
APPENDICES

Appendix A: ACO-PPMSO source code and sample input files

Appendix B: 21-unit case study results

Appendix C: 22-unit case study results

Appendix D: 5-station hydropower system results

Appendices A1, B1, B4, C1, C4 are available on a CD-Rom held in the University of Adelaide Library.

Appendix A

ACO-PPMSO source code & sample input files

Appendix A1: Full ACO-PPMSO source code in Fortran 90

Appendix A2: Sample input file 'ant.txt'

Appendix A3: Sample input file 'task.txt'

Appendix A4: Sample input file 'horizon.txt'

Appendix A5: Sample input file 'seed.txt'

Appendix A1: Full ACO-PPMSO source code

The full ACO-PPMSO source code is contained in the compact disc (CD) attached to this thesis (Appendix_A\A1\ACO-PPMSO.f90).

Appendix A2

Sample input file 'ant.txt'

```
! File = "ant.txt"
!  
F      ! Run 'F-Without; T-With' local search  
50000 ! total evaluation allowed  
50     ! number of ants  
0.8   ! rho  
0.05  ! pbest  
1000  ! initial pheromone  
100   ! reward factor  
1000  ! unserved demand penalty factor  
1000  ! tfeis factor  
10    ! penalty factor for shortened/deferred duration  
1     ! penalty factor for deviation from original schedule
```

Appendix A3

Sample input file 'task.txt'

! Type of optimization '1-New schedule'; '2-Review schedule'

1/

! Total number of fixed-date tasks

! Station | Task_id | No_of_machine | Machine | Start_date | Outage_duration/ Overlapping allowed? (Yes-'T', No-'F')

7/

Gordon	30630	1	2	1 Mar 2006	8	F/
Gordon	30072	1	1	1 Mar 2006	155	T/
Tungatinah	30523	5	1 2 3 4 5	1 Mar 2006	117	T/
Tungatinah	30527	1	2	1 Mar 2006	32	F/
Tungatinah	30961	1	3	1 Mar 2006	115	F/
Tungatinah	30962	1	4	1 Mar 2006	5	F/
Wilmot	30133	1	1	1 Mar 2006	19	F/

! Total number of tasks to be scheduled

! Station | No_of_tasks_in_group | Task1_id | No_of_machine | Machine | Earliest start | Latest finish | --continue

! | No_of_optional_duration | Set of durations | Overlapping allowed? (Yes-'T', No-'F') | Original start date | Original start duration /

! Minimum duration after the last task | Maximum duration after the last task | Task1_id | No_of_machine | - continue

! | Machine | Earliest start | Latest finish | No_of_optional_duration | Set of durations | Overlapping allowed? (Yes-'T', No-'F') | -continue

! | Original start date | Original start duration /

43/

Bastyan	1	30555	1	1	18 Mar 2006	18 Jun 2006	1	3	F	7 Jun 2006	3/
Bastyan	1	30556	1	1	21 Apr 2006	24 Jul 2006	1	5	F	28 May 2006	5/
ButlersG	1	32095	1	1	1 Jan 2006	31 Dec 2006	1	16	F	26 Jun 2006	16/
ButlersG	1	32941	1	1	21 Apr 2006	22 May 2006	1	12	F	23 Apr 2006	12/
ButlersG	1	32111	1	1	23 Jun 2006	31 Dec 2006	1	5	F	4 Oct 2006	5/
Catagunya	1	33628	1	1	1 Jan 2006	31 Dec 2006	1	2	F	18 Mar 2006	2/
Cethana	1	33462	1	1	1 Jan 2006	31 Dec 2006	1	3	F	18 Mar 2006	3/
Devils_Gate	1	33463	1	1	1 Jan 2006	31 Dec 2006	1	3	F	12 Mar 2006	3/
Echo	1	32970	1	1	1 Jan 2006	31 Dec 2006	1	19	F	22 Jul 2006	19/
Echo	1	33223	1	1	1 Jan 2006	31 Dec 2006	1	1	F	10 Sep 2006	1/
Echo	1	33548	1	1	1 Jan 2006	31 Dec 2006	1	1	F	13 Oct 2006	1/
Fisher	1	33459	1	1	1 Jan 2006	31 Dec 2006	1	3	F	17 Dec 2006	3/
Fisher	1	33605	1	1	1 Jan 2006	31 Dec 2006	1	1	F	5 Nov 2006	1/
Gordon	1	30773	3	1 2 3	1 Jan 2006	31 Dec 2006	1	22	F	8 Nov 2006	22/

Gordon	4	33601	3	1 2 3	1 Jan 2006	31 Dec 2006	1	3	F	21 Apr 2006	3/
60	100000	31002	2	2 3	1 Jan 2006	31 Dec 2006	1	3	F	25 Aug 2006	3/
60	100000	30998	2	2 3	1 Jan 2006	31 Dec 2006	1	3	F	27 Oct 2006	3/
60	100000	30999	3	1 2 3	1 Jan 2006	31 Dec 2006	1	3	F	29 Dec 2006	3/
Lemonthyme	1	30553	1	1	1 Jan 2006	19 Jul 2006	1	14	F	13 Mar 2006	14/
Lemonthyme	1	33461	1	1	1 Jan 2006	31 Dec 2006	1	4	F	5 Apr 2006	4/
Liapootah	2	32279	1	1	20 Jan 2006	24 Apr 2006	1	5	F	9 Mar 2006	5/
0	100000	33592	1	1	25 Apr 2006	25 Jul 2006	1	26	F	27 Apr 2006	26 /
Liapootah	3	33625	1	1	1 Jan 2006	31 Dec 2006	1	1	F	7 Oct 2006	1/
0	0	33626	1	2	1 Jan 2006	31 Dec 2006	1	1	F	8 Oct 2006	1/
0	0	33627	1	3	1 Jan 2006	31 Dec 2006	1	1	F	9 Oct 2006	1/
Paloona	1	30560	1	1	1 Jan 2006	31 Dec 2006	1	26	F	5 Mar 2006	26/
Paloona	1	30558	1	1	1 Jan 2006	31 Dec 2006	1	5	F	20 Apr 2006	5/
Paloona	1	30557	1	1	1 Jan 2006	31 Dec 2006	1	3	F	6 May 2006	3/
Poatina	1	32512	1	2	7 Feb 2006	28 Sep 2006	1	54	F	14 Apr 2006	54/
Poatina	1	30185	1	6	20 May 2006	10 Dec 2006	1	26	F	8 Oct 2006	26/
Poatina	1	31446	1	3	1 Jan 2006	31 Dec 2006	1	54	F	26 Jul 2006	54/
Poatina	1	33473	1	2	1 Jan 2006	31 Dec 2006	1	16	F	16 Dec 2006	16/
Rowallan	1	33460	1	1	1 Jan 2006	31 Dec 2006	1	3	F	10 Jul 2006	3/
Tarraleah	1	30793	4	1 2 3 4	17 Dec 2006	31 Dec 2006	1	6	F	25 Dec 2006	6/
Tarraleah	1	30076	1	5	6 Mar 2006	11 Dec 2006	1	102	F	8 Aug 2006	102/
Tarraleah	1	32939	1	2	1 Jan 2006	31 Dec 2006	1	4	F	12 Dec 2006	4/
Tarraleah	1	32940	1	1	1 Jan 2006	31 Dec 2006	1	5	F	7 Aug 2006	5/
Trevallyn	1	33204	1	4	1 Jan 2006	31 Dec 2006	1	30	F	11 Mar 2006	30/
Trevallyn	1	32799	1	1	1 Jan 2006	31 Dec 2006	1	19	F	10 Apr 2006	19/
Trevallyn	1	33624	1	4	1 Jan 2006	31 Dec 2006	1	1	F	12 Sep 2006	1/
Tungatinah	1	30518	1	1	1 Jan 2006	31 Dec 2006	1	28	F	5 Mar 2006	28/
Tungatinah	1	30528	1	1	1 Jan 2006	31 Dec 2006	1	91	F	2 Oct 2006	91/
Tungatinah	1	30519	1	2	1 Jan 2006	31 Dec 2006	1	92	F	21 Aug 2006	92/
Tungatinah	1	33081	1	5	9 May 2006	9 Nov 2006	1	5	F	3 Jun 2006	5/
Tungatinah	1	33079	1	2	23 Jun 2006	31 Dec 2006	1	5	F	20 Jul 2006	5/
Tungatinah	1	33597	1	4	20 Feb 2006	6 Mar 2006	1	1	F	6 Mar 2006	1/
Wayatinah	1	30298	1	3	10 Jan 2006	13 Jul 2006	1	5	F	21 May 2006	5/
Wayatinah	1	33581	1	3	13 Feb 2006	5 Mar 2006	1	1	F	4 Mar 2006	1/
Wilmot	1	33569	1	1	1 Jan 2006	31 Dec 2006	1	1	F	10 Apr 2006	1/

Appendix A4

Sample input file 'horizon.txt'

! File = "horizon.txt"

!

1 Jan 2006 ! Start of planning horizon

31 Dec 2006 ! End of planning horizon

Appendix A5
Sample input file 'seed.txt'

! File = "seed.txt"

!

888888

790224

50377

6857

9997777

409978

397

298

17544

666997

909090

123456789

987654321

91310

54330944

1498

356060

713888

41799929

129739

74575300

365

106517

3514683

825156

266799

17171515

955632

15660000

66565565

6545

575666

91561

33552454

239999

96565

365655656

19

655

36565

65951

35561999

2555856

136555

45689

98654

55563155

99916553

16519565

888317

Appendix B

21-unit case study results

Appendix B1: Original case study - ACO runs results

Appendix B2: Original case study - Student's t-test calculations

Appendix B3: Original Case study - Near-best-known SSR schedule

Appendix B4: Modified case study - ACO runs results

Appendix B5: Modified case study - Student's t-test calculations

Appendix B1
Original case study - ACO
runs results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_B\B1\). The following ACO runs results are included:

- **Elitist-Ant System (EAS) without local search (eas.xls)**
- **Elitist-Ant System (EAS) with PPMSO-2-opt local search (eas_2opt.xls)**
- **Max-Min Ant System (MMAS) without local search (mmas.xls)**
- **Max-Min Ant System (MMAS) with PPMSO-2-opt local search (mmas_2opt.xls)**

Appendix B2
Original case study -
Student's t-test calculations

Student's t-test assessment for heuristic formulation (EAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	EAS			
	Without local search		With PPMO-2-opt local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic
1	206254368	13680967	44410617	13680967
2	163564512	13726703	86403906	13680967
3	84869944	13711703	138795651	13721711
4	308041664	13707287	13929287	13680967
5	360878240	13751791	44345013	13680967
6	365127520	13680967	44858973	13680967
7	140608448	13680967	87202026	13707287
8	116604408	13716463	72543865	13692931
9	86648056	13721711	119103192	13755263
10	193060960	13687191	72667235	13680967
11	75048584	13687191	44595333	13680967
12	189863136	13707463	90128418	13721711
13	15812769	13687191	57754236	13707287
14	162307344	13721711	91913574	13680967
15	90948928	13707463	95053182	13680967
16	169419312	13721711	14528215	13726703
17	166511104	13748207	43714605	13699751
18	292065472	13721711	14775495	13680967
19	61268732	13685383	15443339	13725883
20	14838585	13721711	14936959	13680967
21	167894176	13702219	44175657	13680967
22	123284392	13685383	14606653	13824631
23	118511960	13725295	116718392	13680967
24	44578808	13721711	14584799	13721711
25	165037616	13680967	15355971	13699751
26	336180064	13680967	42975279	13700591
27	174446240	13699287	14375823	13701519
28	172629440	13680967	13738191	13680967
29	41367044	13680967	14463599	13670187
30	91177072	13701983	46010757	13763555
31	161173488	13680967	73040915	13707287
32	69468632	13680967	72338035	13707287
33	142744944	13711703	88075194	13680967
34	87938944	13680967	14506575	13726703
35	157490432	13721711	119609608	13699751
36	113765688	13699751	14685127	13680967
37	75804136	13845247	42977769	13698975
38	212815520	13685383	15203875	13699751
39	46125116	13726703	61803676	13680967
40	177483360	13707287	15325103	13739719
41	50332232	13680967	43094181	13721711

42	88641256	13733783	41573145	13753343
43	45541256	13680967	41328501	13698975
44	84028192	13721711	43566093	13680967
45	73630832	13823971	56179148	13705199
46	118134440	13680967	73507355	13678271
47	44078408	13699751	73413555	13680967
48	122100632	13753343	15343039	13721711
49	183820480	13680967	69182835	13680967
50	270486048	13680967	61916092	13664879
<i>average</i>	140489059	13708266	51615561	13701667
<i>stdev</i>	86004078.06	33569.23156	33722548.91	29101.16056
<i>p-value (xcel)</i>	4.98703E-14		2.27898E-10	
<i>significance</i>	highly significant		highly significant	

Student's t-test assessment for heuristic formulation (MMAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	MMAS			
	Without local search		With PPMSO-2-opt local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic
1	15466909	13679339	14790551	13680967
2	14791547	13680967	14258015	13680967
3	14877831	13664879	14239419	13680967
4	14643431	13680967	14381243	13674923
5	15030777	13685383	41366961	13680967
6	15165923	13680967	14702183	13707463
7	14962535	13680967	14694999	13680967
8	14725623	13687191	14880685	13721711
9	14065633	13680967	14422215	13664879
10	15027419	13698975	14362263	13703391
11	14532339	13721711	14646899	13664879
12	15435891	13680967	14767679	13783535
13	14051851	13680967	14831167	13680967
14	14455859	13670187	41148549	13680967
15	14563147	13698975	13885499	13678271
16	14068487	13699751	13826771	13680967
17	13859357	13664879	15113845	13688195
18	13931477	13698975	14722961	13678271
19	14952779	13699751	13796407	13670187
20	14582359	13687191	14675311	13685383
21	14658909	13670187	14707799	13699751
22	14601409	13674923	14756071	13680967
23	14817805	13685383	14870519	13701267
24	14669847	13680967	13812455	13707287
25	14716023	13669295	69043465	13680967
26	14147067	13674923	42048669	13680967
27	43303220	13670187	15147703	13680967
28	15001467	13678271	15346263	13726703
29	14696959	13680967	14372839	13699751
30	14938003	13698975	14414015	13687191
31	15022985	13684911	15725983	13664879
32	15559763	13680967	14639275	13680967
33	14488697	13664879	14118143	13680967
34	14566663	13700591	14527405	13711703
35	14615899	13680967	14627551	13680967
36	43353160	13680967	14594839	13680967
37	15125021	13680967	14530389	13674923
38	14631087	13680967	14539415	13680967
39	14371355	13674923	15289383	13680967
40	14602547	13680967	14992527	13721711
41	14729679	13674923	14619925	13680967

42	15310189	13680967	13948479	13685383
43	14674363	13680967	15351393	13680967
44	14660095	13680967	15218015	13687191
45	14190135	13674923	14948519	13680967
46	14332103	13678271	43153617	13680967
47	14727743	13685383	14361263	13699751
48	15134695	13664879	14444815	13680967
49	14093395	13664879	15112143	13680967
50	28468666	13674923	14460151	13680967
<i>average</i>	16108002	13681604	17904733	13688255
<i>stdev</i>	5953910.533	11243.65488	10513718.91	19555.38473
<i>p-value (xcel)</i>	0.005855899		0.006626021	
<i>significance</i>	highly significant		highly significant	

Student's t-test assessment for PPMSO-2-opt local search (With heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	With heuristic			
	MMAS		EAS	
	without local search	with local search	without local search	with local search
1	13679339	13680967	13680967	13680967
2	13680967	13680967	13726703	13680967
3	13664879	13680967	13711703	13721711
4	13680967	13674923	13707287	13680967
5	13685383	13680967	13751791	13680967
6	13680967	13707463	13680967	13680967
7	13680967	13680967	13680967	13707287
8	13687191	13721711	13716463	13692931
9	13680967	13664879	13721711	13755263
10	13698975	13703391	13687191	13680967
11	13721711	13664879	13687191	13680967
12	13680967	13783535	13707463	13721711
13	13680967	13680967	13687191	13707287
14	13670187	13680967	13721711	13680967
15	13698975	13678271	13707463	13680967
16	13699751	13680967	13721711	13726703
17	13664879	13688195	13748207	13699751
18	13698975	13678271	13721711	13680967
19	13699751	13670187	13685383	13725883
20	13687191	13685383	13721711	13680967
21	13670187	13699751	13702219	13680967
22	13674923	13680967	13685383	13824631
23	13685383	13701267	13725295	13680967
24	13680967	13707287	13721711	13721711
25	13669295	13680967	13680967	13699751
26	13674923	13680967	13680967	13700591
27	13670187	13680967	13699287	13701519
28	13678271	13726703	13680967	13680967
29	13680967	13699751	13680967	13670187
30	13698975	13687191	13701983	13763555
31	13684911	13664879	13680967	13707287
32	13680967	13680967	13680967	13707287
33	13664879	13680967	13711703	13680967
34	13700591	13711703	13680967	13726703
35	13680967	13680967	13721711	13699751
36	13680967	13680967	13699751	13680967
37	13680967	13674923	13845247	13698975
38	13680967	13680967	13685383	13699751

39	13674923	13680967	13726703	13680967
40	13680967	13721711	13707287	13739719
41	13674923	13680967	13680967	13721711
42	13680967	13685383	13733783	13753343
43	13680967	13680967	13680967	13698975
44	13680967	13687191	13721711	13680967
45	13674923	13680967	13823971	13705199
46	13678271	13680967	13680967	13678271
47	13685383	13699751	13699751	13680967
48	13664879	13680967	13753343	13721711
49	13664879	13680967	13680967	13680967
50	13674923	13680967	13680967	13664879
<i>average</i>	13681604	13688255	13708266	13701667
<i>stdev</i>	11243.65488	19555.38473	33569.23156	29101.16056
<i>p-value (xcel)</i>	0.040352349		0.296222374	
<i>significance</i>	significant		insignificant	

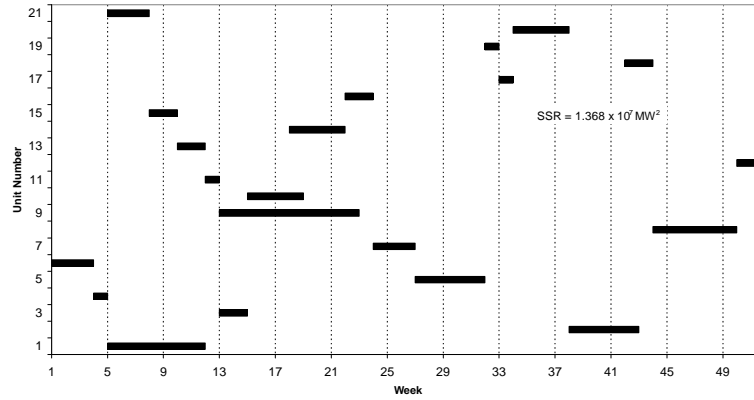
Student's t-test assessment for PPMSO-2-opt local search (Without heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

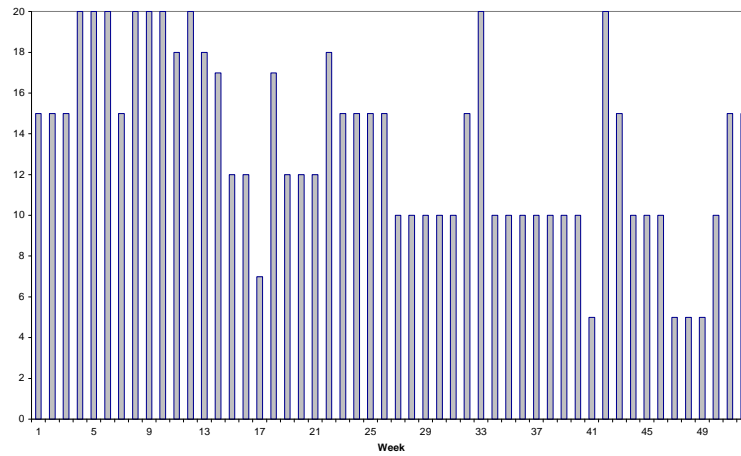
RNS#	<i>Without heuristic</i>			
	MMAS		EAS	
	<i>without local search</i>	<i>with local search</i>	<i>without local search</i>	<i>with local search</i>
1	15466909	14790551	206254368	44410617
2	14791547	14258015	163564512	86403906
3	14877831	14239419	84869944	138795651
4	14643431	14381243	308041664	13929287
5	15030777	41366961	360878240	44345013
6	15165923	14702183	365127520	44858973
7	14962535	14694999	140608448	87202026
8	14725623	14880685	116604408	72543865
9	14065633	14422215	86648056	119103192
10	15027419	14362263	193060960	72667235
11	14532339	14646899	75048584	44595333
12	15435891	14767679	189863136	90128418
13	14051851	14831167	15812769	57754236
14	14455859	41148549	162307344	91913574
15	14563147	13885499	90948928	95053182
16	14068487	13826771	169419312	14528215
17	13859357	15113845	166511104	43714605
18	13931477	14722961	292065472	14775495
19	14952779	13796407	61268732	15443339
20	14582359	14675311	14838585	14936959
21	14658909	14707799	167894176	44175657
22	14601409	14756071	123284392	14606653
23	14817805	14870519	118511960	116718392
24	14669847	13812455	44578808	14584799
25	14716023	69043465	165037616	15355971
26	14147067	42048669	336180064	42975279
27	43303220	15147703	174446240	14375823
28	15001467	15346263	172629440	13738191
29	14696959	14372839	41367044	14463599
30	14938003	14414015	91177072	46010757
31	15022985	15725983	161173488	73040915
32	15559763	14639275	69468632	72338035
33	14488697	14118143	142744944	88075194
34	14566663	14527405	87938944	14506575
35	14615899	14627551	157490432	119609608
36	43353160	14594839	113765688	14685127
37	15125021	14530389	75804136	42977769
38	14631087	14539415	212815520	15203875

39	14371355	15289383	46125116	61803676
40	14602547	14992527	177483360	15325103
41	14729679	14619925	50332232	43094181
42	15310189	13948479	88641256	41573145
43	14674363	15351393	45541256	41328501
44	14660095	15218015	84028192	43566093
45	14190135	14948519	73630832	56179148
46	14332103	43153617	118134440	73507355
47	14727743	14361263	44078408	73413555
48	15134695	14444815	122100632	15343039
49	14093395	15112143	183820480	69182835
50	28468666	14460151	270486048	61916092
<i>average</i>	16108002	17904733	140489059	51615561
<i>stdev</i>	5953910.533	10513718.91	86004078.06	33722548.91
<i>p-value (xcel)</i>	0.296295575		4.20018E-09	
<i>significance</i>	insignificant		highly significant	

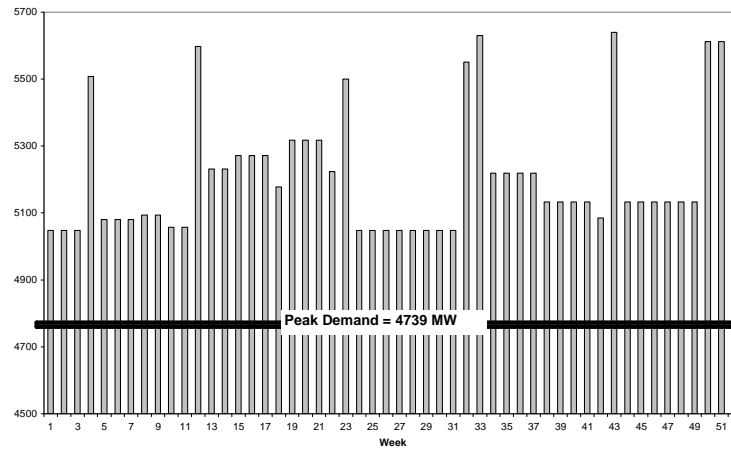
Appendix B3
Original Case study
- Near-best-known SSR
schedule



(a)



(b)



(c)

(a) A maintenance schedule of the 21-unit case study near-best-found-SSR solution ($SSR = 1.368 \times 10^7 \text{ MW}^2$), the associated (b) personpower allocation and (c) reserve capacity levels

Appendix B4
Modified case study - ACO
runs results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_B\B4\). The following ACO runs results are included:

- **Elitist-Ant System (EAS) without local search (eas.xls)**
- **Elitist-Ant System (EAS) with PPMSO-2-opt local search (eas_2opt.xls)**
- **Elitist-Ant System (EAS) with Duration Extender local search (eas_dex.xls)**
- **Max-Min Ant System (MMAS) without local search (mmas.xls)**
- **Max-Min Ant System (MMAS) with PPMSO-2-opt local search (mmas_2opt.xls)**
- **Max-Min Ant System (MMAS) with Duration Extender local search (mmas_dex.xls)**

Appendix B5
Modified case study –
Student's t-test calculations

Student's t-test assessment for heuristic formulation (EAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	EAS					
	Without local search		With PPMO-2-opt local search		With Duration Extender local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic	Without heuristic	With heuristic
1	77614935.9	17237532	128026937.4	29927207.1	66354910.3	17858026
2	73356793.9	19210148	195009202	32627144.3	68153032.3	16975582
3	121779657.4	28257264	121920530.5	41235986.8	129410817.8	20932766
4	168675060.2	28101208	91176014.9	23702859.4	216850657.5	28101616
5	116466865.6	29320878	167214099	31235629.5	187367449.1	37268004
6	156482616.4	28301286	196874366.8	20696486.8	82466968	29883694
7	83946451.6	28333144	116057917.2	38030770.5	80803210.5	29304294
8	162304967	27510506	152588331.9	21997133.8	51168579.4	38389412
9	178355196.5	26469180	88504930.4	26636935.7	94313351.7	28631546
10	92818563	29594306	219071981.3	28795669.3	91239534.5	21021562
11	127142715.8	17182444	108202103.2	21687132.1	100120244.4	20870388
12	180445501.3	20482336	151258337.7	20904029.9	84573593.7	23467088
13	86363418.3	29971206	121300029	37342773	95996522.8	32358808
14	136933173.2	22604976	86937552.4	28750808.3	53814751	16711244
15	65609915.4	17184622	132949043.9	22605960.7	131616736.6	29448498
16	96413970.9	16408324	77884157.9	28699553.3	82245877.6	18291046
17	188175150.2	27191888	96821912.6	22643653.5	67924008	22423568
18	140752334.3	31059482	183572872.8	29457842.8	96581538.8	20451046
19	88282525	25318146	130791260	28808992.1	149191569.3	16124745
20	80601955.1	29000662	210772389	30521533.5	93137572.8	20726216
21	161148095.9	17571976	157352330.4	22400153.9	71188893.7	47645476
22	180404684.9	22125676	123136829.2	21873756.9	150283907.5	26093294
23	164518354	29365884	167357042	17448173.7	82158654.8	17571976
24	71798725.7	21205394	143255110.7	32123419.5	123344559	28748068
25	75083898.3	30930888	99022177.7	21205411.7	158191345.1	20561830
26	142677070.2	29146244	180973709.7	29097358.7	68522043.6	46452152
27	77375057.2	21068820	76892418.3	29778958.7	93714344.2	17668558
28	90336596.3	20416350	181489773.3	22872837.5	131389750.6	24111276
29	173880064.7	30808718	134266820.4	30521533.5	139532287.4	29141018
30	106047870	28850372	98269716.1	28285280.7	139374740.4	26203462
31	96358472.9	30067786	132285287.4	25835499.6	71859918.8	23175326
32	83812135	28846662	125248281.2	30521533.5	141053948.4	15939417
33	137441240.4	27812626	146716315.5	23209654.7	114253308.2	17851324
34	91264176.7	30751772	151005211.9	16541089	95159916.7	22643634
35	66102902.8	23804630	85169727.3	24298059.9	67473911	20422294
36	98508242.9	21068820	157183079.7	26119933.4	192290819.1	29849068
37	119213172.9	20763212	141563412.2	28989837.6	89372090.6	28627552
38	92822661.9	21067130	149334538.5	16124758.7	77652905.3	30150738
39	178830990.2	29745768	134790852.8	23486920.7	72770287.5	23565670
40	75169840.4	28925978	156330971.5	24455223.1	160405218.3	30908628

41	117131045.5	17182444	157404938.7	28612885.3	91196263.6	30077286
42	209047231.4	29036560	116405127.2	28612885.3	89819985.9	31545860
43	132525080.3	27793160	116174840.4	28198142.1	88934194.5	27779626
44	110014687.4	16151565	138756562.1	29540375.2	121735491.9	28401612
45	90504779.2	17386648	107580953.6	27296042.9	69663676.6	23156478
46	139006686.2	21518880	68421915.5	29699760.2	110930693.5	30557270
47	162235560.9	17159072	138183873.6	20932782.7	77868210.5	17571976
48	153463202.4	16643864	110072234.3	29851951.2	92352118.7	31197436
49	111963483.4	27501480	195934887.9	30754435.6	86730858.7	18031188
50	88202623.1	17571250	89205286.7	28595729.2	158451220.3	31813620
<i>average</i>	120388208	24420583	135134364	26871850	105020130	25734045
<i>stdev</i>	39159973.93	5155348.209	36671547.05	5169372.941	37632168.23	7224490.994
<i>p-value (xcel)</i>	8.73573E-23		1.97816E-26		3.49394E-20	
<i>significance</i>	highly significant		highly significant		highly significant	

Student's t-test assessment for heuristic formulation (MMAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	MMAS					
	Without local search		With PPMSO-2-opt local search		With Duration Extender local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic	Without heuristic	With heuristic
1	54284036.8	16445521	45866666.8	28595729.2	49592954.8	17151518
2	59703263.1	26374840	87700500.9	23002244.8	67963408.8	28784008
3	57102322.5	17182444	77555884.6	22935515.5	61214948.5	17999030
4	35722145.2	17021972	66469586.7	20932782.7	96520267	16479257
5	59895727.3	17257832	57377445.5	16568491.5	56193477.9	20811318
6	71016338.8	17216674	83755343.8	16569941.2	49899053.9	29721378
7	78911482.7	16717979	52854559.6	26234475.2	58676558.1	16688805
8	74649015.5	16717979	57902259.5	16688818.3	46930428.7	16575726
9	54033199	27428270	38027955.1	27750771.7	48350911.3	16377624
10	70671050.3	17242090	62431093.7	16322212.3	52547279.8	16771719
11	52779151.6	16535859	82585595	16948776	69020141.1	28910186
12	54502675	20757506	116244671.2	16948776	68077945.5	21185484
13	55717757.5	20984298	60370507.1	22410812.5	51412746.7	17677260
14	82502156.3	16981552	87346430.2	27962927	71542518.2	20536460
15	63174054.2	26830822	81427178	26668085.5	43247938.7	16948762
16	59604833.2	16844930	123544175.6	16609083.7	68059989.9	26924664
17	51093925.9	20484028	67249141.1	25569395.8	44883529.1	20484028
18	46754650.5	20484028	56704774.5	20663535.4	72152657.9	21371326
19	64670759.6	20726216	33638243.4	20610258.2	66244501.7	21205394
20	75456626.4	28447212	90833576.4	16711257.5	77548837.3	17018092
21	97874927.8	16576814	59057850.5	15711855.5	90342944.9	16939544
22	34663635.7	27471032	80575324	26668085.5	27253160	23175508
23	33905435.3	17430864	35815587.7	28125043.7	55918738.9	27057930
24	60519202.4	28284458	57615012.6	29142677.5	54185818.8	28356180
25	53845565.9	17028496	115196460.2	28595729.2	67231521.6	21397052
26	90802101.5	24585992	119979945.9	20451062.3	39055460.7	20589746
27	34961867.8	16536492	42292833.6	27146244.9	54744681.5	16148357
28	63446365.7	16819460	33758979.9	17361679.2	33282567.3	16615594
29	46601821.7	20528848	59330387	28201581.5	59772443.5	15738662
30	109580485.1	16944882	47721367.9	28307894.3	106446754.1	20961220
31	41450229.9	16609070	73844481.8	20932782.7	61119512.1	20484028
32	50767221	20891462	50860998.6	18728443	47481480	16924664
33	51424300.2	18790162	69203615.4	16609083.7	27437112.5	17588306
34	55730702.8	20313102	49723995.1	27218623.1	42143868.4	27948536
35	60362688.9	16925560	120941518.2	18790176.9	90803655.5	16997970
36	45222440.6	19851942	89075412.5	15968614.5	47511360.8	17821988
37	57965057.8	17209264	64170843.8	20451062.3	74238815.2	27551516
38	89284162.9	27858456	79289999.2	29655522.4	62840517.2	20794502
39	28686001.3	15967687	77762363.9	20451062.3	46578859.5	16798538

40	66307867.3	18528356	49392779.1	16535872.8	95967185.8	17121664
41	41541729.3	29027508	78894002.3	25628072.4	41367114	20451046
42	51041421.3	16380589	77736866.5	16717992.6	56735379.5	20605606
43	47170016.7	16771719	60978756.1	26656747.5	59353195.3	16944882
44	98087674.7	23201370	55959010.9	17021986.9	71284598.7	16999294
45	57762509.6	16948762	132100729.6	27984571.2	63733250.2	16246941
46	119154166.4	16562679	107226506.9	16609083.7	42647560.7	16771719
47	43647418.6	20482336	86225176	28899786	80129433.7	16878274
48	64484815.6	17448158	54766292.4	23128581.5	43188968.7	29718194
49	86646503	16975582	63049519	20889558.5	66751740.5	18220738
50	60968114	17006230	60871400.7	16688818.3	44456574.2	17101708
<i>average</i>	61323032	19692788	71666072	22039644	59481687	20131439
<i>stdev</i>	19535592.11	4024094.617	24641419.04	4864993.34	17456431.73	4316487.897
<i>p-value (xcel)</i>	1.91914E-20		2.24142E-19		1.1007E-21	
<i>significance</i>	highly significant		highly significant		highly significant	

Student's t-test assessment for PPMSO-2-opt local search (Without heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	Without heuristic			
	EAS		MMAS	
	with PPMSO-2-opt	without PPMSO-2-opt	with PPMSO-2-opt	without PPMSO-2-opt
1	77614935.9	128026937.4	54284036.8	45866666.8
2	73356793.9	195009202	59703263.1	87700500.9
3	121779657.4	121920530.5	57102322.5	77555884.6
4	168675060.2	91176014.9	35722145.2	66469586.7
5	116466865.6	167214099	59895727.3	57377445.5
6	156482616.4	196874366.8	71016338.8	83755343.8
7	83946451.6	116057917.2	78911482.7	52854559.6
8	162304967	152588331.9	74649015.5	57902259.5
9	178355196.5	88504930.4	54033199	38027955.1
10	92818563	219071981.3	70671050.3	62431093.7
11	127142715.8	108202103.2	52779151.6	82585595
12	180445501.3	151258337.7	54502675	116244671.2
13	86363418.3	121300029	55717757.5	60370507.1
14	136933173.2	86937552.4	82502156.3	87346430.2
15	65609915.4	132949043.9	63174054.2	81427178
16	96413970.9	77884157.9	59604833.2	123544175.6
17	188175150.2	96821912.6	51093925.9	67249141.1
18	140752334.3	183572872.8	46754650.5	56704774.5
19	88282525	130791260	64670759.6	33638243.4
20	80601955.1	210772389	75456626.4	90833576.4
21	161148095.9	157352330.4	97874927.8	59057850.5
22	180404684.9	123136829.2	34663635.7	80575324
23	164518354	167357042	33905435.3	35815587.7
24	71798725.7	143255110.7	60519202.4	57615012.6
25	75083898.3	99022177.7	53845565.9	115196460.2
26	142677070.2	180973709.7	90802101.5	119979945.9
27	77375057.2	76892418.3	34961867.8	42292833.6
28	90336596.3	181489773.3	63446365.7	33758979.9
29	173880064.7	134266820.4	46601821.7	59330387
30	106047870	98269716.1	109580485.1	47721367.9
31	96358472.9	132285287.4	41450229.9	73844481.8
32	83812135	125248281.2	50767221	50860998.6
33	137441240.4	146716315.5	51424300.2	69203615.4
34	91264176.7	151005211.9	55730702.8	49723995.1
35	66102902.8	85169727.3	60362688.9	120941518.2
36	98508242.9	157183079.7	45222440.6	89075412.5
37	119213172.9	141563412.2	57965057.8	64170843.8

38	92822661.9	149334538.5	89284162.9	79289999.2
39	178830990.2	134790852.8	28686001.3	77762363.9
40	75169840.4	156330971.5	66307867.3	49392779.1
41	117131045.5	157404938.7	41541729.3	78894002.3
42	209047231.4	116405127.2	51041421.3	77736866.5
43	132525080.3	116174840.4	47170016.7	60978756.1
44	110014687.4	138756562.1	98087674.7	55959010.9
45	90504779.2	107580953.6	57762509.6	132100729.6
46	139006686.2	68421915.5	119154166.4	107226506.9
47	162235560.9	138183873.6	43647418.6	86225176
48	153463202.4	110072234.3	64484815.6	54766292.4
49	111963483.4	195934887.9	86646503	63049519
50	88202623.1	89205286.7	60968114	60871400.7
<i>average</i>	120388208	135134364	61323032	71666072
<i>stdev</i>	39159973.93	36671547.05	19535592.11	24641419.04
<i>p-value (xcel)</i>	0.054830898		0.022199839	
<i>significance</i>	significant		significant	

Student's t-test assessment for PPMSO-2-opt local search (With heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	With heuristic			
	EAS		MMAS	
	with PPMSO-2-opt	without PPMSO-2-opt	with PPMSO-2-opt	without PPMSO-2-opt
1	17237532	29927207.1	16445521	28595729.2
2	19210148	32627144.3	26374840	23002244.8
3	28257264	41235986.8	17182444	22935515.5
4	28101208	23702859.4	17021972	20932782.7
5	29320878	31235629.5	17257832	16568491.5
6	28301286	20696486.8	17216674	16569941.2
7	28333144	38030770.5	16717979	26234475.2
8	27510506	21997133.8	16717979	16688818.3
9	26469180	26636935.7	27428270	27750771.7
10	29594306	28795669.3	17242090	16322212.3
11	17182444	21687132.1	16535859	16948776
12	20482336	20904029.9	20757506	16948776
13	29971206	37342773	20984298	22410812.5
14	22604976	28750808.3	16981552	27962927
15	17184622	22605960.7	26830822	26668085.5
16	16408324	28699553.3	16844930	16609083.7
17	27191888	22643653.5	20484028	25569395.8
18	31059482	29457842.8	20484028	20663535.4
19	25318146	28808992.1	20726216	20610258.2
20	29000662	30521533.5	28447212	16711257.5
21	17571976	22400153.9	16576814	15711855.5
22	22125676	21873756.9	27471032	26668085.5
23	29365884	17448173.7	17430864	28125043.7
24	21205394	32123419.5	28284458	29142677.5
25	30930888	21205411.7	17028496	28595729.2
26	29146244	29097358.7	24585992	20451062.3
27	21068820	29778958.7	16536492	27146244.9
28	20416350	22872837.5	16819460	17361679.2
29	30808718	30521533.5	20528848	28201581.5
30	28850372	28285280.7	16944882	28307894.3
31	30067786	25835499.6	16609070	20932782.7
32	28846662	30521533.5	20891462	18728443
33	27812626	23209654.7	18790162	16609083.7
34	30751772	16541089	20313102	27218623.1
35	23804630	24298059.9	16925560	18790176.9
36	21068820	26119933.4	19851942	15968614.5
37	20763212	28989837.6	17209264	20451062.3

38	21067130	16124758.7	27858456	29655522.4
39	29745768	23486920.7	15967687	20451062.3
40	28925978	24455223.1	18528356	16535872.8
41	17182444	28612885.3	29027508	25628072.4
42	29036560	28612885.3	16380589	16717992.6
43	27793160	28198142.1	16771719	26656747.5
44	16151565	29540375.2	23201370	17021986.9
45	17386648	27296042.9	16948762	27984571.2
46	21518880	29699760.2	16562679	16609083.7
47	17159072	20932782.7	20482336	28899786
48	16643864	29851951.2	17448158	23128581.5
49	27501480	30754435.6	16975582	20889558.5
50	17571250	28595729.2	17006230	16688818.3
<i>average</i>	24420583	26871850	19692788	22039644
<i>stdev</i>	5155348.209	5169372.941	4024094.617	4864993.34
<i>p-value (xcel)</i>	0.01953724		0.010009394	
<i>significance</i>	significant		significant	

Student's t-test assessment for Duration Extender local search (Without heuristic)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	Without heuristic			
	EAS		MMAS	
	without Duration Extender	with Duration Extender	without Duration Extender	with Duration Extender
1	77614935.9	66354910.3	54284036.8	49592954.8
2	73356793.9	68153032.3	59703263.1	67963408.8
3	121779657.4	129410817.8	57102322.5	61214948.5
4	168675060.2	216850657.5	35722145.2	96520267
5	116466865.6	187367449.1	59895727.3	56193477.9
6	156482616.4	82466968	71016338.8	49899053.9
7	83946451.6	80803210.5	78911482.7	58676558.1
8	162304967	51168579.4	74649015.5	46930428.7
9	178355196.5	94313351.7	54033199	48350911.3
10	92818563	91239534.5	70671050.3	52547279.8
11	127142715.8	100120244.4	52779151.6	69020141.1
12	180445501.3	84573593.7	54502675	68077945.5
13	86363418.3	95996522.8	55717757.5	51412746.7
14	136933173.2	53814751	82502156.3	71542518.2
15	65609915.4	131616736.6	63174054.2	43247938.7
16	96413970.9	82245877.6	59604833.2	68059989.9
17	188175150.2	67924008	51093925.9	44883529.1
18	140752334.3	96581538.8	46754650.5	72152657.9
19	88282525	149191569.3	64670759.6	66244501.7
20	80601955.1	93137572.8	75456626.4	77548837.3
21	161148095.9	71188893.7	97874927.8	90342944.9
22	180404684.9	150283907.5	34663635.7	27253160
23	164518354	82158654.8	33905435.3	55918738.9
24	71798725.7	123344559	60519202.4	54185818.8
25	75083898.3	158191345.1	53845565.9	67231521.6
26	142677070.2	68522043.6	90802101.5	39055460.7
27	77375057.2	93714344.2	34961867.8	54744681.5
28	90336596.3	131389750.6	63446365.7	33282567.3
29	173880064.7	139532287.4	46601821.7	59772443.5
30	106047870	139374740.4	109580485.1	106446754.1
31	96358472.9	71859918.8	41450229.9	61119512.1
32	83812135	141053948.4	50767221	47481480
33	137441240.4	114253308.2	51424300.2	27437112.5
34	91264176.7	95159916.7	55730702.8	42143868.4
35	66102902.8	67473911	60362688.9	90803655.5
36	98508242.9	192290819.1	45222440.6	47511360.8
37	119213172.9	89372090.6	57965057.8	74238815.2

38	92822661.9	77652905.3	89284162.9	62840517.2
39	178830990.2	72770287.5	28686001.3	46578859.5
40	75169840.4	160405218.3	66307867.3	95967185.8
41	117131045.5	91196263.6	41541729.3	41367114
42	209047231.4	89819985.9	51041421.3	56735379.5
43	132525080.3	88934194.5	47170016.7	59353195.3
44	110014687.4	121735491.9	98087674.7	71284598.7
45	90504779.2	69663676.6	57762509.6	63733250.2
46	139006686.2	110930693.5	119154166.4	42647560.7
47	162235560.9	77868210.5	43647418.6	80129433.7
48	153463202.4	92352118.7	64484815.6	43188968.7
49	111963483.4	86730858.7	86646503	66751740.5
50	88202623.1	158451220.3	60968114	44456574.2
<i>average</i>	120388208	105020130	61323032	59481687
<i>stdev</i>	39159973.93	37632168.23	19535592.11	17456431.73
<i>p-value (xcel)</i>	0.048177696		0.620327571	
<i>significance</i>	significant		insignificant	

Student's t-test assessment for Duration Extender local search (With heuristic)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	With heuristic			
	EAS		MMAS	
	without Duration Extender	with Duration Extender	without Duration Extender	with Duration Extender
1	17237532	17858026	16445521	17151518
2	19210148	16975582	26374840	28784008
3	28257264	20932766	17182444	17999030
4	28101208	28101616	17021972	16479257
5	29320878	37268004	17257832	20811318
6	28301286	29883694	17216674	29721378
7	28333144	29304294	16717979	16688805
8	27510506	38389412	16717979	16575726
9	26469180	28631546	27428270	16377624
10	29594306	21021562	17242090	16771719
11	17182444	20870388	16535859	28910186
12	20482336	23467088	20757506	21185484
13	29971206	32358808	20984298	17677260
14	22604976	16711244	16981552	20536460
15	17184622	29448498	26830822	16948762
16	16408324	18291046	16844930	26924664
17	27191888	22423568	20484028	20484028
18	31059482	20451046	20484028	21371326
19	25318146	16124745	20726216	21205394
20	29000662	20726216	28447212	17018092
21	17571976	47645476	16576814	16939544
22	22125676	26093294	27471032	23175508
23	29365884	17571976	17430864	27057930
24	21205394	28748068	28284458	28356180
25	30930888	20561830	17028496	21397052
26	29146244	46452152	24585992	20589746
27	21068820	17668558	16536492	16148357
28	20416350	24111276	16819460	16615594
29	30808718	29141018	20528848	15738662
30	28850372	26203462	16944882	20961220
31	30067786	23175326	16609070	20484028
32	28846662	15939417	20891462	16924664
33	27812626	17851324	18790162	17588306
34	30751772	22643634	20313102	27948536
35	23804630	20422294	16925560	16997970
36	21068820	29849068	19851942	17821988
37	20763212	28627552	17209264	27551516

38	21067130	30150738	27858456	20794502
39	29745768	23565670	15967687	16798538
40	28925978	30908628	18528356	17121664
41	17182444	30077286	29027508	20451046
42	29036560	31545860	16380589	20605606
43	27793160	27779626	16771719	16944882
44	16151565	28401612	23201370	16999294
45	17386648	23156478	16948762	16246941
46	21518880	30557270	16562679	16771719
47	17159072	17571976	20482336	16878274
48	16643864	31197436	17448158	29718194
49	27501480	18031188	16975582	18220738
50	17571250	31813620	17006230	17101708
<i>average</i>	24420583	25734045	19692788	20131439
<i>stdev</i>	5155348.209	7224490.994	4024094.617	4316487.897
<i>p-value (xcel)</i>	0.298197655		0.600358474	
<i>significance</i>	insignificant		insignificant	

Appendix C

22-unit case study results

Appendix C1: Original case study - ACO runs results

Appendix C2: Original case study - Student's t-test calculations

Appendix C3: Original Case study - Tabu search schedule

Appendix C4: Modified case study - ACO runs results

Appendix C5: Modified case study - Student's t-test calculations

Appendix C1
Original case study - ACO
runs results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_C\C1\). The following ACO runs results are included:

- **Elitist-Ant System (EAS) without local search (eas.xls)**
- **Elitist-Ant System (EAS) with PPMSO-2-opt local search (eas_2opt.xls)**
- **Max-Min Ant System (MMAS) without local search (mmas.xls)**
- **Max-Min Ant System (MMAS) with PPMSO-2-opt local search (mmas_2opt.xls)**

Appendix C2
Original case study -
Student's t-test calculations

Student's t-test assessment for heuristic formulation (EAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	EAS			
	Without local search		With PPMSO-2-opt local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic
1	73.683	62.17	68.654	56.649
2	72.034	68.235	60.546	59.842
3	66.38	63.803	68.308	59.154
4	73.914	61.914	65.154	57.704
5	70.38	69.26	68.803	61.615
6	73.077	73.251	67.496	58.559
7	68.939	60.722	67.876	60.405
8	63.405	64.376	79.303	55.67
9	70.654	61.129	69.641	57.435
10	64.649	69.794	69.824	57.683
11	65.799	60.973	61.735	64.17
12	68.466	64.243	70.726	61.145
13	75.098	63.064	65.88	67.966
14	73.414	62.086	60.145	63.149
15	77.88	65.794	61.76	57.217
16	76.004	58.939	68.97	58.401
17	78.03	65.756	68.299	61.183
18	73.74	66.919	65.778	58.794
19	71.355	62.179	68.176	56.948
20	72.163	61.38	66.803	59.448
21	67.38	64.423	58.905	65.936
22	69.132	65.885	62.568	65.923
23	77.457	65.538	67.423	62.885
24	74.876	66.923	66.991	59.111
25	73.893	60.538	63.03	58.713
26	69.957	63.53	74.077	59.717
27	64.312	65.385	59.713	62.572
28	74.855	63.799	66.543	58.846
29	73.794	63.192	66.428	58.607
30	72.658	63.478	79.991	59.683
31	71.808	64.67	65.692	65.405
32	71.157	70.423	59.107	60.641
33	72.611	61.88	63.649	64.265
34	77.713	63.846	60.564	63.751
35	73.713	65.206	71.859	64.833
36	67.475	60.111	69.324	61.342
37	77.145	62.5	73.265	60.414
38	76.056	65.303	63.38	64.858
39	72.808	63.235	69.735	56.059
40	72.649	66.423	73.038	61.004

41	74.504	62.274	60.457	56.05
42	75.799	64.962	66.923	59.615
43	65.299	68.556	69.337	62.817
44	69.132	58.41	65.009	58.294
45	77.351	59.756	69.803	61.149
46	81.145	67.799	69.448	63.251
47	69.787	70.858	68.149	59.111
48	80.269	61.269	64.803	60.607
49	68.197	66.568	73.692	58.919
50	71.586	62.919	64.76	60.154
<i>average</i>	72.27	64.31	67.03	60.55
<i>stdev</i>	4.169126144	3.209197877	4.702215479	2.898527718
<i>p-value (xcel)</i>	7.95729E-18		1.91186E-12	
<i>significance</i>	highly significant		highly significant	

Student's t-test assessment for heuristic formulation (MMAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	MMAS			
	Without local search		With PPMSO-2-opt local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic
1	70.846	67.428	60.717	55.717
2	65.217	68.448	60.717	58.55
3	65.342	59.163	67.833	57.751
4	68.751	57.799	60.303	58.568
5	67.982	61.367	64.321	58.996
6	68.654	60.982	64.145	57.41
7	67.453	60.509	61.376	64.328
8	66.914	61.688	65.179	57.482
9	63.751	66.55	61.627	58.774
10	64.32	63.188	71.141	63.136
11	65.611	65.192	68.586	61.679
12	71.077	65.731	66.303	57.217
13	63.308	59.111	76.654	61.82
14	74.419	64.71	71.688	59.256
15	67.722	59.491	64.91	60.842
16	63.948	60.948	72.197	62.765
17	62.701	65.709	59.265	56.88
18	60.577	68.654	59.602	57.645
19	66.62	61.79	61.645	54.675
20	66.059	61.26	62.26	56.281
21	68.645	59.457	65.141	61.786
22	62.466	63.111	64.717	58.389
23	63.226	58.607	59.389	65.226
24	66.115	64.957	67.555	60.256
25	63.269	61.439	70.064	58.355
26	68.072	66.538	60.842	58.107
27	71.308	61.615	64.025	60.491
28	59.914	55.722	62.828	60.333
29	65.928	61.154	65.213	54.679
30	63.581	62.038	63.799	58.559
31	66.303	59.405	64.833	57.692
32	74.76	59.885	66.794	66.555
33	69.209	63.876	72.419	55.251
34	74.67	60.217	64.337	58.247
35	66.996	62.12	63.491	62.543
36	64.785	57.154	63.29	59.675
37	65.294	64.38	68.645	61.538
38	68.914	64.747	73.059	56.751
39	63.516	65.568	65.577	57.098
40	70.547	58.756	60.072	58.876
41	76.166	64.32	63.175	56.987

42	64.41	60.564	64.645	59.059
43	65.781	62.389	60.717	59.175
44	67.79	58.231	69.5	54.559
45	63.328	62.342	59.294	60.901
46	66.107	63.115	66.013	63.127
47	64.962	65.072	59.077	66.414
48	64.419	63.611	69.222	58.521
49	70.462	60.077	57.641	60.611
50	72.679	60.794	64.688	61.328
<i>average</i>	66.90	62.22	64.81	59.42
<i>stdev</i>	3.671420415	2.973975002	4.271175219	2.873330467
<i>p-value (xcel)</i>	3.7378E-10		8.26403E-11	
<i>significance</i>	highly significant		highly significant	

Student's t-test assessment for PPMSO-2-opt local search (Without heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	<i>Without heuristic</i>			
	MMAS		EAS	
	without local search	<i>with local search</i>	without local search	<i>with local search</i>
1	70.846	60.717	73.683	68.654
2	65.217	60.717	72.034	60.546
3	65.342	67.833	66.38	68.308
4	68.751	60.303	73.914	65.154
5	67.982	64.321	70.38	68.803
6	68.654	64.145	73.077	67.496
7	67.453	61.376	68.939	67.876
8	66.914	65.179	63.405	79.303
9	63.751	61.627	70.654	69.641
10	64.32	71.141	64.649	69.824
11	65.611	68.586	65.799	61.735
12	71.077	66.303	68.466	70.726
13	63.308	76.654	75.098	65.88
14	74.419	71.688	73.414	60.145
15	67.722	64.91	77.88	61.76
16	63.948	72.197	76.004	68.97
17	62.701	59.265	78.03	68.299
18	60.577	59.602	73.74	65.778
19	66.62	61.645	71.355	68.176
20	66.059	62.26	72.163	66.803
21	68.645	65.141	67.38	58.905
22	62.466	64.717	69.132	62.568
23	63.226	59.389	77.457	67.423
24	66.115	67.555	74.876	66.991
25	63.269	70.064	73.893	63.03
26	68.072	60.842	69.957	74.077
27	71.308	64.025	64.312	59.713
28	59.914	62.828	74.855	66.543
29	65.928	65.213	73.794	66.428
30	63.581	63.799	72.658	79.991
31	66.303	64.833	71.808	65.692
32	74.76	66.794	71.157	59.107
33	69.209	72.419	72.611	63.649
34	74.67	64.337	77.713	60.564
35	66.996	63.491	73.713	71.859
36	64.785	63.29	67.475	69.324
37	65.294	68.645	77.145	73.265
38	68.914	73.059	76.056	63.38

39	63.516	65.577	72.808	69.735
40	70.547	60.072	72.649	73.038
41	76.166	63.175	74.504	60.457
42	64.41	64.645	75.799	66.923
43	65.781	60.717	65.299	69.337
44	67.79	69.5	69.132	65.009
45	63.328	59.294	77.351	69.803
46	66.107	66.013	81.145	69.448
47	64.962	59.077	69.787	68.149
48	64.419	69.222	80.269	64.803
49	70.462	57.641	68.197	73.692
50	72.679	64.688	71.586	64.76
<i>average</i>	66.90	64.81	72.27	67.03
<i>stdev</i>	3.671420415	4.271175219	4.169126144	4.702215479
<i>p-value (xcel)</i>	0.010211007		5.4409E-08	
<i>significance</i>	highly significant		highly significant	

Student's t-test assessment for PPMSO-2-opt local search (With heuristic)

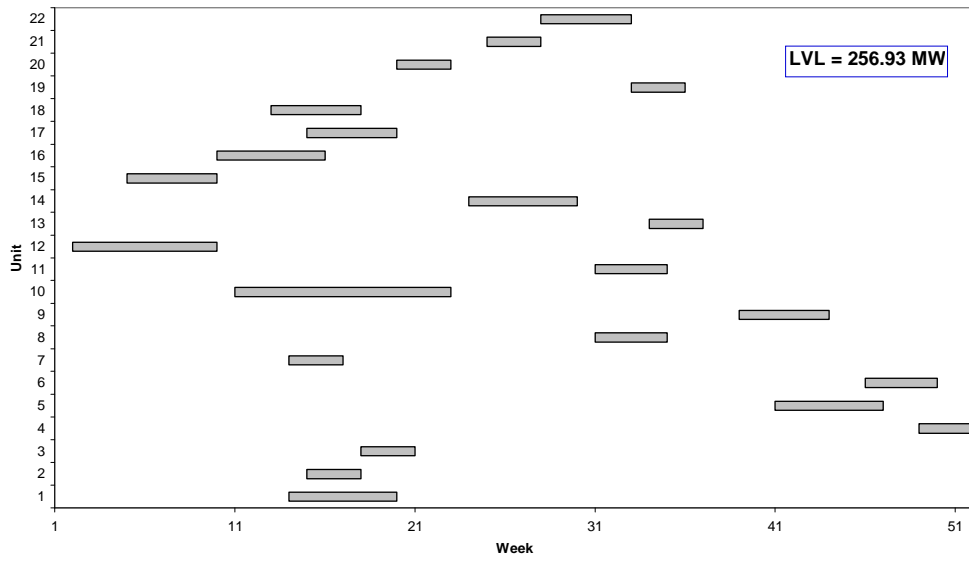
Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	With heuristic			
	MMAS		EAS	
	without local search	with local search	without local search	with local search
1	67.428	55.717	62.17	56.649
2	68.448	58.55	68.235	59.842
3	59.163	57.751	63.803	59.154
4	57.799	58.568	61.914	57.704
5	61.367	58.996	69.26	61.615
6	60.982	57.41	73.251	58.559
7	60.509	64.328	60.722	60.405
8	61.688	57.482	64.376	55.67
9	66.55	58.774	61.129	57.435
10	63.188	63.136	69.794	57.683
11	65.192	61.679	60.973	64.17
12	65.731	57.217	64.243	61.145
13	59.111	61.82	63.064	67.966
14	64.71	59.256	62.086	63.149
15	59.491	60.842	65.794	57.217
16	60.948	62.765	58.939	58.401
17	65.709	56.88	65.756	61.183
18	68.654	57.645	66.919	58.794
19	61.79	54.675	62.179	56.948
20	61.26	56.281	61.38	59.448
21	59.457	61.786	64.423	65.936
22	63.111	58.389	65.885	65.923
23	58.607	65.226	65.538	62.885
24	64.957	60.256	66.923	59.111
25	61.439	58.355	60.538	58.713
26	66.538	58.107	63.53	59.717
27	61.615	60.491	65.385	62.572
28	55.722	60.333	63.799	58.846
29	61.154	54.679	63.192	58.607
30	62.038	58.559	63.478	59.683
31	59.405	57.692	64.67	65.405
32	59.885	66.555	70.423	60.641
33	63.876	55.251	61.88	64.265
34	60.217	58.247	63.846	63.751
35	62.12	62.543	65.206	64.833
36	57.154	59.675	60.111	61.342
37	64.38	61.538	62.5	60.414
38	64.747	56.751	65.303	64.858

39	65.568	57.098	63.235	56.059
40	58.756	58.876	66.423	61.004
41	64.32	56.987	62.274	56.05
42	60.564	59.059	64.962	59.615
43	62.389	59.175	68.556	62.817
44	58.231	54.559	58.41	58.294
45	62.342	60.901	59.756	61.149
46	63.115	63.127	67.799	63.251
47	65.072	66.414	70.858	59.111
48	63.611	58.521	61.269	60.607
49	60.077	60.611	66.568	58.919
50	60.794	61.328	62.919	60.154
<i>average</i>	62.22	59.42	64.31	60.55
<i>stdev</i>	2.973975002	2.873330467	3.209197877	2.898527718
<i>p-value (xcel)</i>	5.88838E-06		1.74909E-08	
<i>significance</i>	highly significant		highly significant	

Appendix C3

Tabu search schedule



The maintenance schedule obtained by tabu search (El-Amin *et al.*, 2000)

Appendix C4
Modified case study - ACO
runs results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_C\C4\). The following ACO runs results are included:

- **Elitist-Ant System (EAS) without local search (eas.xls)**
- **Elitist-Ant System (EAS) with PPMSO-2-opt local search (eas_2opt.xls)**
- **Elitist-Ant System (EAS) with Duration Extender local search (eas_dex.xls)**
- **Max-Min Ant System (MMAS) without local search (mmas.xls)**
- **Max-Min Ant System (MMAS) with PPMSO-2-opt local search (mmas_2opt.xls)**
- **Max-Min Ant System (MMAS) with Duration Extender local search (mmas_dex.xls)**

Appendix C5
Modified case study -
Student's t-test calculations

Student's t-test assessment for heuristic formulation (EAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	EAS					
	Without local search		With PPMSO-2-opt local search		With Duration Extender local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic	Without heuristic	With heuristic
1	2733.019	1755.355	2649.692	1771.669	2654.792	1574.346
2	2713.192	1591.75	2448.753	1822.777	2328.034	1811.314
3	2536.183	1951.006	2789.257	1745.181	2499.115	1794.143
4	2862	1772.851	2844.379	1554.298	2487.637	1391.876
5	2776.42	1590.846	2644.898	1562.875	2635.32	1774.533
6	2915.131	1705.096	3291.945	1750.917	2599.368	1927.041
7	3777.124	1561.846	2800.519	1569.346	2201.119	1879.982
8	2592.759	2015.28	2935.115	1612.394	2580.831	1838.776
9	2906.823	1559.346	4326.466	1963.211	2805.016	1586.25
10	3785.84	1365.595	2645.834	1543.914	2180.363	1789.018
11	2742.922	1765.195	2331.923	1956.509	2397.145	1567.346
12	2918.805	1845.254	2444.636	1573.625	4082.532	1597.894
13	2406.183	2001.737	2591.59	1779.164	2313.981	1673.3
14	2632.071	1586.25	2869.225	1971.711	2806.327	1589.394
15	2716.223	1985.148	2571.885	1813.635	2460.991	1770.172
16	3075.404	1716.635	2710.562	1174.104	1975.006	1817.893
17	2621.336	1911.28	2850.16	1769.775	2701.746	1588.942
18	3356.507	1555	3122.574	1588.942	4140.446	1590.25
19	2647.763	1576.25	4112.308	1922.734	2054.825	1547
20	2915.902	1590.798	3024.365	1756.243	2461.642	1556.875
21	2567.15	1748.876	2689.027	1891.302	2448.934	2010.237
22	2445.59	1927.077	3920.331	1870.918	2408.683	1578.25
23	3108.019	1705.096	2624.63	1751.805	2708.743	1604.712
24	2756.547	1612.49	2694.817	1699.327	2607.795	1763.343
25	3258.769	1769.112	2737.385	1702.729	2482.086	1584.609
26	2676.829	2041.647	2381.24	1889.503	2794.01	1588.942
27	2470.998	1894.107	2777.84	1747.766	2765.442	1576.25
28	3347.301	1874.612	2670.641	1569.346	2608.269	1261.101
29	2591.923	1759.305	2853.692	1586.375	3965.532	1558.25
30	2396.213	1714.904	2577.238	1699.327	2146.288	1612.442
31	2865.874	1667.065	2681.858	1769.775	1953.994	1564.298
32	2532.115	1781.472	4357.136	1553.846	2543.92	1661.25
33	2215.331	1577.298	4214.781	1710.865	2169.213	1899.331
34	3166.692	1772.075	2370.178	1576.25	2187.555	1809.997
35	2951.343	1924.438	3417.827	1716.635	2712.672	1565.5
36	3098.789	1576.25	2571.885	1576.25	2385.16	1561.846
37	3111.311	1827.082	2569.509	1768.624	2171.703	1588.942
38	2856.066	1752.204	2699.319	1789.882	2148.404	1829.382
39	2853.361	2153.969	2900.769	1759.027	2562.388	1590.375
40	2278.584	1817.674	2519.394	2238.337	2534.735	1550

41	2186.215	1732.212	3439.769	1705.096	2101.814	1194.273
42	2430.719	1941.053	2495.567	1373.929	2214.213	1589.394
43	4267.312	1567.346	2716.501	1576.25	2370.666	1589.125
44	2568.151	2127.515	2572.308	1860.519	2668.362	1597.846
45	2240.201	1378.979	2837.481	1964.509	2399.896	1549.346
46	2537.979	1760.481	2702.827	1798.689	2128.709	2135.763
47	2821.243	1584.298	2648.25	1911.692	2746.615	1774.882
48	2632.751	1895.647	2633.735	1699.327	2160.861	1614.625
49	2684.876	1819.948	2966.385	1588.942	2375.857	1589.125
50	2342.888	1710.288	2559.635	1668.402	2620.961	1571.798
<i>average</i>	2797.85	1756.34	2876.16	1724.37	2529.19	1652.63
<i>stdev</i>	410.3271156	175.553561	501.1389237	172.6258719	454.7111482	167.8462085
<i>p-value (xcel)</i>	3.54217E-25		1.50479E-22		4.70456E-19	
<i>significance</i>	highly significant		highly significant		highly significant	

Student's t-test assessment for heuristic formulation (MMAS)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	MMAS					
	Without local search		With PPMSO-2-opt local search		With Duration Extender local search	
	Without heuristic	With heuristic	Without heuristic	With heuristic	Without heuristic	With heuristic
1	1827.659	1221.479	1947.814	1364.911	2074.868	1586.75
2	2054.391	1904.013	1944.333	1500.102	2120.75	1643.188
3	2021.365	1576.375	2077.169	1640.889	2107.786	1351.106
4	1911.621	1562.375	2811.344	1573.933	3612.186	1575.5
5	2091.327	1065.355	1923.916	1850.473	2118.914	1875.08
6	1631.124	2017.442	2031.173	1233.284	1986.769	1754.899
7	2308.077	1615.029	1758.375	1217.166	1861.811	1806.97
8	1988.774	1194.896	2669.827	1685.105	4085.767	1370.37
9	2098.734	1190.334	2036.544	1007.544	1905.699	1808.308
10	2052.75	1777.657	3700.414	1243.411	2137.234	1674.325
11	2230.558	1052.929	2344.167	1065.355	3709.448	1610.942
12	2746.596	1019.12	1785.544	1017.589	2003.171	1213.154
13	1635.5	1406.272	1987.479	1651.513	1950.777	1826.024
14	2128.726	1216.331	1936.93	1835.882	2083.707	1665.213
15	2341.611	1035.599	1947.981	1008.698	1905.865	1644.75
16	2528.268	1757.874	1948.558	2007.142	1816.442	1575.57
17	1895.647	1552.043	1736.99	1025.259	1652.394	1284.388
18	1894.391	1687.3	2194.635	1622.99	2006.935	1592.875
19	2135.917	1658.586	1890.854	1648.521	1989.231	1294.058
20	2036.366	1598.703	1912.788	1604.894	2099.827	1617.49
21	1772.957	1424.618	2072.479	1820.647	1973.687	1637.047
22	2871.154	1402.118	2025.699	1748.947	1873.467	1266.746
23	1898.994	1676.759	2210.765	1751.805	1918.169	1015.666
24	3998.669	1352.76	1997.102	1594.442	1842.5	1792.97
25	1930.769	1624.442	1675.99	1011.775	1931.87	1550
26	1630.394	1016.975	1955.891	1174.03	2184.827	1641.966
27	2197.278	1048.513	1986.598	1811.254	1892.682	1854.189
28	1836.612	1014.874	1902.404	1340.538	2168.016	1621.797
29	1704.982	1540.423	1687.75	1637.047	1780.25	1055.621
30	1838.277	1422.621	1961.278	1761.246	2188.982	1240.651
31	1800.864	1660.812	1702.875	1870.013	2114.118	1184.095
32	2458.701	1588.25	1999.692	1017.522	1900.096	1282.606
33	1770.566	1726.432	2147.13	1741.553	2069.209	1576.5
34	2117.219	1008.129	1987.622	1402.953	2413.787	1256.343
35	1630.442	1610.87	1999.405	1774.604	2138.032	1265.973
36	1824.888	1766.793	3936.71	2084.592	2001.13	1784.712
37	3395.539	1918.888	1977.648	1636.165	1945.503	1233.266
38	1659.875	1631.124	1632.25	1804.649	1632.25	1639.274
39	2297.145	1756.72	1991.827	1748.947	2067.135	1395.009
40	1439.328	1933.704	1984.737	1186.402	1935.366	1009.467

41	2086.75	1480.491	2006.201	1818.272	2075.748	1605.962
42	2200.22	1285.259	2087.775	1439.627	1648.75	2049.26
43	1853.124	1585.293	2165.652	1686.658	2452.367	1020.643
44	1973.16	1222.18	2017.87	1581.25	1899.841	1659.808
45	2059.609	1631.124	2050.801	1001.124	2069.209	1608.99
46	1848.45	1774.393	2390.828	1191.462	1931.661	1017.973
47	2312.899	1288.154	1640.894	1865.926	2084.135	1017.951
48	1910.935	1789.302	1937.467	1589.87	1754	1694.849
49	1916.305	1530.774	2105.284	1547.308	2099.929	1581.25
50	2026.132	1654.444	1614.394	1247.574	1780	1298.625
<i>average</i>	2076.43	1489.54	2068.80	1513.86	2099.93	1492.60
<i>stdev</i>	440.1632991	280.4457761	425.8696681	306.2558976	467.3712778	267.3755308
<i>p-value (xcel)</i>	8.04104E-12		4.98884E-11		1.05178E-11	
<i>significance</i>	highly significant		highly significant		highly significant	

Student's t-test assessment for PPMSO-2-opt local search (Without heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	Without heuristic			
	EAS		MMAS	
	<i>without PPMSO-2-opt</i>	<i>with PPMSO-2-opt</i>	<i>without PPMSO-2-opt</i>	<i>with PPMSO-2-opt</i>
1	2733.019	2649.692	1827.659	1947.814
2	2713.192	2448.753	2054.391	1944.333
3	2536.183	2789.257	2021.365	2077.169
4	2862	2844.379	1911.621	2811.344
5	2776.42	2644.898	2091.327	1923.916
6	2915.131	3291.945	1631.124	2031.173
7	3777.124	2800.519	2308.077	1758.375
8	2592.759	2935.115	1988.774	2669.827
9	2906.823	4326.466	2098.734	2036.544
10	3785.84	2645.834	2052.75	3700.414
11	2742.922	2331.923	2230.558	2344.167
12	2918.805	2444.636	2746.596	1785.544
13	2406.183	2591.59	1635.5	1987.479
14	2632.071	2869.225	2128.726	1936.93
15	2716.223	2571.885	2341.611	1947.981
16	3075.404	2710.562	2528.268	1948.558
17	2621.336	2850.16	1895.647	1736.99
18	3356.507	3122.574	1894.391	2194.635
19	2647.763	4112.308	2135.917	1890.854
20	2915.902	3024.365	2036.366	1912.788
21	2567.15	2689.027	1772.957	2072.479
22	2445.59	3920.331	2871.154	2025.699
23	3108.019	2624.63	1898.994	2210.765
24	2756.547	2694.817	3998.669	1997.102
25	3258.769	2737.385	1930.769	1675.99
26	2676.829	2381.24	1630.394	1955.891
27	2470.998	2777.84	2197.278	1986.598
28	3347.301	2670.641	1836.612	1902.404
29	2591.923	2853.692	1704.982	1687.75
30	2396.213	2577.238	1838.277	1961.278
31	2865.874	2681.858	1800.864	1702.875
32	2532.115	4357.136	2458.701	1999.692
33	2215.331	4214.781	1770.566	2147.13
34	3166.692	2370.178	2117.219	1987.622
35	2951.343	3417.827	1630.442	1999.405
36	3098.789	2571.885	1824.888	3936.71
37	3111.311	2569.509	3395.539	1977.648
38	2856.066	2699.319	1659.875	1632.25

39	2853.361	2900.769	2297.145	1991.827
40	2278.584	2519.394	1439.328	1984.737
41	2186.215	3439.769	2086.75	2006.201
42	2430.719	2495.567	2200.22	2087.775
43	4267.312	2716.501	1853.124	2165.652
44	2568.151	2572.308	1973.16	2017.87
45	2240.201	2837.481	2059.609	2050.801
46	2537.979	2702.827	1848.45	2390.828
47	2821.243	2648.25	2312.899	1640.894
48	2632.751	2633.735	1910.935	1937.467
49	2684.876	2966.385	1916.305	2105.284
50	2342.888	2559.635	2026.132	1614.394
<i>average</i>	2798	2876	2076	2069
<i>stdev</i>	410.3271156	501.1389237	440.1632991	425.8696681
<i>p-value (xcel)</i>	0.394779541		0.929932045	
<i>significance</i>	insignificant		insignificant	

Student's t-test assessment for PPMSO-2-opt local search (With heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	With heuristic			
	EAS		MMAS	
	<i>without PPMSO-2-opt</i>	<i>with PPMSO-2-opt</i>	<i>without PPMSO-2-opt</i>	<i>with PPMSO-2-opt</i>
1	1755.355	1771.669	1221.479	1364.911
2	1591.75	1822.777	1904.013	1500.102
3	1951.006	1745.181	1576.375	1640.889
4	1772.851	1554.298	1562.375	1573.933
5	1590.846	1562.875	1065.355	1850.473
6	1705.096	1750.917	2017.442	1233.284
7	1561.846	1569.346	1615.029	1217.166
8	2015.28	1612.394	1194.896	1685.105
9	1559.346	1963.211	1190.334	1007.544
10	1365.595	1543.914	1777.657	1243.411
11	1765.195	1956.509	1052.929	1065.355
12	1845.254	1573.625	1019.12	1017.589
13	2001.737	1779.164	1406.272	1651.513
14	1586.25	1971.711	1216.331	1835.882
15	1985.148	1813.635	1035.599	1008.698
16	1716.635	1174.104	1757.874	2007.142
17	1911.28	1769.775	1552.043	1025.259
18	1555	1588.942	1687.3	1622.99
19	1576.25	1922.734	1658.586	1648.521
20	1590.798	1756.243	1598.703	1604.894
21	1748.876	1891.302	1424.618	1820.647
22	1927.077	1870.918	1402.118	1748.947
23	1705.096	1751.805	1676.759	1751.805
24	1612.49	1699.327	1352.76	1594.442
25	1769.112	1702.729	1624.442	1011.775
26	2041.647	1889.503	1016.975	1174.03
27	1894.107	1747.766	1048.513	1811.254
28	1874.612	1569.346	1014.874	1340.538
29	1759.305	1586.375	1540.423	1637.047
30	1714.904	1699.327	1422.621	1761.246
31	1667.065	1769.775	1660.812	1870.013
32	1781.472	1553.846	1588.25	1017.522
33	1577.298	1710.865	1726.432	1741.553
34	1772.075	1576.25	1008.129	1402.953
35	1924.438	1716.635	1610.87	1774.604
36	1576.25	1576.25	1766.793	2084.592
37	1827.082	1768.624	1918.888	1636.165
38	1752.204	1789.882	1631.124	1804.649

39	2153.969	1759.027	1756.72	1748.947
40	1817.674	2238.337	1933.704	1186.402
41	1732.212	1705.096	1480.491	1818.272
42	1941.053	1373.929	1285.259	1439.627
43	1567.346	1576.25	1585.293	1686.658
44	2127.515	1860.519	1222.18	1581.25
45	1378.979	1964.509	1631.124	1001.124
46	1760.481	1798.689	1774.393	1191.462
47	1584.298	1911.692	1288.154	1865.926
48	1895.647	1699.327	1789.302	1589.87
49	1819.948	1588.942	1530.774	1547.308
50	1710.288	1668.402	1654.444	1247.574
<i>average</i>	1756	1724	1490	1514
<i>stdev</i>	175.553561	172.6258719	280.4457761	306.2558976
<i>p-value (xcel)</i>	0.360702816		0.679719902	
<i>significance</i>	insignificant		insignificant	

Student's t-test assessment for Duration Extender local search (Without heuristic)

Note: (1) Values shown are objective function values (OFCs).
 (2) Tests are based on a 95% significance level.

RNS#	Without heuristic			
	EAS		MMAS	
	without Duration Extender	with Duration Extender	without Duration Extender	with Duration Extender
1	2733.019	2654.792	1827.659	2074.868
2	2713.192	2328.034	2054.391	2120.75
3	2536.183	2499.115	2021.365	2107.786
4	2862	2487.637	1911.621	3612.186
5	2776.42	2635.32	2091.327	2118.914
6	2915.131	2599.368	1631.124	1986.769
7	3777.124	2201.119	2308.077	1861.811
8	2592.759	2580.831	1988.774	4085.767
9	2906.823	2805.016	2098.734	1905.699
10	3785.84	2180.363	2052.75	2137.234
11	2742.922	2397.145	2230.558	3709.448
12	2918.805	4082.532	2746.596	2003.171
13	2406.183	2313.981	1635.5	1950.777
14	2632.071	2806.327	2128.726	2083.707
15	2716.223	2460.991	2341.611	1905.865
16	3075.404	1975.006	2528.268	1816.442
17	2621.336	2701.746	1895.647	1652.394
18	3356.507	4140.446	1894.391	2006.935
19	2647.763	2054.825	2135.917	1989.231
20	2915.902	2461.642	2036.366	2099.827
21	2567.15	2448.934	1772.957	1973.687
22	2445.59	2408.683	2871.154	1873.467
23	3108.019	2708.743	1898.994	1918.169
24	2756.547	2607.795	3998.669	1842.5
25	3258.769	2482.086	1930.769	1931.87
26	2676.829	2794.01	1630.394	2184.827
27	2470.998	2765.442	2197.278	1892.682
28	3347.301	2608.269	1836.612	2168.016
29	2591.923	3965.532	1704.982	1780.25
30	2396.213	2146.288	1838.277	2188.982
31	2865.874	1953.994	1800.864	2114.118
32	2532.115	2543.92	2458.701	1900.096
33	2215.331	2169.213	1770.566	2069.209
34	3166.692	2187.555	2117.219	2413.787
35	2951.343	2712.672	1630.442	2138.032
36	3098.789	2385.16	1824.888	2001.13
37	3111.311	2171.703	3395.539	1945.503

38	2856.066	2148.404	1659.875	1632.25
39	2853.361	2562.388	2297.145	2067.135
40	2278.584	2534.735	1439.328	1935.366
41	2186.215	2101.814	2086.75	2075.748
42	2430.719	2214.213	2200.22	1648.75
43	4267.312	2370.666	1853.124	2452.367
44	2568.151	2668.362	1973.16	1899.841
45	2240.201	2399.896	2059.609	2069.209
46	2537.979	2128.709	1848.45	1931.661
47	2821.243	2746.615	2312.899	2084.135
48	2632.751	2160.861	1910.935	1754
49	2684.876	2375.857	1916.305	2099.929
50	2342.888	2620.961	2026.132	1780
<i>average</i>	2797.85	2529.19	2076.43	2099.93
<i>stdev</i>	410.3271156	454.7111482	440.1632991	467.3712778
<i>p-value (xcel)</i>	0.002520183		0.796371484	
<i>significance</i>	highly significant		insignificant	

Student's t-test assessment for Duration Extender local search (With heuristic)

Note: (1) Values shown are objective function values (OFCs).
(2) Tests are based on a 95% significance level.

RNS#	With heuristic			
	EAS		MMAS	
	without Duration Extender	with Duration Extender	without Duration Extender	with Duration Extender
1	1755.355	1574.346	1221.479	1586.75
2	1591.75	1811.314	1904.013	1643.188
3	1951.006	1794.143	1576.375	1351.106
4	1772.851	1391.876	1562.375	1575.5
5	1590.846	1774.533	1065.355	1875.08
6	1705.096	1927.041	2017.442	1754.899
7	1561.846	1879.982	1615.029	1806.97
8	2015.28	1838.776	1194.896	1370.37
9	1559.346	1586.25	1190.334	1808.308
10	1365.595	1789.018	1777.657	1674.325
11	1765.195	1567.346	1052.929	1610.942
12	1845.254	1597.894	1019.12	1213.154
13	2001.737	1673.3	1406.272	1826.024
14	1586.25	1589.394	1216.331	1665.213
15	1985.148	1770.172	1035.599	1644.75
16	1716.635	1817.893	1757.874	1575.57
17	1911.28	1588.942	1552.043	1284.388
18	1555	1590.25	1687.3	1592.875
19	1576.25	1547	1658.586	1294.058
20	1590.798	1556.875	1598.703	1617.49
21	1748.876	2010.237	1424.618	1637.047
22	1927.077	1578.25	1402.118	1266.746
23	1705.096	1604.712	1676.759	1015.666
24	1612.49	1763.343	1352.76	1792.97
25	1769.112	1584.609	1624.442	1550
26	2041.647	1588.942	1016.975	1641.966
27	1894.107	1576.25	1048.513	1854.189
28	1874.612	1261.101	1014.874	1621.797
29	1759.305	1558.25	1540.423	1055.621
30	1714.904	1612.442	1422.621	1240.651
31	1667.065	1564.298	1660.812	1184.095
32	1781.472	1661.25	1588.25	1282.606
33	1577.298	1899.331	1726.432	1576.5
34	1772.075	1809.997	1008.129	1256.343
35	1924.438	1565.5	1610.87	1265.973
36	1576.25	1561.846	1766.793	1784.712
37	1827.082	1588.942	1918.888	1233.266

38	1752.204	1829.382	1631.124	1639.274
39	2153.969	1590.375	1756.72	1395.009
40	1817.674	1550	1933.704	1009.467
41	1732.212	1194.273	1480.491	1605.962
42	1941.053	1589.394	1285.259	2049.26
43	1567.346	1589.125	1585.293	1020.643
44	2127.515	1597.846	1222.18	1659.808
45	1378.979	1549.346	1631.124	1608.99
46	1760.481	2135.763	1774.393	1017.973
47	1584.298	1774.882	1288.154	1017.951
48	1895.647	1614.625	1789.302	1694.849
49	1819.948	1589.125	1530.774	1581.25
50	1710.288	1571.798	1654.444	1298.625
<i>average</i>	1756.34	1652.63	1489.54	1492.60
<i>stdev</i>	175.553561	167.8462085	280.4457761	267.3755308
<i>p-value (xcel)</i>	0.003231461		0.955518611	
<i>significance</i>	highly significant		insignificant	

Appendix D

5-station hydropower system results

Appendix D1: Scenario-1 ACO results

Appendix D2: Scenario-1 random evaluation results

Appendix D3: Scenario-2 ACO results

Appendix D4: Scenario-2 random evaluation results

Appendix D5: Student's t-test assessment for *Duration Extender* local search

Appendix D1: Scenario-1 ACO results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_D\D1\).

Appendix D2: Scenario-1 random evaluation results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_D\D2\).

Appendix D3: Scenario-2 ACO results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_D\D3\).

Appendix D4: Scenario-2 random evaluation results

The contents of this section are contained in the compact disc (CD) attached to this thesis (Appendix_D\D4\).

Appendix D5: Student's t-test assessment for *Duration*

Extender local search

RNS#	dry		int		wet	
	without Duration Extender	with <i>Duration Extender</i>	without Duration Extender	with <i>Duration Extender</i>	without Duration Extender	with <i>Duration Extender</i>
1	22557.04	22511.53	3310.15	2913.87	2.123	2.123
2	22515.83	22626.08	3780.93	2894.41	2.123	2.123
3	22514.06	22554.02	3310.02	2873.44	2.123	2.123
4	22542.75	22505.66	3310.57	2887.43	2.121	2.121
5	22526.96	22535.59	3781.76	2887.36	2.120	2.120
6	22556.84	22510.20	3310.65	3310.07	2.123	2.123
7	22570.47	22508.84	3366.11	2886.24	2.123	2.123
8	22540.90	20351.37	3373.26	2884.93	2.123	2.123
9	22511.58	22601.35	3309.85	3314.40	2.123	2.123
10	22537.85	22597.81	3780.50	3310.74	2.120	2.120
11	22498.22	20011.97	3781.32	2887.69	2.123	2.123
12	24050.61	22504.66	3780.84	2897.01	2.120	2.120
13	22557.89	22500.44	3310.25	2898.94	2.123	2.123
14	22538.73	22561.23	3781.61	2891.61	2.123	2.123
15	22524.57	22493.34	3310.80	2874.62	2.120	2.120
16	25162.85	22496.83	3374.68	2891.05	2.120	2.120
17	22517.56	22498.75	3781.90	2903.46	2.120	2.120
18	22618.05	22509.85	3781.08	3308.81	2.120	2.120
19	22523.82	22497.25	3313.74	3309.77	2.124	2.123
20	22507.04	22515.14	3780.93	3308.70	2.120	2.120
21	22485.69	22534.03	3780.80	3312.18	2.123	2.123
22	22548.85	22504.00	3396.46	3309.87	2.120	2.120
23	22506.89	22476.17	3780.77	3309.91	2.120	2.120
24	22642.53	22512.00	3780.77	3309.51	2.120	2.120
25	22517.82	20015.49	3780.89	3310.99	2.121	2.121
26	22494.03	22502.55	3781.60	3309.58	2.123	2.123
27	22530.26	22514.58	3317.38	3313.44	2.123	2.123
28	22505.71	22625.56	2889.40	3309.19	2.123	2.123
29	22729.05	20017.91	3309.38	3313.53	2.120	2.120
30	22524.46	22548.49	3308.63	3309.58	2.120	2.119
average	22678.63	22204.76	3525.23	3114.74	2.122	2.122
min	22485.69	20011.97	2889.40	2873.44	2.120	2.119
max	25162.85	22626.08	3781.90	3314.40	2.124	2.123
stdev	546.25	842.62	256.86	213.13	0.00	0.00
p-value(xcel)	0.006364797		0.000000005		0.499198470	
significance	highly significant		highly significant		insignificant	

Note

- Values shown are objective function values (OFCs).
- Tests are based on a 95% significance level.