8
9	798	798	798	25	798	798	6.6
10	759	761	773.4	122.8	759	760.6	115.8
$d = 0.85$							
1	774	774	774	46.6	774	774	28
2	771	775	777.2	105.8	773	773.8	180
3	772	772	774.8	48	772	772.4	132
4	761	765	767.2	155.2	765	767.8	113.6
5	761	762	762.4	254.6	763	765.8	195.2
6	757	759	759	103	759	759	73.4
7	782	782	782	2.4	782	782	2.4
8	758	762	763.4	123.2	762	763.2	122.4
9	798	798	798	17	798	798	5.4
10	759	761	763.4	210.8	761	764.8	179.6
$d = 0.90$							
1	774	774	774	37.4	774	774	20
2	771	774	777.2	115.4	774	774.8	55
3	772	776	776	38	772	772.8	65.2
4	762	768	768	192.4	765	767.2	84.6
5	761	763	765	129	765	767.2	237.2
6	757	759	760	100.4	759	759.6	100.6
7	782	782	782	1.4	782	782	1.4
8	761	762	762.6	77.4	762	762.4	89.8
9	798	798	798	9.2	798	798	2.8
10	759	763	764.8	172.4	759	760.6	166.2
$d = 0.95$							
1	774	774	774	37.4	774	774	19.6
2	771	774	777.2	115.4	774	774.8	55
3	772	772	775.4	121.2	772	773.4	129.2
4	762	768	769	144.8	765	767.4	73.4
5	761	767	767.4	113	763	765.4	159.2
6	757	759	760	100.4	759	759.6	100.6
7	782	782	782	<1	782	782	1
8	761	761	762.6	42	761	761.8	82.8
9	798	798	798	8.8	798	798	2
10	759	763	764	85	761	761.2	88.6
$d = 1$							
1	774	774	774	36.2	774	774	14.2
2	771	772	777.6	72.8	773	775	58
3	772	772	774.2	90.2	772	772.4	46.6
4	765	768	768.6	184	765	769.2	143.6
5	762	766	767.2	86.4	765	767.8	117.4
6	765	769	769	25.2	766	767.4	104
7	782	782	782	<1	782	782	1.2
8	761	761	762.6	42.2	762	763	92.4
9	798	798	798	13.2	798	798	4.8
10	759	759	763	101.8	761	762.2	101.2

Table 10: Comparison of HGA and HGP with other methods (Set F)

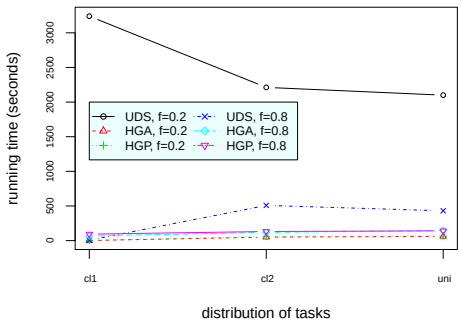
Class / Instance	UDS [2]	GA [3]		HGA			HGP		
	obj.	*obj.*	*time*	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$q = 2$									
1	1509	1509	15	1510	1512.4	135.6	1509	1509	25
2	1510	1524	14	1510	1510.4	56.4	1510	1510	8.6
3	1510	1511	14	1510	1510.6	22.8	1510	1510.4	54.4
4	1510	1511	15	1511	1511	44	1510	1510.2	44.6
5	1509	1521	15	1509	1509.2	70.4	1509	1509	14.8
6	1509	1510	13	1510	1510	3.6	1509	1509.6	17.8
7	1511	1512	15	1511	1511.4	18.6	1511	1511	12.8
8	1509	1511	14	1510	1510.2	36.6	1509	1509.8	39
9	1510	1511	15	1510	1510.6	144.2	1510	1510	47.2
10	1510	1510	13	1511	1511	25	1510	1510	63.8
$q = 3$									
1	1007	1014	31	1014	1016.2	92.6	1012	1013.2	113.6
2	1008	1013	31	1012	1013	185.8	1008	1010.2	143.8
3	1008	1013	27	1010	1011.8	92.2	1010	1010.6	138
4	1009	1015	27	1010	1011.4	100.8	1011	1011.4	141.8
5	1007	1011	35	1017	1017.2	53	1009	1011.2	153.8
6	1008	1009	30	1009	1012.2	115.4	1009	1009.2	100.2
7	1009	1011	28	1009	1009.6	53.2	1009	1009.6	69.6
8	1008	1009	29	1011	1012.8	60.2	1009	1009.8	108.6
9	1012	1019	30	1012	1016	175.2	1012	1013.2	114.6
10	1008	1012	29	1011	1011.8	105.4	1010	1011.4	62.2
$q = 4$									
1	774	784	33	774	774	40	774	774	13.8
2	771	782	34	772	777.6	81	773	775	57.6
3	772	784	28	772	774.2	100.2	772	772.4	46
4	765	803	32	768	768.8	180.8	765	769.2	141.6
5	762	792	34	766	767.2	95.6	765	767.8	115.4
6	765	769	35	769	769	28	766	767.4	102.6
7	782	782	28	782	782	<1	782	782	1.2
8	761	781	31	761	762.6	48.4	762	763	91.4
9	798	860	35	798	798	14.6	798	798	4.6
10	759	792	47	759	763	113.4	761	762.2	100
$q = 5$									
1	730	–	–	730	730	2	730	730	<1
2	768	–	–	768	768	3.8	768	768	<1
3	770	–	–	770	770.4	20.6	769▲	769.8	62
4	748	–	–	748	748	11.4	748	748	4.2
5	732	–	–	732	732	2.2	732	732	<1
6	714	–	–	714	714	37.6	714	714	6.4
7	780	–	–	780	780	<1	780	780	<1
8	650	–	–	655	663.4	193.2	659	659.6	24.4
9	797	–	–	796▲	796	35.8	796▲	796	11.6
10	684	–	–	685	685	3.6	684	684.2	136.8
$q = 6$									
1	730	–	–	730	730	1.2	730	730	<1
2	768	–	–	767▲	767.4	100.8	767▲	767.2	79.4
3	769	–	–	768▲	768.4	39.4	768▲	768	39.4
4	746	–	–	746	746	36	746	746	17.4
5	732	–	–	731▲	731.2	179.8	731▲	731.6	66.4
6	714	–	–	714	714	13.8	714	714	1.8
7	779	–	–	777▲	777.2	120.2	777▲	777.2	116.2
8	643	–	–	643	643	27	643	643	1
9	797	–	–	796▲	796	41	795▲	795.8	46.8
10	683	–	–	683	683	5.8	683	683	<1

Table 11: Comparison of HGA and HGP with other methods (Set G)

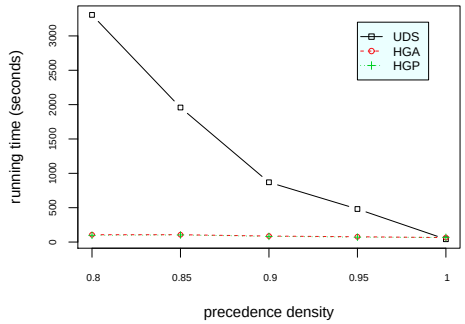
Class / Instance	UDS [2]	HGA			HGP		
	obj.	*best*	*avg.*	t_{best}	*best*	*avg.*	t_{best}
$s = 0$							
1	757	762	764	231.2	758	759.4	104.8
2	759	762	764.2	159.2	762	765.2	143.2
3	759	763	765.8	200.4	762	763.4	154
4	759	761	764.2	128	761	763.4	160.2
5	758	760	762.2	200	761	763.8	103.4
6	758	761	762	141.6	761	762	165.4
7	760	761	761.6	111.2	761	762	63.8
8	757	760	761.8	74.6	759	760.8	121.4
9	758	759	762.8	175.2	765	766.4	94.2
10	759	760	762.2	162.6	763	767	91.8
$s = 1$							
1	774	774	774	36.4	774	774	14.4
2	771	772	777.6	74	773	775.8	44.4
3	772	772	774.2	93.4	772	772.6	41
4	765	768	768.6	186.6	765	769.2	144.6
5	762	766	767.2	87.8	765	767.8	117.8
6	765	769	769	25.8	766	767.4	104.4
7	782	782	782	<1	782	782	1.2
8	761	761	762.6	43	762	763	92.6
9	798	798	798	13.6	798	798	4.8
10	759	759	763	103.6	761	762.2	101.8
$s = 2$							
1	1059	1059	1059	<1	1059	1059	<1
2	950	949▲	949	113.8	949▲	949	43
3	976	976	976.4	8.4	976	976	55
4	1104	1104	1104.4	21.2	1103▲	1103.4	87.6
5	833	833	833	2	833	833	<1
6	1031	1031	1031	5.8	1031	1031	<1
7	1042	1042	1042	<1	1042	1042	<1
8	954	953▲	953	33	953▲	953	86
9	1075	1074▲	1074.4	121.6	1074▲	1074.2	56.4
10	930	930	930	8.4	930	930	<1
$s = 3$							
1	1381	1381	1381	<1	1381	1381	<1
2	1288	1288	1288	<1	1288	1288	<1
3	1098	1098	1098	1	1098	1098	<1
4	1365	1365	1365	<1	1365	1365	<1
5	1040	1040	1040	<1	1040	1040	<1
6	1262	1262	1262	<1	1262	1262	<1
7	1431	1430▲	1430	4	1430▲	1430	<1
8	1092	1092	1092	<1	1092	1092	<1
9	1252	1252	1252	<1	1252	1252	<1
10	1190	1190	1190	1	1190	1190	<1
$s = 4$							
1	1501	1501	1501	<1	1501	1501	<1
2	1328	1328	1328	<1	1328	1328	<1
3	1275	1276	1276.2	12.8	1275	1275	13
4	1443	1444	1444	5	1443	1443.4	75.6
5	1327	1327	1327	<1	1327	1327	<1
6	1622	1622	1622	<1	1622	1622	<1
7	1448	1448	1448	1.2	1448	1448	<1
8	1345	1345	1345	<1	1345	1345	<1
9	1328	1328	1328	1	1328	1328	<1
10	1437	1437	1437	3.8	1437	1437	<1



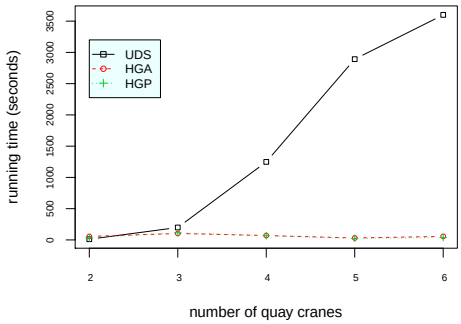
(a) Sets $A - C$



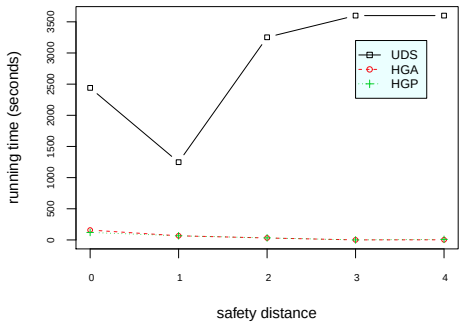
(b) Set D



(c) Set E



(d) Set F



(e) Set G

Figure 1: Computational times of HGA, HGP and UDS. (The computational times of HGA and HGP are very similar in these datasets. In Figure 1 (b), the lines for HGA ($f = 0.2$) and HGP ($f = 0.2$) almost overlap each other. HGA ($f = 0.8$) and HGP ($f = 0.8$) are also in the same situation.)