A Master-Apprentice Evolutionary Algorithm for the Flexible Job Shop Scheduling Problem

Abstract

This paper presents an evolutionary algorithm based on two individuals (called master-apprentice evolutionary algorithm, MAE) for solving the flexible job shop scheduling problem, which distinguishes itself from both single solution-based and traditional population-based metaheuristics. MAE integrates a tabu search procedure, a path-relinking recombination operator, and an individual updating strategy. At each generation, a path relinking recombination operator is applied on the two individuals to generate two child solutions. The individual updating strategy is conducted once a given number of generations (called a cycle) is reached: one of the two individuals is updated at the end of a cycle with the best solution found in the previous cycle. The other individual is initialized when the two individuals are close to each other at each generation. Computational experiments on 178 public instances show that MAE achieves highly competitive results in terms of both solution quality and computational efficiency compared with the state-of-the-art algorithms in the literature. Specifically, it improves the previous best known results for 47 instances while matching the best known results on all except 5 of the remaining instances with short computational time.

Keywords: flexible job shop scheduling problem, master-apprentice evolutionary algorithm, path relinking.

1. The computational results of MAE

This paper is an appendix of the paper submitted to IJCAI-2018, which provides the overall computational results of MAE on the benchmark sets (*DPdata* (Dauzre-Prs and Paulli, 1997), *BCdata* (Barnes and Chambers, 1998), *BRdata* (Brandimarte, 1993), and *HUdata* (Hurink et al., 1994)) and make comparisons with the recent state-of-the-art algorithms (SSPR Gonzlez et al. (2015) and GRASP-mELS Kemmo-Tchomt et al. (2017)) in the literature.

1.1. The results of MAE on DPdata set

Table 1: Comparison between MAE and other reference algorithms on *DPdata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
01a	2505*	2505	2505	**2505**	**2505**	**2505**
02a	2228*	2228	2228	2229	2229	2228
03a	2228*	2228	2228	**2228**	**2228**	**2228**
04a	2503*	2503	2503	**2503**	**2503**	**2503**
05a	2192	2204	2189	2211	2212	2203
06a	2163	2171	2162	2183	2195	**2181**
07a	2216	2264	2187	2274	2276	2254
08a	2061*	2061	2061	2064	2069	2062
09a	2061*	2061	2061	**2062**	2069	**2062**
10a	2212	2241	2178	2269	2263	2245
11a	2018	2037	2017	2051	2065	2045
12a	1969	1984	1969	2018	2039	2008
13a	2197	2239	2161	2248	2252	2236
14a	2161*	2161	2161	2163	2170	2162
15a	2161*	2161	2161	**2162**	2172	**2162**
16a	2193	2231	2148	2244	2243	2232
17a	2088	2105	2088	2130	2145	2121
18a	2057	2070	2057	2119	2146	2108

1.2. The results of MAE on BCdata set

1.3. The results of MAE on BRdata set

1.4. The results of MAE on HUdata set

References

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Table 2: Comparison between MAE and other reference algorithms on *BCdata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
mt10c1	927*	927	655	**927**	**927**	**927**
mt10cc	908*	908	655	**908**	**908**	**908**
mt10x	918*	918	655	**918**	**918**	**918**
mt10xx	918*	918	655	**918**	**918**	**918**
mt10xxx	918*	918	655	**918**	**918**	**918**
mt10xy	905*	905	655	**905**	**905**	**905**
mt10xyz	847*	847	655	**847**	**847**	**847**
setb4c9	914*	914	857	**914**	**914**	**914**
setb4cc	907*	907	857	**907**	**907**	**907**
setb4x	925*	925	846	**925**	**925**	**925**
setb4xx	925*	925	846	**925**	**925**	**925**
setb4xxx	925*	925	846	**925**	**925**	**925**
setb4xy	910*	910	845	**910**	**910**	**910**
setb4xyz	902*	902	838	905	**902**	**902**
seti5c12	1169*	1169	1027	1170	**1169**	1170
seti5cc	1135*	1135	955	**1135**	**1135**	**1135**
seti5x	1198*	1198	955	**1198**	**1198**	**1198**
seti5xx	1194*	1194	955	1197	**1194**	1197
seti5xxx	1194*	1194	955	**1194**	**1194**	1197
seti5xy	1135*	1135	955	**1135**	**1135**	1135
seti5xyz	1125*	1125	955	**1125**	**1125**	**1125**

Table 3: Comparison between MAE and other reference algorithms on *BRdata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
Mk01	40*	40	36	**40**	**40**	**40**
Mk02	26*	26	24	**26**	**26**	**26**
Mk03	204*	204	204	**204**	**204**	**204**
Mk04	60*	60	48	**60**	**60**	**60**
Mk05	172*	172	168	**172**	**172**	**172**
Mk06	57*	57	33	**57**	58	**57**
Mk07	139*	139	133	**139**	**139**	**139**
Mk08	523*	523	523	**523**	**523**	**523**
Mk09	307*	307	299	**307**	**307**	**307**
Mk10	189	193	165	196	197	**193**

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Hurink, J., Jurisch, B., Thole, M., 1994. Tabu search for the job-shop scheduling problem with multi-purpose machines. Operations-Research-Spektrum 15 (4), 205–215.

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Table 4: Comparison between MAE and other reference algorithms on *edata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
edata-abz5	1167*	1167	-	-	-	**1167**
edata-abz6	925*	925	-	-	-	**925**
edata-abz7	604	610	-	-	-	610
edata-abz8	625	636	-	-	-	636
edata-abz9	644*	644	-	-	-	646
edata-car1	6176*	6176	-	-	-	**6176**
edata-car2	6327*	6327	-	-	-	**6327**
edata-car3	6856*	6856	-	-	-	**6856**
edata-car4	7789*	7789	-	-	-	**7789**
edata-car5	7229*	7229	-	-	-	**7229**
edata-car6	7990*	7990	-	-	-	**7990**
edata-car7	6123*	6123	-	-	-	**6123**
edata-car8	7689*	7689	-	-	-	**7689**
edata-la01	609*	609	609	**609**	**609**	**609**
edata-la02	655*	655	655	**655**	**655**	**655**
edata-la03	550*	550	550	**550**	**550**	**550**
edata-la04	568*	568	568	**568**	**568**	**568**
edata-la05	503*	503	503	**503**	**503**	**503**
edata-la06	833*	833	833	**833**	**833**	**833**
edata-la07	762*	762	762	**762**	**762**	**762**
edata-la08	845*	845	845	**845**	**845**	**845**
edata-la09	878*	878	878	**878**	**878**	**878**
edata-la10	866*	866	866	**866**	**866**	**866**
edata-la11	1103*	1103	1087	**1103**	**1103**	**1103**
edata-la12	960*	960	960	**960**	**960**	**960**
edata-la13	1053*	1053	1053	**1053**	**1053**	**1053**
edata-la14	1123*	1123	1123	**1123**	**1123**	**1123**
edata-la15	1111*	1111	1111	**1111**	**1111**	**1111**
edata-la16	892*	892	892	**892**	**892**	**892**
edata-la17	707*	707	707	**707**	**707**	**707**
edata-la18	842*	842	842	**842**	**842**	**842**
edata-la19	796*	796	796	**796**	**796**	**796**
edata-la20	857*	857	857	**857**	**857**	**857**
edata-la21	1009*	1009	895	1010	**1009**	**1009**
edata-la22	880*	880	832	**880**	**880**	**880**
edata-la23	950*	950	950	**950**	**950**	**950**
edata-la24	908*	908	881	**908**	**908**	**908**
edata-la25	936*	936	894	939	**936**	**936**
edata-la26	1106*	1106	1089	1109	1107	1111
edata-la27	1181*	1181	1181	**1181**	**1181**	**1181**
edata-la28	1142*	1142	1116	1144	1144	**1142**
edata-la29	1107*	1107	1058	1111	1113	1112
edata-la30	1188*	1188	1147	1204	1198	1193
edata-la31	1532*	1532	1523	1533	1536	**1532**
edata-la32	1698*	1698	1698	**1698**	**1698**	**1698**
edata-la33	1547*	1547	1547	**1547**	**1547**	**1547**
edata-la34	1599*	1599	1592	**1599**	**1599**	**1599**
edata-la35	1736*	1736	1736	**1736**	**1736**	**1736**
edata-la36	1160*	1160	1006	**1160**	**1160**	**1160**
edata-la37	1397*	1397	1355	**1397**	**1397**	**1397**
edata-la38	1141*	1141	1019	**1141**	**1141**	**1141**
edata-la39	1184*	1184	1151	**1184**	**1184**	**1184**
edata-la40	1144*	1144	1034	**1144**	**1144**	**1144**
edata-mt06	55*	55	55	**55**	**55**	**55**
edata-mt10	871*	871	871	**871**	**871**	**871**
edata-mt20	1088*	1088	1088	**1088**	**1088**	**1088**
edata-orb1	977*	977	-	-	-	**977**
edata-orb10	933*	933	-	-	-	**933**
edata-orb2	865*	865	-	-	-	**865**
edata-orb3	951*	951	-	-	-	**951**
edata-orb4	984*	984	-	-	-	**984**
edata-orb5	842*	842	-	-	-	**842**
edata-orb6	958*	958	-	-	-	**958**
edata-orb7	389*	389	-	-	-	**389**
edata-orb8	894*	894	-	-	-	**894**
edata-orb9	933*	933	-	-	-	**933**

Table 5: Comparison between MAE and other reference algorithms on *rdata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
rdata-abz5	954*	954	-	-	-	**954**
rdata-abz6	807*	807	-	-	-	**807**
rdata-abz7	493	524	-	-	-	522
rdata-abz8	507	536	-	-	-	535
rdata-abz9	517	536	-	-	-	536
rdata-car1	5034*	5034	-	-	-	**5034**
rdata-car2	5985*	5985	-	-	-	**5985**
rdata-car3	5622*	5622	-	-	-	**5622**
rdata-car4	6514*	6514	-	-	-	**6514**
rdata-car5	5615*	5615	-	-	-	**5615**
rdata-car6	6147*	6147	-	-	-	**6147**
rdata-car7	4425*	4425	-	-	-	**4425**
rdata-car8	5692*	5692	-	-	-	**5692**
rdata-la01	570*	570	570	571	**570**	**570**
rdata-la02	529*	529	529	530	**529**	**529**
rdata-la03	477*	477	477	**477**	**477**	**477**
rdata-la04	502*	502	502	**502**	**502**	**502**
rdata-la05	457*	457	457	**457**	**457**	**457**
rdata-la06	799*	799	799	**799**	**799**	**799**
rdata-la07	749*	749	749	**749**	**749**	**749**
rdata-la08	765*	765	765	**765**	**765**	**765**
rdata-la09	853*	853	853	**853**	**853**	**853**
rdata-la10	804*	804	804	**804**	**804**	**804**
rdata-la11	1071*	1071	1071	**1071**	**1071**	**1071**
rdata-la12	936*	936	936	**936**	**936**	**936**
rdata-la13	1038*	1038	1038	**1038**	**1038**	**1038**
rdata-la14	1070*	1070	1070	**1070**	**1070**	**1070**
rdata-la15	1089*	1089	1089	**1089**	**1089**	**1089**
rdata-la16	717*	717	717	**717**	**717**	**717**
rdata-la17	646*	646	646	**646**	**646**	**646**
rdata-la18	666*	666	666	**666**	**666**	**666**
rdata-la19	700*	700	647	**700**	**700**	**700**
rdata-la20	756*	756	756	**756**	**756**	**756**
rdata-la21	808	825	808	830	832	825
rdata-la22	741	755	737	756	757	753
rdata-la23	816	832	816	835	836	831
rdata-la24	775	796	775	802	802	795
rdata-la25	768	783	752	784	784	779
rdata-la26	1056	1057	1056	1059	1060	1057
rdata-la27	1085*	1085	1085	1089	1089	1086
rdata-la28	1075	1076	1075	1078	1077	1076
rdata-la29	993	994	993	996	996	994
rdata-la30	1068	1071	1068	1074	1074	1071
rdata-la31	1520*	1520	1520	**1520**	1521	**1520**
rdata-la32	1657*	1657	1657	1658	1658	**1657**
rdata-la33	1497*	1497	1497	1498	1498	**1497**
rdata-la34	1535*	1535	1535	**1535**	**1535**	**1535**
rdata-la35	1549*	1549	1549	1550	1550	**1549**
rdata-la36	1023*	1023	1016	**1023**	**1023**	**1023**
rdata-la37	1062*	1062	989	1069	1066	**1062**
rdata-la38	954*	954	943	961	958	**954**
rdata-la39	1011*	1011	966	1024	1018	**1011**
rdata-la40	955*	955	955	961	958	**955**
rdata-mt06	47*	47	47	**47**	**47**	**47**
rdata-mt10	686*	686	679	**686**	**686**	**686**
rdata-mt20	1022*	1022	1022	**1022**	**1022**	**1022**
rdata-orb1	746*	746	-	-	-	**746**
rdata-orb10	742*	742	-	-	-	**742**
rdata-orb2	696*	696	-	-	-	**696**
rdata-orb3	712*	712	-	-	-	**712**
rdata-orb4	753*	753	-	-	-	**753**
rdata-orb5	639*	639	-	-	-	**639**
rdata-orb6	754*	754	-	-	-	**754**
rdata-orb7	302*	302	-	-	-	**302**
rdata-orb8	639*	639	-	-	-	**639**
rdata-orb9	694*	694	-	-	-	**694**

Table 6: Comparison between MAE and other reference algorithms on *vdata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
vdata-abz5	859*	859	-	-	-	**859**
vdata-abz6	742*	742	-	-	-	**742**
vdata-abz7	492*	492	-	-	-	498
vdata-abz8	506	507	-	-	-	512
vdata-abz9	497*	497	-	-	-	503
vdata-car1	5005*	5005	-	-	-	**5005**
vdata-car2	5929*	5929	-	-	-	**5929**
vdata-car3	5597*	5597	-	-	-	**5597**
vdata-car4	6514*	6514	-	-	-	**6514**
vdata-car5	4909	4911	-	-	-	4910
vdata-car6	5486*	5486	-	-	-	**5486**
vdata-car7	4281*	4281	-	-	-	**4281**
vdata-car8	4613*	4613	-	-	-	**4613**
vdata-la01	570*	570	570	**570**	**570**	**570**
vdata-la02	529*	529	529	**529**	**529**	**529**
vdata-la03	477*	477	477	**477**	**477**	**477**
vdata-la04	502*	502	502	**502**	**502**	**502**
vdata-la05	457*	457	457	**457**	**457**	**457**
vdata-la06	799*	799	799	**799**	**799**	**799**
vdata-la07	749*	749	749	**749**	**749**	**749**
vdata-la08	765*	765	765	**765**	**765**	**765**
vdata-la09	853*	853	853	**853**	**853**	**853**
vdata-la10	804*	804	804	**804**	**804**	**804**
vdata-la11	1071*	1071	1071	**1071**	**1071**	**1071**
vdata-la12	936*	936	936	**936**	**936**	**936**
vdata-la13	1038*	1038	1038	**1038**	**1038**	**1038**
vdata-la14	1070*	1070	1070	**1070**	**1070**	**1070**
vdata-la15	1089*	1089	1089	**1089**	**1089**	**1089**
vdata-la16	717*	717	717	**717**	**717**	**717**
vdata-la17	646*	646	646	**646**	**646**	**646**
vdata-la18	663*	663	663	**663**	**663**	**663**
vdata-la19	617*	617	617	**617**	**617**	**617**
vdata-la20	756*	756	756	**756**	**756**	**756**
vdata-la21	800*	800	800	802	804	801
vdata-la22	733*	733	733	734	737	**733**
vdata-la23	809*	809	809	811	813	810
vdata-la24	773*	773	773	775	776	774
vdata-la25	751*	751	751	753	755	752
vdata-la26	1052*	1052	1052	1053	1054	**1052**
vdata-la27	1084*	1084	1084	**1084**	1086	**1084**
vdata-la28	1069*	1069	1069	**1069**	1070	**1069**
vdata-la29	993*	993	993	994	995	**993**
vdata-la30	1068*	1068	1068	1069	1070	**1068**
vdata-la31	1520*	1520	1520	**1520**	1521	**1520**
vdata-la32	1657*	1657	1657	1658	1658	**1657**
vdata-la33	1497*	1497	1497	**1497**	1498	**1497**
vdata-la34	1535*	1535	1535	**1535**	**1535**	**1535**
vdata-la35	1549*	1549	1549	**1549**	**1549**	**1549**
vdata-la36	948*	948	948	**948**	**948**	**948**
vdata-la37	986*	986	986	**986**	**986**	**986**
vdata-la38	943*	943	943	**943**	**943**	**943**
vdata-la39	922*	922	922	**922**	**922**	**922**
vdata-la40	955*	955	955	**955**	**955**	**955**
vdata-mt06	47*	47	47	**47**	**47**	**47**
vdata-mt10	655*	655	655	**655**	**655**	**655**
vdata-mt20	1022*	1022	1022	**1022**	**1022**	**1022**
vdata-orb1	695*	695	-	-	-	**695**
vdata-orb10	681*	681	-	-	-	**681**
vdata-orb2	620*	620	-	-	-	**620**
vdata-orb3	648*	648	-	-	-	**648**
vdata-orb4	753*	753	-	-	-	**753**
vdata-orb5	584*	584	-	-	-	**584**
vdata-orb6	715*	715	-	-	-	**715**
vdata-orb7	275*	275	-	-	-	**275**
vdata-orb8	573*	573	-	-	-	**573**
vdata-orb9	659*	659	-	-	-	**659**

Table 7: Comparison between MAE and other reference algorithms on *sdata* instance set

Ins.	Qunitiq		SSPR		GRASP-mELS	MAE
	LB	UB	LB	best	best	best
sdata-abz5	1234*	1234	-	-	-	**1234**
sdata-abz6	943*	943	-	-	-	**943**
sdata-abz7	656*	656	-	-	-	658
sdata-abz8	653	667	-	-	-	667
sdata-abz9	678*	678	-	-	-	**678**
sdata-car1	7038*	7038	-	-	-	**7038**
sdata-car2	7166*	7166	-	-	-	**7166**
sdata-car3	7312*	7312	-	-	-	**7312**
sdata-car4	8003*	8003	-	-	-	**8003**
sdata-car5	7702*	7702	-	-	-	**7702**
sdata-car6	8313*	8313	-	-	-	**8313**
sdata-car7	6558*	6558	-	-	-	**6558**
sdata-car8	8264*	8264	-	-	-	**8264**
sdata-la01	666*	666	666	**666**	-	**666**
sdata-la02	655*	655	655	**655**	-	**655**
sdata-la03	597*	597	597	**597**	-	**597**
sdata-la04	590*	590	590	**590**	-	**590**
sdata-la05	593*	593	593	**593**	-	**593**
sdata-la06	926*	926	926	**926**	-	**926**
sdata-la07	890*	890	890	**890**	-	**890**
sdata-la08	863*	863	863	**863**	-	**863**
sdata-la09	951*	951	951	**951**	-	**951**
sdata-la10	958*	958	958	**958**	-	**958**
sdata-la11	1222*	1222	1222	**1222**	-	**1222**
sdata-la12	1039*	1039	1039	**1039**	-	**1039**
sdata-la13	1150*	1150	1150	**1150**	-	**1150**
sdata-la14	1292*	1292	1292	**1292**	-	**1292**
sdata-la15	1207*	1207	1207	**1207**	-	**1207**
sdata-la16	945*	945	945	**945**	-	**945**
sdata-la17	784*	784	784	**784**	-	**784**
sdata-la18	848*	848	848	**848**	-	**848**
sdata-la19	842*	842	842	**842**	-	**842**
sdata-la20	902*	902	902	**902**	-	**902**
sdata-la21	1046*	1046	1040	**1046**	-	**1046**
sdata-la22	927*	927	927	**927**	-	**927**
sdata-la23	1032*	1032	1032	**1032**	-	**1032**
sdata-la24	935*	935	935	**935**	-	**935**
sdata-la25	977*	977	977	**977**	-	**977**
sdata-la26	1218*	1218	1218	**1218**	-	**1218**
sdata-la27	1235*	1235	1235	**1235**	-	**1235**
sdata-la28	1216*	1216	1216	**1216**	-	**1216**
sdata-la29	1152*	1152	1120	1160	-	1153
sdata-la30	1355*	1355	1355	**1355**	-	**1355**
sdata-la31	1784*	1784	1784	**1784**	-	**1784**
sdata-la32	1850*	1850	1850	**1850**	-	**1850**
sdata-la33	1719*	1719	1719	**1719**	-	**1719**
sdata-la34	1721*	1721	1721	**1721**	-	**1721**
sdata-la35	1888*	1888	1888	**1888**	-	**1888**
sdata-la36	1268*	1268	1268	**1268**	-	**1268**
sdata-la37	1397*	1397	1397	**1397**	-	**1397**
sdata-la38	1196*	1196	1184	1198	-	**1196**
sdata-la39	1233*	1233	1233	**1233**	-	**1233**
sdata-la40	1222*	1222	1222	1224	-	1224
sdata-mt06	55*	55	55	**55**	-	**55**
sdata-mt10	930*	930	930	**930**	-	**930**
sdata-mt20	1165*	1165	1165	**1165**	-	**1165**
sdata-orb1	1059*	1059	-	-	-	**1059**
sdata-orb10	944*	944	-	-	-	**944**
sdata-orb2	888*	888	-	-	-	**888**
sdata-orb3	1005*	1005	-	-	-	**1005**
sdata-orb4	1005*	1005	-	-	-	**1005**
sdata-orb5	887*	887	-	-	-	**887**
sdata-orb6	1010*	1010	-	-	-	**1010**
sdata-orb7	397*	397	-	-	-	**397**
sdata-orb8	899*	899	-	-	-	**899**
sdata-orb9	934*	934	-	-	-	**934**