

A Hybrid Metaheuristic for the Quadratic Assignment Problem[†]

Lin-Yu Tseng*

Department of Computer Science
National Chung Hsing University
Taichung, Taiwan 402, R.O.C.

Tel : 886-4-22874020

Fax : 886-4-22853869

e-mail: lytseng@cs.nchu.edu.tw

Shyi-Ching Liang

Department of Applied Mathematics
National Chung Hsing University
Taichung, Taiwan 402, R.O.C.

e-mail: scliang@mail.cyut.edu.tw

Table 1. The computational results of ANGEL on all QAPLIB instances with sizes not less than 30.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
nug30	6124	10/10	8	1	3	42.91	1.31	18.83	6124	6124	6124	0.00	0.00
esc32a	130	10/10	3	1	1	17.77	0.58	6.82	130	130	130	0.00	0.00
esc32b	168	10/10	1	1	1	1.61	0.06	0.42	168	168	168	0.00	0.00
esc32c	642	10/10	1	1	1	0.08	0.02	0.03	642	642	642	0.00	0.00
esc32d	200	10/10	1	1	1	1.09	0.05	0.17	200	200	200	0.00	0.00
esc32e	2	10/10	1	1	1	0.06	0.02	0.02	2	2	2	0.00	0.00
esc32f	2	10/10	1	1	1	0.05	0.02	0.02	2	2	2	0.00	0.00
esc32g	6	10/10	1	1	1	0.06	0.00	0.02	6	6	6	0.00	0.00
esc32h	438	10/10	1	1	1	1.17	0.06	0.29	438	438	438	0.00	0.00
esc64a	116	10/10	1	1	1	0.99	0.06	0.26	116	116	116	0.00	0.00
esc128	64	10/10	1	1	1	3.74	0.56	2.27	64	64	64	0.00	0.00
kra30a	88900	10/10	4	1	1	17.41	0.17	7.25	88900	88900	88900	0.00	0.00
kra30b	91420	10/10	19	1	7	115.72	1.00	40.22	91420	91420	91420	0.00	0.00
tho30	149936	10/10	4	1	1	22.97	0.28	7.07	149936	149936	149936	0.00	0.00
tho40	240516	4/10	30	2	20	665.20	3.89	231.76	240620	240516	240540	0.01	0.00
tho150	8133864	0/10	30	13	14	23229.46	1132.72	12537.11	8142736	8137808	8141521	0.09	0.05
wil50	48816	10/10	30	17	22	1733.38	577.12	838.53	48816	48816	48816	0.00	0.00
wil100	273038	2/10	30	30	30	7889.70	714.41	6665.62	273090	273038	273058	0.01	0.00
ste36a	9526	10/10	7	1	3	76.47	2.55	37.48	9526	9526	9526	0.00	0.00
ste36b	15852	10/10	4	1	1	34.67	0.45	6.37	15852	15852	15852	0.00	0.00
ste36c	8239110	10/10	5	1	2	46.28	7.78	27.28	8239110	8239110	8239110	0.00	0.00
sko42	15812	10/10	11	1	3	185.81	1.25	42.43	15812	15812	15812	0.00	0.00
sko49	23386	2/10	30	18	28	820.89	50.28	454.68	23410	23386	23399	0.06	0.00
sko56	34458	4/10	30	3	22	943.03	91.77	544.36	34472	34458	34462	0.01	0.00
sko64	48498	6/10	30	1	19	1881.33	50.20	1040.72	48508	48498	48500	0.00	0.00
sko72	66256	1/10	30	12	28	4643.67	1683.88	4249.65	66274	66256	66268	0.02	0.00
sko81	90998	0/10	30	30	30	8531.74	6320.72	6739.64	91040	91008	91021	0.03	0.01
sko90	115534	0/10	30	30	30	5973.88	4938.52	5524.15	115590	115560	115583	0.04	0.02
sko100a	152002	2/10	30	30	30	11753.38	10520.47	10235.89	152066	152002	152034	0.02	0.00
sko100b	153890	3/10	30	30	30	12346.46	11258.07	11546.33	153944	153890	153908	0.01	0.00
sko100c	147862	3/10	30	30	30	13687.69	12445.57	13234.48	147890	147862	147869	0.00	0.00
sko100d	149576	0/10	30	30	30	12867.02	12411.94	12552.93	149658	149584	149619	0.03	0.01
sko100e	149150	7/10	30	30	30	12256.22	11887.84	12484.66	149174	149150	149153	0.00	0.00
sko100f	149036	0/10	30	30	30	12719.13	12580.61	12651.49	149132	149060	149086	0.03	0.02
tai30a	1818146	1/10	30	14	28	186.38	8.84	84.74	1827982	1818146	1824347	0.34	0.00
tai35a	2422002	1/10	30	29	29	334.86	44.80	212.11	2440626	2422002	2433802	0.49	0.00
tai40a	3139370	0/10	30	30	30	895.94	760.22	783.14	3169600	3148944	3157975	0.59	0.30
tai50a	4941410	0/10	30	30	30	1965.83	1587.44	1778.98	4,993,076	4953544	4983296	0.85	0.25
tai60a	7208572	0/10	30	30	30	4498.35	3782.03	3509.69	7293292	7267664	7282896	1.03	0.82
tai80a	13557864	0/10	30	30	30	9276.78	9048.87	9132.04	13713552	13633980	13674695	0.86	0.56
tai100a	21125314	0/10	30	30	30	20174.68	20092.35	20137.12	21342240	21226054	21293854	0.80	0.48
tai64c	1855928	10/10	1	1	1	3.47	0.25	1.54	1855928	1855928	1855928	0.00	0.00
tai256c	44759294	0/10	10	10	10	27589.55	25350.31	26320.92	44802030	44799798	44801150	0.09	0.09
tai30b	637117113	10/10	3	1	1	38.95	0.75	15.05	637117113	637117113	637117113	0.00	0.00
tai35b	283315445	10/10	3	1	1	56.11	1.27	19.09	283315445	283315445	283315445	0.00	0.00
tai40b	637250948	10/10	3	1	1	89.49	1.63	35.26	637250948	637250948	637250948	0.00	0.00
tai50b	458821517	10/10	5	1	2	474.83	35.97	173.51	458821517	458821517	458821517	0.00	0.00
tai60b	608215054	10/10	3	1	1	489.94	10.67	169.77	608215054	608215054	608215054	0.00	0.00
tai80b	818415043	10/10	13	1	6	7431.17	198.47	3617.40	818415043	818415043	818415043	0.00	0.00
tai100b	1185996137	5/10	30	30	30	43512.53	40342.56	41932.35	1.186E+09	1.186E+09	1.186E+09	0.01	0.00
tai150b	498896643	0/10	10	10	10	22040.75	19415.11	20206.81	499486180	499151120	499387126	0.10	0.05
lipa30a	13178	10/10	2	1	1	31.27	0.19	7.30	13178	13178	13178	0.00	0.00
lipa40a	31538	10/10	4	1	1	196.55	4.33	67.31	31538	31538	31538	0.00	0.00
lipa50a	62093	10/10	6	1	2	709.78	15.17	314.17	62093	62093	62093	0.00	0.00
lipa60a	107218	10/10	17	2	6	4790.31	282.52	1523.23	107218	107218	107218	0.00	0.00
lipa70a	169755	9/10	30	1	6	9991.86	300.47	2379.64	170717	169755	169851	0.06	0.00
lipa80a	253195	0/10	15	1	8	12779.63	387.94	6835.86	254642	254496	254580	0.55	0.51
lipa90a	360630	3/10	20	2	7	15952.04	3789.93	7583.05	362533	360630	361883.67	0.35	0.00
lipa30b	151426	10/10	1	1	1	0.64	0.05	0.29	151426	151426	151426	0.00	0.00
lipa40b	476581	10/10	1	1	1	1.70	0.16	0.75	476581	476581	476581	0.00	0.00
lipa50b	1210244	10/10	1	1	1	14.34	0.94	3.12	1210244	1210244	1210244	0.00	0.00
lipa60b	2520135	10/10	1	1	1	49.08	2.16	13.45	2520135	2520135	2520135	0.00	0.00
lipa70b	4603200	10/10	1	1	1	360.58	4.92	84.79	4603200	4603200	4603200	0.00	0.00
lipa80b	7763962	10/10	2	1	1	529.34	6.25	145.33	7763962	7763962	7763962	0.00	0.00
lipa90b	12490441	10/10	1	1	1	325.75	12.47	157.84	12490441	12490441	12490441	0.00	0.00

Table 2. Comparison of results obtained by ANGEL, GA+LS, and ACO+LS.

instance	best known value	success/runs	CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.				avg.	best
nug30	6124	10/10	42.91	1.31	18.83	6124	6124	6124	0.00	0.00
	GA+LS	10/10	254.13	2.41	62.96	6124	6124	6124	0.00	0.00
	ACO+LS	8/10	500.03	5.28	192.40	6128	6124	6124	0.00	0.00
esc64a	116	10/10	0.99	0.06	0.26	116	116	116	0.00	0.00
	GA+LS	10/10	6.38	1.24	2.02	116	116	116	0.00	0.00
	ACO+LS	10/10	1.66	0.14	0.52	116	116	116	0.00	0.00
esc128	64	10/10	3.74	0.56	2.27	64	64	64	0.00	0.00
	GA+LS	10/10	29.09	10.88	16.67	64	64	64	0.00	0.00
	ACO+LS	10/10	351.05	10.02	93.78	64	64	64	0.00	0.00
kra30a	88900	10/10	17.41	0.17	7.25	88900	88900	88900	0.00	0.00
	GA+LS	10/10	89.45	1.11	31.58	88900	88900	88900	0.00	0.00
	ACO+LS	6/10	500.03	3.94	297.83	90090	88900	89289	0.44	0.00
kra30b	91420	10/10	115.72	1.00	40.22	91420	91420	91420	0.00	0.00
	GA+LS	10/10	301.13	1.73	115.52	91420	91420	91420	0.00	0.00
	ACO+LS	1/10	500.03	168.42	466.86	91650	91420	91536	0.13	0.00
ste36a	9526	10/10	76.47	2.55	37.48	9526	9526	9526	0.00	0.00
	GA+LS	10/10	312.13	3.72	155.83	9526	9526	9526	0.00	0.00
	ACO+LS	0/10	500.05	500.15	500.02	9612	9548	9596	0.73	0.23
ste36b	15852	10/10	34.67	0.45	6.37	15852	15852	15852	0.00	0.00
	GA+LS	10/10	18.83	1.05	6.55	15852	15852	15852	0.00	0.00
	ACO+LS	10/10	495.19	1.00	167.45	15852	15852	15852	0.00	0.00
ste36c	8239110	10/10	46.28	7.78	27.28	8239110	8239110	8239110	0.00	0.00
	GA+LS	10/10	130.94	5.28	52.39	8239110	8239110	8239110	0.00	0.00
	ACO+LS	0/10	500.05	500.15	500.02	8267442	8254628	8261531	0.27	0.19
tai50b	458821517	10/10	474.83	35.97	173.51	458821517	458821517	458821517	0.00	0.00
	GA+LS	10/10	369.92	3.44	160.95	458821517	458821517	458821517	0.00	0.00
	ACO+LS	0/10	500.39	500.02	500.24	461646151	459186020	460869717	0.45	0.08
tai60b	608215054	10/10	489.94	10.67	169.77	608215054	608215054	608215054	0.00	0.00
	GA+LS	10/10	473.11	8.86	208.54	608215054	608215054	608215054	0.00	0.00
	ACO+LS	0/10	500.50	500.05	500.24	611777282	609676041	610487342	0.37	0.24
tai80b	818415043	10/10	7431.17	198.47	3617.40	818415043	818415043	818415043	0.00	0.00
	GA+LS	10/10	9452.63	1121.74	4705.32	818415043	818415043	818415043	0.00	0.00
	ACO+LS	0/10	15001.14	15000.23	15000.71	828716315	822352406	824564103	0.75	0.48
lipa40a	31538	10/10	196.55	4.33	67.31	31538	31538	31538	0.00	0.00
	GA+LS	10/10	155.80	4.77	48.28	31538	31538	31538	0.00	0.00
	ACO+LS	0/10	500.11	500.15	500.45	31918	31821	31898	1.14	0.90
lipa50a	62093	10/10	709.78	15.17	314.17	62093	62093	62093	0.00	0.00
	GA+LS	10/10	797.84	21.88	251.69	62093	62093	62093	0.00	0.00
	ACO+LS	0/10	500.19	500.08	500.12	62783	62713	62762	1.08	1.00
lipa60a	107218	10/10	4790.31	282.52	1523.23	107218	107218	107218	0.00	0.00
	GA+LS	10/10	9553.02	130.97	3132.27	107218	107218	107218	0.00	0.00
	ACO+LS	0/10	15000.44	15000.06	15000.2	108211	108152	108182	0.90	0.87

Table 3. Comparison of results obtained by ANGEL, GA+LS, and ACO+LS.

instance	best known value	success/runs						gap (%)	
			worst	best	avg.	avg.	best		
wil100	273038	2/10	273222	273038	273092.8	0.02	0.00		
	GA+LS	0/10	273246	273056	273135	0.04	0.01		
	ACO+LS	0/10	274098	273840	274013	0.36	0.29		
sko100a	152002	0/10	152110	152012	152072	0.05	0.01		
	GA+LS	0/10	152116	152012	152076	0.05	0.01		
	ACO+LS	0/10	153026	152626	152859	0.56	0.41		
sko100b	153890	1/10	153966	153890	153928	0.02	0.00		
	GA+LS	1/10	153996	153890	153951	0.04	0.00		
	ACO+LS	0/10	154874	154630	154796	0.59	0.48		
tai100a	21125314	0/10	21415346	21301496	21345414	1.04	0.83		
	GA+LS	0/10	21394176	21330426	21360227	1.11	0.97		
	ACO+LS	0/10	21562628	21468862	21530183	1.92	1.63		
tai100b	1185996137	2/10	1188632658	1185996137	1186889236	0.08	0.00		
	GA+LS	1/10	1188825033	1185996137	1187063980	0.09	0.00		
	ACO+LS	0/10	1196862332	1192492357	1195155655	0.77	0.55		
tai150b	498896643	0/10	502372382	498900451	500595927	0.34	0.00		
	GA+LS	0/10	502505450	499151120	500656046	0.35	0.05		
	ACO+LS	0/10	506447101	503960414	505386784	1.30	1.01		
lipa90a	360630	0/10	362732	362562	362663	0.56	0.54		
	GA+LS	0/10	362735	362572	362687	0.57	0.54		
	ACO+LS	0/10	363103	362892	363040	0.67	0.63		
lipa90b	12490441	10/10	12490441	12490441	12490441	0.00	0.00		
	GA+LS	10/10	12490441	12490441	12490441	0.00	0.00		
	ACO+LS	0/10	15122743	12793563	13711631	9.78	2.43		

Table 4. Comparison of results obtained by ANGEL and ANGEL+EliteGroup.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
sko49	23386	2/10	30	18	28	820.89	50.28	454.68	23410	23386	23399	0.06	0.00
	with elite group	5/10	30	2	23	6219.41	175.75	3025.35	23410	23386	23393	0.03	0.00
sko56	34458	4/10	30	3	22	943.03	91.77	544.36	34472	34458	34462	0.01	0.00
	with elite group	7/10	30	2	15	2364.72	23.52	743.54	34468	34458	34460	0.01	0.00
tai25a	1167256	3/10	30	7	23	95.03	12.17	56.79	1174640	1167256	1170608	0.29	0.00
	with elite group	10/10	27	1	12	700.81	0.86	308.16	1167256	1167256	1167256	0.00	0.00
tai30a	1818146	1/10	30	14	28	186.38	8.84	84.74	1827982	1818146	1824347	0.34	0.00
	with elite group	4/10	30	6	24	1087.03	41.13	622.99	1825384	1818146	1821938	0.21	0.00
tai35a	2422002	1/10	30	29	29	334.86	44.80	212.11	2440626	2422002	2433802	0.49	0.00
	with elite group	3/10	30	7	26	1891.95	397.38	1225.35	2443772	2422002	2432986	0.45	0.00

Table 5. Comparison of results obtained by ANGEL using different crossover operators.

instance	best known value	success/runs	CPU time (sec.)		
			max.	min.	avg.
nug30	6124	10/10	42.91	1.31	18.83
	OX1	10/10	182.28	0.45	61.13
	DPX	10/10	105.95	2.98	28.32
esc64a	116	10/10	0.99	0.06	0.26
	OX1	10/10	1.13	0.09	1.12
	DPX	10/10	0.27	0.08	0.11
esc128	64	10/10	3.74	0.56	2.27
	OX1	10/10	9.23	0.84	3.45
	DPX	10/10	7.94	0.70	3.00
kra30a	88900	10/10	17.41	0.17	7.25
	OX1	10/10	205.22	0.20	58.45
	DPX	10/10	14.06	0.17	7.58
kra30b	91420	10/10	115.72	1.00	40.22
	OX1	10/10	1418.09	3.41	201.55
	DPX	10/10	220.36	3.03	80.13
ste36a	9526	10/10	76.47	2.55	37.48
	OX1	10/10	485.52	16.72	118.15
	DPX	10/10	94.58	4.86	46.50
ste36b	15852	10/10	34.67	0.45	6.37
	OX1	10/10	34.02	0.50	10.62
	DPX	10/10	9.81	0.49	5.07
ste36c	8239110	10/10	46.28	7.78	27.28
	OX1	10/10	435.80	0.78	85.11
	DPX	10/10	140.75	9.03	36.90
tai50b	458821517	10/10	474.83	35.97	173.51
	OX1	10/10	1479.28	11.41	663.08
	DPX	10/10	588.59	141.17	320.08
tai60b	608215054	10/10	489.94	10.67	169.77
	OX1	10/10	2788.30	123.03	943.86
	DPX	10/10	3611.11	354.38	937.83
tai80b	818415043	10/10	7431.17	198.47	3617.40
	OX1	10/10	37401.00	239.84	11254.60
	DPX	10/10	42430.80	6585.63	18860.59
lipa40a	31538	10/10	196.55	4.33	67.31
	OX1	10/10	649.19	2.83	189.20
	DPX	10/10	174.23	21.58	94.45
lipa50a	62093	10/10	709.78	15.17	314.17
	OX1	10/10	6596.66	19.67	1288.07
	DPX	10/10	1669.27	141.45	539.92
lipa60a	107218	10/10	4790.31	282.52	1523.23
	OX1	10/10	23965.15	13345.69	18312.67
	DPX	10/10	6539.37	551.63	2503.98

Table 6. Quality of various heuristic methods for QAPLIB instances.

instance	PGA			HAS-QAP	ANT	Ro-TS	RTSs	MMAS	GA-1	GA-2	GA-3	MA	GRASP	ANGEL		
	success/ runs	gap (%)		gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap(%)	gap (%)	success/ runs	gap (%)	
		avg.	best	avg.	best	avg.	avg.	avg.	avg.	avg.	avg.	best	avg.		best	
nug12	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
nug14	4/10	0.26	0.00											10/10	0.00	0.00
nug15	7/10	0.19	0.00						0.00	0.00	0.00			10/10	0.00	0.00
nug16a	6/10	0.40	0.00											10/10	0.00	0.00
nug16b	10/10	0.00	0.00											10/10	0.00	0.00
nug17	3/10	0.32	0.00											10/10	0.00	0.00
nug18	0/10	0.48	0.31											10/10	0.00	0.00
nug20	4/10	0.23	0.00	0.000	0.00	0.000	0.763	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
nug21	6/10	0.13	0.00											10/10	0.00	0.00
nug22	8/10	0.10	0.00											10/10	0.00	0.00
nug24	5/10	0.47	0.00											10/10	0.00	0.00
nug25	5/10	0.11	0.00											10/10	0.00	0.00
nug30	0/10	0.68	0.42	0.098	0.00	0.013	0.892	0.020	0.07	0.07	0.07	0.004	0.42	10/10	0.00	0.00
bur26a	6/10	0.03	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00	0.000	0.00	10/10	0.00	0.00
bur26b	9/10	0.02	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
bur26c	6/10	0.00	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
bur26d	7/10	0.00	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
bur26e	8/10	0.00	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
bur26f	10/10	0.00	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
bur26g	10/10	0.00	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
bur26h	8/10	0.00	0.00	0.000	0.00	0.002	0.092	0.000	0.00	0.00	0.00		0.00	10/10	0.00	0.00
chr12a	7/10	1.50	0.00						0.00	0.00	0.00			10/10	0.00	0.00
chr12b	7/10	1.10	0.00						0.00	0.00	0.00			10/10	0.00	0.00
chr12c	5/10	0.81	0.00						0.00	0.00	0.00			10/10	0.00	0.00
chr15a	1/10	1.63	0.00						0.00	0.00	0.40			10/10	0.00	0.00
chr15b	8/10	3.08	0.00						0.00	0.00	0.00			10/10	0.00	0.00
chr15c	3/10	8.91	0.00						0.00	4.59	0.00			10/10	0.00	0.00
chr18a	1/10	3.39	0.00						0.00	0.18	0.40			10/10	0.00	0.00
chr18b	8/10	0.17	0.00						0.00	0.00	0.00			10/10	0.00	0.00
chr20a	0/10	5.86	0.18		0.00				0.18	7.21	0.00		1.82	10/10	0.00	0.00
chr20b	0/10	5.48	3.12		2.79				7.40	3.48	5.13		5.92	6/10	0.87	0.00
chr20c	0/10	8.44	4.51		0.00				4.72	0.00	0.00		0.00	10/10	0.00	0.00
chr22a	3/10	1.29	0.00		0.00				0.62	0.62	0.75		2.31	10/10	0.00	0.00
chr22b	0/10	2.55	1.46		0.97				1.19	2.87	0.00		2.58	10/10	0.00	0.00
chr25a	0/10	9.46	2.27	3.082	0.00				10.54	12.86	0.00	0.000	2.32	10/10	0.00	0.00

Table 6 (continued)

instance	PGA			HAS-QAP	ANT	Ro-TS	RTSs	MMAS	GA-1	GA-2	GA-3	MA	GRASP	ANGEL		
	success/ runs	gap (%)		gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap(%)	gap (%)	success/ runs	gap (%)	
		avg.	best	avg.	best	avg.	avg.	avg.	avg.	avg.	avg.	best	avg.		best	
esc16a	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16b	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16c	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16d	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16e	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16g	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16h	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16i	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc16j	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc32a	0/10	4.27	1.52		0.00				3.08	0.00	0.00		1.54	10/10	0.00	0.00
esc32b	4/10	6.87	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc32c	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc32d	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc32e	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc32f	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc32g	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc32h	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
esc64a	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
esc128	10/10	0.00	0.00											10/10	0.00	0.00
els19	4/10	2.15	0.00	0.000					0.00	0.00	0.00			10/10	0.00	0.00
had12	10/10	0.00	0.00											10/10	0.00	0.00
had14	10/10	0.00	0.00											10/10	0.00	0.00
had16	9/10	0.01	0.00											10/10	0.00	0.00
had18	10/10	0.00	0.00											10/10	0.00	0.00
had20	10/10	0.00	0.00		0.00								0.00	10/10	0.00	0.00
kra30a	0/10	2.02	0.89	0.630	0.00	0.268	1.048	0.135	1.34	1.57	0.00	0.000	0.00	10/10	0.00	0.00
kra30b	1/10	0.36	0.00	0.071	0.00	0.023	0.128	0.014	0.18	0.08	0.00		0.32	10/10	0.00	0.00
scr12	10/10	0.00	0.00						0.00	0.00	0.00			10/10	0.00	0.00
scr15	8/10	0.76	0.00						0.00	0.00	0.00			10/10	0.00	0.00
scr20	1/10	1.12	0.00		0.00				0.03	0.03	0.00		0.00	10/10	0.00	0.00
rou12	6/10	0.05	0.00						0.00	0.00	0.00			10/10	0.00	0.00
rou15	6/10	0.63	0.00						0.00	0.00	0.00			10/10	0.00	0.00
rou20	1/10	0.89	0.00		0.00				0.08	0.20	0.16		0.00	10/10	0.00	0.00
tho30	3/10	0.29	0.00		0.00				0.31	0.39	0.00		0.00	10/10	0.00	0.00
tho40	0/10	0.90	0.05		0.66				0.33	0.20	0.32		1.17	4/10	0.01	0.00
tho150	0/10	0.76	0.41									0.151		0/10	0.09	0.05
wil50	1/10	0.13	0.00	0.061					0.09	0.10	0.07			10/10	0.00	0.00
wil100	0/10	0.32	0.15						0.18	0.21	0.20			2/10	0.01	0.00
ste36a	1/10	2.32	0.00		0.76	0.155	2.043	0.061	1.47	1.39	0.27	0.045	1.81	10/10	0.00	0.00
ste36b	3/10	2.75	0.00		0.25	0.081	0.081	0.000					0.92	10/10	0.00	0.00
ste36c	1/10	1.20	0.00		0.33								0.89	10/10	0.00	0.00
sko42	0/10	0.78	0.35	0.076		0.025	0.683	0.004	0.23	0.00	0.25			10/10	0.00	0.00
sko49	0/10	0.58	0.19	0.141		0.076	0.590	0.039	0.27	0.27	0.21			2/10	0.06	0.00
sko56	0/10	0.49	0.06	0.101		0.088	0.656	0.072	0.08	0.07	0.02			4/10	0.01	0.00
sko64	0/10	0.49	0.09	0.129		0.071	0.654	0.036	0.38	0.17	0.22			6/10	0.00	0.00
sko72	0/10	0.53	0.21	0.277		0.146	0.558	0.103	0.44	0.27	0.29			1/10	0.02	0.00
sko81	0/10	0.62	0.12	0.144		0.136	0.406	0.078	0.23	0.40	0.20			0/10	0.03	0.01
sko90	0/10	0.60	0.43	0.231		0.128	0.530	0.128	0.43	0.33	0.27			0/10	0.04	0.02
sko100a	0/10	0.52	0.22			0.108	0.429	0.132	0.19	0.30	0.21	0.096		2/10	0.02	0.00
sko100b	0/10	0.59	0.30						0.48	0.24	0.14			3/10	0.01	0.00
sko100c	0/10	0.59	0.06						0.01	0.27	0.20			3/10	0.00	0.00
sko100d	0/10	0.57	0.27						0.35	0.38	0.17			0/10	0.03	0.01
sko100e	0/10	0.68	0.33						0.23	0.24	0.24			7/10	0.00	0.00
sko100f	0/10	0.63	0.41						0.19	0.32	0.29			0/10	0.03	0.02

Table 6 (continued)

instance	PGA			HAS-QAP	ANT	Ro-TS	RTSs	MMAS	GA-1	GA-2	GA-3	MA	GRASP	ANGEL		
	success/ runs	gap (%)		gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap (%)	gap(%)	gap (%)	success/ runs	gap (%)	
		avg.	best	avg.	best	avg.	avg.	avg.	avg.	avg.	avg.	avg.	best		avg.	best
tai12a	9/10	0.21	0.00											10/10	0.00	0.00
tai15a	1/10	0.69	0.00											10/10	0.00	0.00
tai17a	0/10	1.49	0.55											10/10	0.00	0.00
tai20a	0/10	1.62	0.84	0.675	0.00	0.108	0.169	0.067					0.00	7/10	0.11	0.00
tai25a	0/10	1.66	0.77	1.189	0.55	0.274	0.365	0.507					1.34	3/10	0.29	0.00
tai30a	0/10	1.78	1.34	1.311	1.46	0.426	0.301	0.259					1.58	1/10	0.34	0.00
tai35a	0/10	2.32	1.29	1.762	1.64	0.589	0.457	0.610					1.90	1/10	0.49	0.00
tai40a	0/10	2.10	1.08	1.989	2.05	0.990	0.569	0.782					2.20	0/10	0.59	0.30
tai50a	0/10	2.20	1.31	2.800		1.125	0.832	1.147				1.314		0/10	0.85	0.25
tai60a	0/10	2.18	1.79	3.070		1.203	0.822	0.981						0/10	0.03	0.82
tai80a	0/10	1.66	1.41	2.689		0.900	0.497	0.741				1.106		0/10	0.86	0.56
tai100a	0/10	1.64	1.29			0.894	0.361	0.685				1.089		0/10	0.80	0.48
tai64c	10/10	0.00	0.00											10/10	0.00	0.00
tai256c	0/10	0.22	0.16									0.070		0/10	0.09	0.09
tai12b	10/10	0.00	0.00											10/10	0.00	0.00
tai15b	8/10	0.04	0.00											10/10	0.00	0.00
tai20b	7/10	0.14	0.00	0.091		0.000	0.000	0.000						10/10	0.00	0.00
tai25b	4/10	0.13	0.00	0.000		0.000	4.427	0.000						10/10	0.00	0.00
tai30b	7/10	0.26	0.00	0.000		0.107	0.357	0.000						10/10	0.00	0.00
tai35b	3/10	0.18	0.00	0.026		0.064	0.576	0.024						10/10	0.00	0.00
tai40b	8/10	0.25	0.00	0.000		0.531	0.401	0.000						10/10	0.00	0.00
tai50b	1/10	0.46	0.00	0.192		0.342	0.426	0.029						10/10	0.00	0.00
tai60b	3/10	0.40	0.00	0.048		0.417	0.364	0.014				0.000		10/10	0.00	0.00
tai80b	0/10	0.81	0.03	0.667		0.591	1.033	0.318				0.004		10/10	0.00	0.00
tai100b	0/10	0.51	0.32			0.369	0.555	0.142				0.038		5/10	0.01	0.00
tai150b	0/10	0.97	0.20									0.361		0/10	0.10	0.05
lipa20a	9/10	0.14	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
lipa30a	4/10	0.84	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
lipa40a	1/10	0.95	0.00		1.02				0.00	1.10	0.96		1.13	10/10	0.00	0.00
lipa50a	0/10	0.92	0.82						0.95	0.93	0.95			10/10	0.00	0.00
lipa60a	0/10	0.79	0.64						0.90	0.82	0.77			10/10	0.00	0.00
lipa70a	0/10	0.71	0.62						0.72	0.73	0.71			9/10	0.06	0.00
lipa80a	0/10	0.64	0.61						0.65	0.67	0.61			0/10	0.55	0.51
lipa90a	0/10	0.58	0.54						0.59	0.62	0.58			3/10	0.35	0.00
lipa20b	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
lipa30b	7/10	4.28	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
lipa40b	10/10	0.00	0.00		0.00				0.00	0.00	0.00		0.00	10/10	0.00	0.00
lipa50b	3/10	10.70	0.00						0.00	0.00	0.00			10/10	0.00	0.00
lipa60b	2/10	12.83	0.00						0.00	0.00	0.00			10/10	0.00	0.00
lipa70b	0/10	16.10	15.90						0.00	0.00	0.00			10/10	0.00	0.00
lipa80b	0/10	16.71	16.56						19.69	0.00	0.00			10/10	0.00	0.00
lipa90b	1/10	15.48	0.00						0.00	0.00	0.00	0.000		10/10	0.00	0.00

Table 7. The computation results of ANGEL on QAPLIB *nug* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
nug12	578	10/10	1	1	1	0.38	0.00	0.06	578	578	578	0.00	0.00
nug14	1014	10/10	6	1	2	2.77	0.02	0.86	1014	1014	1014	0.00	0.00
nug15	1150	10/10	2	1	1	0.94	0.02	0.25	1150	1150	1150	0.00	0.00
nug16a	1610	10/10	3	1	1	1.64	0.02	0.38	1610	1610	1610	0.00	0.00
nug16b	1240	10/10	1	1	1	0.20	0.02	0.04	1240	1240	1240	0.00	0.00
nug17	1732	10/10	2	1	1	1.94	0.03	0.62	1732	1732	1732	0.00	0.00
nug18	1930	10/10	4	1	2	5.14	1.16	2.51	1930	1930	1930	0.00	0.00
nug20	2570	10/10	2	1	1	2.53	0.06	0.53	2570	2570	2570	0.00	0.00
nug21	2438	10/10	3	1	1	6.44	0.05	2.86	2438	2438	2438	0.00	0.00
nug22	3596	10/10	1	1	1	2.09	0.03	0.38	3596	3596	3596	0.00	0.00
nug24	3488	10/10	3	1	1	5.44	0.27	2.95	3488	3488	3488	0.00	0.00
nug25	3744	10/10	3	1	1	7.17	0.17	2.40	3744	3744	3744	0.00	0.00
nug30	6124	10/10	8	1	3	42.91	1.31	18.83	6124	6124	6124	0.00	0.00

Table 8. The computation results of ANGEL on QAPLIB *bur* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
bur26a	5426670	10/10	5	1	2	98.56	0.13	29.84	5426670	5426670	5426670	0.00	0.00
bur26b	3817852	10/10	2	1	1	20.05	0.59	5.36	3817852	3817852	3817852	0.00	0.00
bur26c	5426795	10/10	1	1	1	7.11	0.17	1.95	5426795	5426795	5426795	0.00	0.00
bur26d	3821225	10/10	1	1	1	4.72	0.22	1.50	3821225	3821225	3821225	0.00	0.00
bur26e	5386879	10/10	1	1	1	1.98	0.14	0.56	5386879	5386879	5386879	0.00	0.00
bur26f	3782044	10/10	1	1	1	1.83	0.11	0.66	3782044	3782044	3782044	0.00	0.00
bur26g	10117172	10/10	1	1	1	15.77	0.11	5.42	10117172	10117172	10117172	0.00	0.00
bur26h	7098658	10/10	1	1	1	1.53	0.03	0.54	7098658	7098658	7098658	0.00	0.00

Table 9. The computation results of ANGEL on QAPLIB *chr* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
chr12a	9552	10/10	3	1	1	0.84	0.02	0.20	9552	9552	9552	0.00	0.00
chr12b	9742	10/10	8	1	2	5.27	0.02	0.88	9742	9742	9742	0.00	0.00
chr12c	11156	10/10	3	1	1	4.27	0.00	0.57	11156	11156	11156	0.00	0.00
chr15a	9896	10/10	10	1	3	6.36	0.05	1.66	9896	9896	9896	0.00	0.00
chr15b	7990	10/10	3	1	1	1.27	0.03	0.48	7990	7990	7990	0.00	0.00
chr15c	9504	10/10	4	1	1	7.16	0.03	1.22	9504	9504	9504	0.00	0.00
chr18a	11098	10/10	3	1	1	2.78	0.14	1.16	11098	11098	11098	0.00	0.00
chr18b	1534	10/10	2	1	1	1.14	0.03	0.35	1534	1534	1534	0.00	0.00
chr20a	2192	10/10	19	1	7	33.41	1.38	13.62	2192	2192	2192	0.00	0.00
chr20b	2298	6/10	20	3	17	35.30	0.81	22.21	2352	2298	2318	0.87	0.00
chr20c	14142	10/10	5	1	2	6.89	0.05	2.88	14142	14142	14142	0.00	0.00
chr22a	6156	10/10	6	1	3	11.91	0.16	6.27	6156	6156	6156	0.00	0.00
chr22b	6194	10/10	20	1	9	47.67	1.58	20.32	6194	6194	6194	0.00	0.00
chr25a	3796	10/10	20	1	5	42.89	0.22	13.01	3796	3796	3796	0.00	0.00

Table 10. The computation results of ANGEL on QAPLIB *esc* and *els* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
esc16a	68	10/10	1	1	1	0.14	0.00	0.03	68	68	68	0.00	0.00
esc16b	292	10/10	1	1	1	0.05	0.00	0.02	292	292	292	0.00	0.00
esc16c	160	10/10	1	1	1	0.05	0.00	0.01	160	160	160	0.00	0.00
esc16d	16	10/10	1	1	1	0.13	0.00	0.02	16	16	16	0.00	0.00
esc16e	28	10/10	1	1	1	0.06	0.00	0.02	28	28	28	0.00	0.00
esc16g	26	10/10	1	1	1	0.06	0.00	0.01	26	26	26	0.00	0.00
esc16h	996	10/10	1	1	1	0.05	0.00	0.01	996	996	996	0.00	0.00
esc16i	14	10/10	1	1	1	0.06	0.00	0.02	14	14	14	0.00	0.00
esc16j	8	10/10	1	1	1	0.06	0.00	0.02	8	8	8	0.00	0.00
esc32a	130	10/10	3	1	1	17.77	0.58	6.82	130	130	130	0.00	0.00
esc32b	168	10/10	1	1	1	1.61	0.06	0.42	168	168	168	0.00	0.00
esc32c	642	10/10	1	1	1	0.08	0.02	0.03	642	642	642	0.00	0.00
esc32d	200	10/10	1	1	1	1.09	0.05	0.17	200	200	200	0.00	0.00
esc32e	2	10/10	1	1	1	0.06	0.02	0.02	2	2	2	0.00	0.00
esc32f	2	10/10	1	1	1	0.05	0.02	0.02	2	2	2	0.00	0.00
esc32g	6	10/10	1	1	1	0.06	0.00	0.02	6	6	6	0.00	0.00
esc32h	438	10/10	1	1	1	1.17	0.06	0.29	438	438	438	0.00	0.00
esc64a	116	10/10	1	1	1	0.99	0.06	0.26	116	116	116	0.00	0.00
esc128	64	10/10	1	1	1	3.74	0.56	2.27	64	64	64	0.00	0.00
els19	17212548	10/10	10	1	4	11.14	0.05	4.25	17212548	17212548	17212548	0.00	0.00

Table 11. The computation results of ANGEL on QAPLIB *had* and *kra* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
had12	1652	10/10	1	1	1	0.45	0.00	0.07	1652	1652	1652	0.00	0.00
had14	2724	10/10	1	1	1	0.13	0.00	0.04	2724	2724	2724	0.00	0.00
had16	3720	10/10	1	1	1	0.22	0.00	0.04	3720	3720	3720	0.00	0.00
had18	5358	10/10	1	1	1	0.61	0.00	0.12	5358	5358	5358	0.00	0.00
had20	6922	10/10	1	1	1	0.99	0.00	0.13	6922	6922	6922	0.00	0.00
kra30a	88900	10/10	4	1	1	17.41	0.17	7.25	88900	88900	88900	0.00	0.00
kra30b	91420	10/10	19	1	7	115.72	1.00	40.22	91420	91420	91420	0.00	0.00

Table 12. The computation results of ANGEL on QAPLIB *scr* and *rou* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
scr12	31410	10/10	1	1	1	0.09	0.00	0.03	31410	31410	31410	0.00	0.00
scr15	51140	10/10	1	1	1	0.27	0.02	0.07	51140	51140	51140	0.00	0.00
scr20	110030	10/10	3	1	1	4.02	0.06	0.80	110030	110030	110030	0.00	0.00
rou12	235528	10/10	4	1	1	0.94	0.02	0.30	235528	235528	235528	0.00	0.00
rou15	354210	10/10	2	1	1	0.67	0.06	0.31	354210	354210	354210	0.00	0.00
rou20	725522	10/10	20	1	7	23.48	0.42	9.38	725522	725522	725522	0.00	0.00

Table 13. The computation results of ANGEL on QAPLIB *tho*, *wil* and *ste* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
tho30	149936	10/10	4	1	1	22.97	0.28	7.07	149936	149936	149936	0.00	0.00
tho40	240516	4/10	30	2	20	665.20	3.89	231.76	240620	240516	240540	0.01	0.00
tho150	8133864	0/10	30	13	14	23229.46	1132.72	12537.11	8142736	8137808	8141521	0.09	0.05
wil50	48816	10/10	30	17	22	1733.38	577.12	838.53	48816	48816	48816	0.00	0.00
wil100	273038	2/10	30	30	30	7889.70	714.41	6665.62	273090	273038	273058	0.01	0.00
ste36a	9526	10/10	7	1	3	76.47	2.55	37.48	9526	9526	9526	0.00	0.00
ste36b	15852	10/10	4	1	1	34.67	0.45	6.37	15852	15852	15852	0.00	0.00
ste36c	8239110	10/10	5	1	2	46.28	7.78	27.28	8239110	8239110	8239110	0.00	0.00

Table 14. The computation results of ANGEL on QAPLIB *sko* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
sko42	15812	10/10	11	1	3	185.81	1.25	42.43	15812	15812	15812	0.00	0.00
sko49	23386	2/10	30	18	28	820.89	50.28	454.68	23410	23386	23399	0.06	0.00
sko56	34458	4/10	30	3	22	943.03	91.77	544.36	34472	34458	34462	0.01	0.00
sko64	48498	6/10	30	1	19	1881.33	50.20	1040.72	48508	48498	48500	0.00	0.00
sko72	66256	1/10	30	12	28	4643.67	1683.88	4249.65	66274	66256	66268	0.02	0.00
sko81	90998	0/10	30	30	30	8531.74	6320.72	6739.64	91040	91008	91021	0.03	0.01
sko90	115534	0/10	30	30	30	5973.88	4938.52	5524.15	115590	115560	115583	0.04	0.02
sko100a	152002	2/10	30	30	30	11753.38	10520.47	10235.89	152066	152002	152034	0.02	0.00
sko100b	153890	3/10	30	30	30	12346.46	11258.07	11546.33	153944	153890	153908	0.01	0.00
sko100c	147862	3/10	30	30	30	13687.69	12445.57	13234.48	147890	147862	147869	0.00	0.00
sko100d	149576	0/10	30	30	30	12867.02	12411.94	12552.93	149658	149584	149619	0.03	0.01
sko100e	149150	7/10	30	30	30	12256.22	11887.84	12484.66	149174	149150	149153	0.00	0.00
sko100f	149036	0/10	30	30	30	12719.13	12580.61	12651.49	149132	149060	149086	0.03	0.02

Table 15. The computation results of ANGEL on QAPLIB *tai* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
tai12a	224416	10/10	2	1	1	0.39	0.02	0.07	224416	224416	224416	0.00	0.00
tai15a	388214	10/10	2	1	1	1.05	0.03	0.31	388214	388214	388214	0.00	0.00
tai17a	491812	10/10	6	1	2	5.19	0.09	1.93	491812	491812	491812	0.00	0.00
tai20a	703482	7/10	30	2	20	52.59	1.77	23.15	706786	703482	704240	0.11	0.00
tai25a	1167256	3/10	30	7	23	95.03	12.17	56.79	1174640	1167256	1170608	0.29	0.00
tai30a	1818146	1/10	30	14	28	186.38	8.84	84.74	1827982	1818146	1824347	0.34	0.00
tai35a	2422002	1/10	30	29	29	334.86	44.80	212.11	2440626	2422002	2433802	0.49	0.00
tai40a	3139370	0/10	30	30	30	895.94	760.22	783.14	3169600	3148944	3157975	0.59	0.30
tai50a	4941410	0/10	30	30	30	1965.83	1587.44	1778.98	4,993,076	4953544	4983296	0.85	0.25
tai60a	7208572	0/10	30	30	30	4498.35	3782.03	3509.69	7293292	7267664	7282896	1.03	0.82
tai80a	13557864	0/10	30	30	30	9276.78	9048.87	9132.04	13713552	13633980	13674695	0.86	0.56
tai100a	21125314	0/10	30	30	30	20174.68	20092.35	20137.12	21342240	21226054	21293854	0.80	0.48
tai64c	1855928	10/10	1	1	1	3.47	0.25	1.54	1855928	1855928	1855928	0.00	0.00
tai256c	44759294	0/10	10	10	10	27589.55	25350.31	26320.92	44802030	44799798	44801150	0.09	0.09

Table 16. The computation results of ANGEL on QAPLIB *tai-b* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
tai12b	39464925	10/10	1	1	1	0.45	0.02	0.18	39464925	39464925	39464925	0.00	0.00
tai15b	51765268	10/10	1	1	1	1.09	0.03	0.31	51765268	51765268	51765268	0.00	0.00
tai20b	122455319	10/10	1	1	1	1.92	0.05	0.60	122455319	122455319	122455319	0.00	0.00
tai25b	344355646	10/10	4	1	1	29.63	0.14	5.70	344355646	344355646	344355646	0.00	0.00
tai30b	637117113	10/10	3	1	1	38.95	0.75	15.05	637117113	637117113	637117113	0.00	0.00
tai35b	283315445	10/10	3	1	1	56.11	1.27	19.09	283315445	283315445	283315445	0.00	0.00
tai40b	637250948	10/10	3	1	1	89.49	1.63	35.26	637250948	637250948	637250948	0.00	0.00
tai50b	458821517	10/10	5	1	2	474.83	35.97	173.51	458821517	458821517	458821517	0.00	0.00
tai60b	608215054	10/10	3	1	1	489.94	10.67	169.77	608215054	608215054	608215054	0.00	0.00
tai80b	818415043	10/10	13	1	6	7431.17	198.47	3617.40	818415043	818415043	818415043	0.00	0.00
tai100b	1185996137	5/10	30	30	30	43512.53	40342.56	41932.35	1.186E+09	1.186E+09	1.186E+09	0.01	0.00
tai150b	498896643	0/10	10	10	10	22040.75	19415.11	20206.81	499486180	499151120	499387126	0.10	0.05

Table 17. The computation results of ANGEL on QAPLIB *lipa-a* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
lipa20a	3683	10/10	1	1	1	3.61	0.05	0.71	3683	3683	3683	0.00	0.00
lipa30a	13178	10/10	2	1	1	31.27	0.19	7.30	13178	13178	13178	0.00	0.00
lipa40a	31538	10/10	4	1	1	196.55	4.33	67.31	31538	31538	31538	0.00	0.00
lipa50a	62093	10/10	6	1	2	709.78	15.17	314.17	62093	62093	62093	0.00	0.00
lipa60a	107218	10/10	17	2	6	4790.31	282.52	1523.23	107218	107218	107218	0.00	0.00
lipa70a	169755	9/10	30	1	6	9991.86	300.47	2379.64	170717	169755	169851	0.06	0.00
lipa80a	253195	0/10	15	1	8	12779.63	387.94	6835.86	254642	254496	254580	0.55	0.51
lipa90a	360630	3/10	20	2	7	15952.04	3789.93	7583.05	362533	360630	361883.67	0.35	0.00

Table 18. The computation results of ANGEL on QAPLIB *lipa-b* type instances.

instance	best known value	success/runs	trials			CPU time (sec.)			worst	best	avg.	gap (%)	
			max.	min.	avg.	max.	min.	avg.				avg.	best
lipa20b	27076	10/10	1	1	1	2.11	0.05	0.53	27076	27076	27076	0.00	0.00
lipa30b	151426	10/10	1	1	1	0.64	0.05	0.29	151426	151426	151426	0.00	0.00
lipa40b	476581	10/10	1	1	1	1.70	0.16	0.75	476581	476581	476581	0.00	0.00
lipa50b	1210244	10/10	1	1	1	14.34	0.94	3.12	1210244	1210244	1210244	0.00	0.00
lipa60b	2520135	10/10	1	1	1	49.08	2.16	13.45	2520135	2520135	2520135	0.00	0.00
lipa70b	4603200	10/10	1	1	1	360.58	4.92	84.79	4603200	4603200	4603200	0.00	0.00
lipa80b	7763962	10/10	2	1	1	529.34	6.25	145.33	7763962	7763962	7763962	0.00	0.00
lipa90b	12490441	10/10	1	1	1	325.75	12.47	157.84	12490441	12490441	12490441	0.00	0.00