

Appendix C: Comparison of single-objective optimization results for the IS-MRIPSP

Table C1 – C5.

Table C1

Details of the optimization results of the IS-MRIPSP benchmark instance#1 for each objective independently.

Optimization results	Deterministic (Lower problem)	Deterministic (Upper problem)	Stochastic (Lower problem)	Stochastic (Upper problem)	Interval (Risk-seeker)	Interval (Risk-averse)	Interval-stochastic (Risk-seeker)	Interval-stochastic (Risk-averse)
Objective: Project makespan	4	8	4	8	[4, 8]	[8, 8]	[4, 8]	[8, 8]
Resource costs	333.3	509.3	333.3	509.3	[140.5, 458.3]	[275, 458.3]	[140.5, 458.3]	[275, 458.3]
Total number of iterations	0	181	0	0	624	0	624	0
Extended solver steps	0	0	0	0	0	0	0	0
CPU time (sec.)	0.06	0.09	0.08	0.09	0.56	0.54	4.23	2.38
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	10%	-	-	100%	60%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	9	-	-	0	4
Objective: Resource costs	300	138.89	300	138.89	[37.04, 125]	[75, 125]	[37.04, 125]	[75, 125]
Project makespan	13	21	13	21	[12, 12]	[21, 21]	[12, 12]	[21, 21]
Total number of iterations	741	8500	47	4273	2792274	24935	1347715	20772
Extended solver steps	0	37	0	16	176157	1003	104686	541
CPU time (sec.)	0.11	1.1	0.09	0.56	180.02	5.07	211.2	7.29
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	100%	-	-	90%	90%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	0	-	-	1	1
Total integer variables	177		187		2152		2172	
Total random variables	-		1		-		2	
Total number of scenarios	-		10		-		10	
Total non-zero elements	1595		2902		36913		52859	
Total constraints	44		54		3095		3115	

Table C2

Details of the optimization results of the IS-MRIPSP benchmark instance#2 for each objective independently.

Optimization results	Deterministic (Lower problem)	Deterministic (Upper problem)	Stochastic (Lower problem)	Stochastic (Upper problem)	Interval (Risk-seeker)	Interval (Risk-averse)	Interval-stochastic (Risk-seeker)	Interval-stochastic (Risk-averse)
Objective: Project makespan	9	16	9	16	[9, 16]	[16, 16]	[9, 16]	[16, 16]
Resource costs	707.89	1694.7	707.89	2363.17	[788.7, 2402.1]	[1180.6, 2121.4]	[788.7, 2402.1]	[1180.6, 2121.4]
Total number of iterations	93	459	93	354	8715	3652	8715	3652
Extended solver steps	0	0	0	0	0	0	0	0
CPU time (sec.)	0.15	0.18	0.51	0.56	10.86	1.10	56.39	56.87
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	30%	-	-	100%	60%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	7	-	-	0	4
Objective: Resource costs	263.16	902.68	263.16	902.68	[324.04, 809.94]	[443.85, 809.94]	[293.08, 842.1]	[443.85, 809.94]
Project makespan	13	35	13	35	[18, 18]	[35, 35]	[18, 18]	[35, 35]
Total number of iterations	11006992	58091528	3868100	18887077	13889263	9851124	4391100	4391201
Extended solver steps	740146	740876	187920	33766	80491	83026	20956	16529
CPU time (sec.)	283.53	1418.49	282.76	1610.63	2051.65	1977.14	1994.34	1927.72
Optimality gap (%)	-	-	-	-	-	-	0.0011	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	0%	-	-	90%	100%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	10	-	-	1	0
Total integer variables	1072		1082		29495		29515	
Total random variables	-		2		-		4	
Total number of scenarios	-		10		-		10	
Total non-zero elements	16398		31566		608897		1075802	
Total constraints	153		172		39672		39710	

Table C3

Details of the optimization results of the IS-MRIPSP benchmark instance#3 for each objective independently.

Optimization results	Deterministic (Lower problem)	Deterministic (Upper problem)	Stochastic (Lower problem)	Stochastic (Upper problem)	Interval (Risk-seeker)	Interval (Risk-averse)	Interval-stochastic (Risk-seeker)	Interval-stochastic (Risk-averse)
Objective: Project makespan	8	18	8	18	[8, 18]	[18, 18]	[8, 18]	[18, 18]
Resource costs	197.78	1512.48	432.72	1757.13	[376.12, 894.74]	[510.38, 1020.76]	[326.55, 855.85]	[510.38, 1020.76]
Total number of iterations	2404	4359	801	873	79879	37256	34242	13869
Extended solver steps	0	0	0	0	0	0	0	0
CPU time (sec.)	0.95	0.9	1.45	2.28	626.98	162.64	734.74	528.72
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	70%	-	-	-	50%	40%
Actual probability (CCPU)	-	-	-	0%	-	-	100%	0%
Unsatisfied scenarios (CCPL)	-	-	3	-	-	-	5	6
Unsatisfied scenarios (CCPU)	-	-	-	10	-	-	0	10
Objective: Resource costs	126.67	497.68	126.67	497.68	[216.17, 516.95]	[258.48, 516.95]	[216.17, 516.95]	[257.04, 514.08]
Project makespan	12	33	11	23	[10, 20]	[21, 21]	[10, 20]	[23, 23]
Total number of iterations	86770812	92868138	30883930	55276743	11945159	7421908	11197172	8499658
Extended solver steps	289972	95278	48096	30373	17528	2688	9957	10325
CPU time (sec.)	4039.06	4047.53	3905.1	9002.17	6499.67	7156.96	7628.72	8173.02
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	90%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	0%	-	-	100%	0%
Unsatisfied scenarios (CCPL)	-	-	1	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	10	-	-	0	10
Total integer variables	3894		3904		155578		155598	
Total random variables	-		2		-		4	
Total number of scenarios	-		10		-		10	
Total non-zero elements	37468		71356		3241013		4472163	
Total constraints	229		248		195695		195733	

Table C4

Details of the optimization results of the IS-MRIPSP benchmark instance#4 for each objective independently.

Optimization results	Deterministic (Lower problem)	Deterministic (Upper problem)	Stochastic (Lower problem)	Stochastic (Upper problem)	Interval (Risk-seeker)	Interval (Risk-averse)	Interval-stochastic (Risk-seeker)	Interval-stochastic (Risk-averse)
Objective: Project makespan	9	14	9	14	[9, 14]	[14, 14]	[9, 14]	[14, 14]
Resource costs	458.81	2013.93	458.81	1972.08	[541, 1249.56]	[1160.22, 1857.64]	[541, 1249.56]	[1160.22, 1857.64]
Total number of iterations	834	3852	834	747	35579	14968	35579	14968
Extended solver steps	0	0	0	0	0	0	0	0
CPU time (sec.)	0.57	1.95	1.72	2.89	214.15	290.11	735.62	783.8
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	40%	-	-	100%	60%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	3	-	-	0	2
Objective: Resource costs	210.988	813.24	210.988	813.24	[292.98, 648.61]	[500, 802.63]	[377.19, 776.32]	[401.04, 651.89]
Project makespan	22	34	22	34	[20, 22]	[24, 24]	[14, 20]	[28, 28]
Total number of iterations	481789093	408997687	402399260	393094832	39230966	40874829	45019127	31408669
Extended solver steps	8179829	5991859	216498	177926	19724	13168	5672	18926
CPU time (sec.)	59396.65	59415.32	59470.92	59405.30	88102.59	88044.50	88393.16	88271.61
Optimality gap (%)	-	-	-	-	-	0.237	0.225	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	100%	-	-	100%	100%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	0	-	-	0	0
Total integer variables	6083		6088		319774		319784	
Total random variables	-		3		-		6	
Total number of scenarios	-		5		-		5	
Total non-zero elements	65913		106385		7252196		10450661	
Total constraints	290		303		379113		379139	

Table C5

Details of the optimization results of the IS-MRIPSP benchmark instance#5 for each objective independently.

Optimization results	Deterministic (Lower problem)	Deterministic (Upper problem)	Stochastic (Lower problem)	Stochastic (Upper problem)	Interval (Risk-seeker)	Interval (Risk-averse)	Interval-stochastic (Risk-seeker)	Interval-stochastic (Risk-averse)
Objective: Project makespan	15	25	15	25	[15, 25]	[25, 25]	[15, 25]	[25, 25]
Resource costs	779.64	4470.54	779.64	4207.047	[953.5, 2708.98]	[2403.27, 4243.78]	[1512.67, 3906.15]	[1661.96, 2934.02]
Total number of iterations	4131	11109	4174	7335	523650	270980	518111	194084
Extended solver steps	0	0	0	0	0	0	0	0
CPU time (sec.)	6.84	4.16	7.72	10.29	3532.29	2281.74	5424.01	4232.11
Optimality gap (%)	-	-	-	-	-	-	-	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	40%	-	-	100%	80%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	3	-	-	0	1
Objective: Resource costs	284.21	1021.26	315.26	1252.10	[432.94, 1092.43]	[632.84, 1133.68]	[432.94, 1092.43]	[632.84, 1133.68]
Project makespan	27	45	24	41	[18, 28]	[30, 30]	[18, 28]	[30, 30]
Total number of iterations	421568165	213639637	457216138	221611222	158286579	169297143	169854321	171323454
Extended solver steps	95966	30924	124587	20936	15297	12706	12524	13506
CPU time (sec.)	87451.38	87562.63	87753.87	87820.98	96524.13	97726.12	97328.92	98924.53
Optimality gap (%)	-	-	10.925	22.603	-	-	-	-
Actual probability (CCPL)	-	-	100%	-	-	-	100%	100%
Actual probability (CCPU)	-	-	-	40%	-	-	80%	40%
Unsatisfied scenarios (CCPL)	-	-	0	-	-	-	0	0
Unsatisfied scenarios (CCPU)	-	-	-	3	-	-	1	3
Total integer variables	13926		13931		1212419		1212429	
Total random variables	-		2		-		4	
Total number of scenarios	-		5		-		5	
Total non-zero elements	146401		200848		27659575		29491441	
Total constraints	463		472		1432019		1432037	

Appendix D: Compromise project schedules and renewable resource availabilities for the multi-objective IS-MRIPSP

Table D1 – D5.

Table D1

Compromise project schedules and resource availabilities for the benchmark instance#1 according to the project manager's risk attitude.

Project activities	Completion time interval (Risk-seeker)	Mode	Completion time interval (Risk-averse)	Mode
1	[0, 0]	1	[0, 0]	1
2	[3, 5]	1	[5, 5]	1
3	[4, 5]	1	[4, 5]	1
4	[4, 6]	2	[8, 8]	2
5	[5, 8]	1	[8, 8]	1
6	[6, 9]	1	[11, 11]	1
7	[6, 9]	1	[11, 11]	1
Resource costs	[37.04, 187.5]		[141.6, 236.1]	
Renewable resource availability (R1)	[1.24, 3.75]		[4.72, 4.72]	
Total number of iterations	14334		34757	
Extended solver steps	192		2143	
CPU time (sec.)	5.49		7.24	
Optimality gap (%)	-		-	
Actual probability (CCPL)	100%		100%	
Actual probability (CCPU)	100%		90%	
Unsatisfied scenarios (CCPL)	0		0	
Unsatisfied scenarios (CCPU)	0		1	

Table D2

Compromise project schedules and resource availabilities for the benchmark instance#2 according to the project manager's risk attitude.

Project activities	Completion time interval	Mode	Completion time interval	Mode
	(Risk-seeker)		(Risk-averse)	
1	[0, 0]	1	[0, 0]	1
2	[1, 3]	1	[3, 3]	1
3	[3, 3]	1	[8, 10]	1
4	[5, 5]	1	[5, 5]	1
5	[3, 6]	1	[6, 6]	1
6	[7, 7]	1	[15, 15]	1
7	[8, 8]	1	[8, 8]	2
8	[5, 10]	1	[12, 12]	1
9	[11, 16]	1	[21, 21]	1
10	[11, 16]	2	[11, 12]	1
11	[11, 16]	1	[21, 21]	1
12	[11, 16]	1	[21, 21]	1
Resource costs	[332.3, 1158.3]		[586.37, 1065.02]	
Renewable resource availability (R1)	[7.84, 13.43]		[13.15, 13.15]	
Renewable resource availability (R2)	[5.84, 12.42]		[10.77, 10.77]	
Total number of iterations	1881104		2776519	
Extended solver steps	58535		24814	
CPU time (sec.)	2165.46		2222.19	
Optimality gap (%)	-		-	
Actual probability (CCPL)	100%		100%	
Actual probability (CCPU)	100%		60%	
Unsatisfied scenarios (CCPL)	0		0	
Unsatisfied scenarios (CCPU)	0		4	

Table D3

Compromise project schedules and resource availabilities for the benchmark instance#3 according to the project manager's risk attitude.

Project activities	Completion time interval (Risk-seeker)	Mode	Completion time interval (Risk-averse)	Mode
1	[0, 0]	1	[0, 0]	1
2	[1, 2]	1	[3, 3]	1
3	[2, 4]	1	[4, 4]	1
4	[1, 4]	2	[4, 4]	1
5	[2, 4]	1	[4, 4]	1
6	[4, 10]	1	[6, 6]	1
7	[3, 3]	1	[9, 9]	2
8	[4, 7]	2	[7, 7]	2
9	[3, 7]	2	[9, 9]	2
10	[6, 6]	1	[12, 12]	1
11	[5, 10]	1	[10, 10]	1
12	[6, 12]	1	[12, 12]	1
13	[6, 13]	1	[13, 13]	1
14	[7, 12]	1	[16, 16]	1
15	[5, 14]	1	[11, 12]	1
16	[7, 16]	1	[16, 16]	1
17	[7, 15]	2	[16, 17]	2
18	[8, 16]	2	[18, 18]	2
19	[8, 18]	1	[18, 18]	1
20	[8, 18]	1	[18, 18]	1
Resource costs	[216.17, 516.95]		[258.48, 516.95]	
Renewable resource availability (R1)	[7.5, 11.11]		[11.11, 11.11]	
Renewable resource availability (R2)	[7.06, 7.37]		[7.37, 7.37]	
Total number of iterations	50558		81918	
Extended solver steps	2001		1533	
CPU time (sec.)	897.78		660.0	
Optimality gap (%)	-		-	
Actual probability (CCPL)	80%		80%	
Actual probability (CCPU)	100%		0%	
Unsatisfied scenarios (CCPL)	2		2	
Unsatisfied scenarios (CCPU)	0		10	

Table D4

Compromise project schedules and resource availabilities for the benchmark instance#4 according to the project manager's risk attitude.

Project activities	Completion time interval (Risk-seeker)	Mode	Completion time interval (Risk-averse)	Mode
1	[0, 0]	1	[0, 0]	1
2	[1, 2]	1	[2, 2]	1
3	[1, 1]	1	[1, 1]	1
4	[3, 7]	2	[3, 5]	1
5	[2, 3]	1	[3, 3]	1
6	[2, 3]	1	[3, 3]	1
7	[2, 5]	1	[5, 5]	1
8	[6, 6]	1	[8, 8]	2
9	[5, 8]	1	[10, 10]	1
10	[6, 9]	1	[11, 11]	1
11	[4, 5]	3	[5, 5]	3
12	[7, 11]	1	[13, 13]	1
13	[8, 10]	1	[12, 12]	1
14	[7, 7]	1	[7, 8]	1
15	[9, 11]	1	[13, 13]	1
16	[8, 11]	1	[13, 13]	1
17	[5, 8]	1	[10, 10]	1
18	[10, 12]	2	[13, 13]	1
19	[9, 14]	1	[16, 16]	1
20	[11, 14]	1	[16, 16]	1
21	[11, 14]	1	[16, 16]	1
22	[11, 14]	1	[16, 16]	1
Resource costs	[388.16, 853.23]		[661.46, 1055.95]	
Renewable resource availability (R1)	[7.02, 9.69]		[13.95, 13.95]	
Renewable resource availability (R2)	[8.26, 11.25]		[12.75, 12.75]	
Total number of iterations	37253499		9814917	
Extended solver steps	44540		13873	
CPU time (sec.)	18043.60		17120.76	
Optimality gap (%)	-		-	
Actual probability (CCPL)	100%		100%	
Actual probability (CCPU)	100%		60%	
Unsatisfied scenarios (CCPL)	0		0	
Unsatisfied scenarios (CCPU)	0		2	

Table D5

Compromise project schedules and resource availabilities for the benchmark instance#5 according to the project manager's risk attitude.

Project activities	Completion time interval (Risk-seeker)	Mode	Completion time interval (Risk-averse)	Mode	Project activities	Completion time interval (Risk-seeker)	Mode	Completion time interval (Risk-averse)	Mode
1	[0, 0]	1	[0, 0]	1	17	[11, 12]	1	[15, 15]	1
2	[2, 4]	1	[4, 4]	1	18	[7, 8]	1	[15, 15]	1
3	[2, 4]	1	[5, 5]	2	19	[5, 7]	1	[14, 14]	1
4	[2, 3]	1	[3, 3]	1	20	[3, 8]	1	[12, 12]	1
5	[6, 6]	1	[12, 12]	1	21	[9, 13]	1	[10, 10]	1
6	[6, 10]	1	[7, 7]	1	22	[11, 15]	1	[13, 14]	1
7	[3, 5]	1	[5, 5]	1	23	[14, 22]	3	[16, 18]	1
8	[6, 10]	1	[10, 10]	1	24	[12, 17]	1	[17, 17]	1
9	[3, 5]	1	[5, 5]	1	25	[12, 17]	1	[17, 17]	2
10	[13, 16]	1	[19, 21]	1	26	[11, 18]	2	[19, 19]	2
11	[4, 6]	1	[6, 6]	1	27	[14, 20]	1	[21, 21]	1
12	[7, 11]	1	[11, 11]	1	28	[15, 22]	2	[22, 22]	2
13	[12, 17]	1	[21, 21]	1	29	[16, 25]	1	[25, 25]	1
14	[10, 15]	1	[15, 15]	1	30	[16, 25]	1	[25, 25]	1
15	[7, 10]	1	[10, 10]	2	31	[15, 22]	2	[25, 25]	2
16	[9, 14]	1	[14, 14]	1	32	[16, 25]	1	[25, 25]	1
Resource costs	[595.75, 1558.78]		[923.92, 1662.68]						
Renewable resource availability (R1)	[11.76, 16.83]		[16.83, 16.83]						
Renewable resource availability (R2)	[10.38, 15.82]		[18.42, 18.42]						
Total number of iterations	56401873		58562839						
Extended solver steps	31681		16010						
CPU time (sec.)	28749.05		29211.13						
Optimality gap (%)	-		-						
Actual probability (CCPL)	100%		100%						
Actual probability (CCPU)	100%		60%						
Unsatisfied scenarios (CCPL)	0		0						
Unsatisfied scenarios (CCPU)	0		2						