

Table 2: Feasibility Rate of RCM36-46 under different equality constraint thresholds

Problem	M	D	NSGA-II					CCMO					PPS-MOEA/D				
			10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1
RCM36	2	28	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	4.7619e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	2.8571e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0
RCM37	2	28	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	7.6190e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	3.3333e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0
RCM38	2	28	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	4.2857e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0
RCM39	3	28	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	6.1905e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.9048e-1	0.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0
RCM40	2	34	0.0000e+0	0.0000e+0	0.0000e+0	4.7619e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	3.3333e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0
RCM41	3	34	0.0000e+0	0.0000e+0	0.0000e+0	4.2857e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	2.8571e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0
RCM42	2	34	0.0000e+0	0.0000e+0	0.0000e+0	4.2857e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	2.8571e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0
RCM43	2	34	0.0000e+0	0.0000e+0	0.0000e+0	4.2857e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0
RCM44	3	34	0.0000e+0	0.0000e+0	0.0000e+0	4.2857e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	4.7619e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0
RCM45	3	34	0.0000e+0	0.0000e+0	0.0000e+0	4.2857e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	3.3333e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0
RCM46	4	34	0.0000e+0	0.0000e+0	0.0000e+0	4.7619e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	3.8095e-1	1.0000e+0	0.0000e+0	0.0000e+0	0.0000e+0	1.0000e+0	1.0000e+0

Table 3: Average FR of the EMO algorithms for 21 RCM problems and reformulation versions

Problem	M	D	ng	nh	CCMO	NSGA-II	PPS-MOEA/D	Problem	M	D	ng	nh	CCMO	NSGA-II	PPS-MOEA/D	Problem	M	D	ng	nh	CCMO	NSGA-II	PPS-MOEA/D
RCM22	2	9	2	4	0.0000e+0	0.0000e+0	1.0000e+0	RCM33	2	30	29	0	8.5714e-1	9.5238e-1	1.0000e+0	RCM40	2	34	0	26	3.3333e-1	4.7619e-1	1.0000e+0
RCM22-re	2	7	3	2	4.7619e-2	4.7619e-2	1.0000e+0	RCM33-re	2	31	0	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM40-re	2	26	16	18	5.7143e-1	7.1429e-1	1.0000e+0
RCM23	2	6	1	4	1.0000e+0	1.0000e+0	1.0000e+0	RCM34	2	30	29	0	8.0952e-1	1.0000e+0	1.0000e+0	RCM41	3	34	0	26	2.8571e-1	4.2857e-1	1.0000e+0
RCM23-re	2	5	3	3	1.0000e+0	1.0000e+0	1.0000e+0	RCM34-re	2	31	0	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM41-re	3	26	16	18	5.7143e-1	3.8095e-1	1.0000e+0
RCM24	3	9	0	6	0.0000e+0	0.0000e+0	1.0000e+0	RCM35	2	30	29	0	6.1905e-1	1.0000e+0	1.0000e+0	RCM42	2	34	0	26	2.8571e-1	4.2857e-1	1.0000e+0
RCM24-re	3	5	0	2	1.0000e+0	1.0000e+0	1.0000e+0	RCM35-re	2	31	0	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM42-re	2	26	16	18	3.3333e-1	4.2857e-1	1.0000e+0
RCM28	2	7	4	4	9.5238e-1	4.7619e-2	1.0000e+0	RCM36	2	28	0	24	2.8571e-1	4.7619e-1	1.0000e+0	RCM43	2	34	0	26	3.8095e-1	4.2857e-1	1.0000e+0
RCM28-re	2	5	2	2	1.0000e+0	1.0000e+0	1.0000e+0	RCM36-re	2	24	8	20	2.8571e-1	7.6190e-1	1.0000e+0	RCM43-re	2	26	16	18	3.8095e-1	6.6667e-1	1.0000e+0
RCM30	2	25	24	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM37	2	28	0	24	3.3333e-1	7.6190e-1	1.0000e+0	RCM44	3	34	0	26	4.7619e-1	4.2857e-1	1.0000e+0
RCM30-re	2	26	0	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM37-re	2	24	8	20	3.3333e-1	6.6667e-1	0.0000e+0	RCM44-re	3	26	16	18	4.7619e-1	4.7619e-1	1.0000e+0
RCM31	2	25	24	0	9.5238e-1	1.0000e+0	1.0000e+0	RCM38	2	28	0	24	1.0000e+0	4.2857e-1	0.0000e+0	RCM45	3	34	0	26	3.3333e-1	4.2857e-1	1.0000e+0
RCM31-re	2	26	0	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM38-re	2	24	8	20	1.0000e+0	7.6190e-1	0.0000e+0	RCM45-re	3	26	16	18	6.1905e-1	6.6667e-1	1.0000e+0
RCM32	2	25	24	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM39	3	28	0	24	1.9048e-1	6.1905e-1	1.0000e+0	RCM46	4	34	0	26	3.8095e-1	4.7619e-1	1.0000e+0
RCM32-re	2	26	0	0	1.0000e+0	1.0000e+0	1.0000e+0	RCM39-re	3	24	8	20	2.8571e-1	5.2381e-1	1.0000e+0	RCM46-re	4	26	16	18	4.2857e-1	7.1429e-1	1.0000e+0

Table 4: Average HV of the EMO algorithms for 21 RCM problems and reformulation versions

Problem	M	D	ng	nh	CCMO	NSGA-II	PPS-MOEA/D	Problem	M	D	ng	nh	CCMO	NSGA-II	PPS-MOEA/D	Problem	M	D	ng	nh	CCMO	NSGA-II	PPS-MOEA/D
RCM22	2	9	2	4	---	---	7.1945e-1	RCM33	2	30	29	0	3.3213e-3	0.0000e+0	5.0883e-1	RCM40	2	34	0	26	2.1546e-1	2.0022e+0	7.6834e-1
RCM22-re	2	7	3	2	9.0454e-1	6.0379e-1	7.0233e-1	RCM33-re	2	31	0	0	7.4705e-1	7.4905e-1	7.6466e-1	RCM40-re	2	26	16	18	7.4506e-1	7.7651e-1	7.9502e-1
RCM23	2	6	1	4	3.0199e-1	2.3474e-1	7.8589e-1	RCM34	2	30	29	0	0.0000e+0	0.0000e+0	1.5393e-4	RCM41	3	34	0	26	0.0000e+0	0.0000e+0	2.7791e-1
RCM23-re	2	5	3	3	3.4446e-1	2.9342e-1	8.1859e-1	RCM34-re	2	31	0	0	8.0542e-1	8.0543e-1	8.2957e-1	RCM41-re	3	26	16	18	0.0000e+0	0.0000e+0	1.3693e-1
RCM24	3	9	0	6	---	---	4.9015e-1	RCM35	2	30	29	0	6.1047e-1	6.0636e-1	6.8281e-1	RCM42	2	34	0	26	0.0000e+0	0.0000e+0	0.0000e+0
RCM24-re	3	5	0	2	1.7359e-1	3.6609e-1	5.2855e-1	RCM35-re	2	31	0	0	9.8778e-1	9.9826e-1	9.9557e-1	RCM42-re	2	26	16	18	0.0000e+0	0.0000e+0	0.0000e+0
RCM28	2	7	4	4	3.3715e-2	1.7636e-2	3.2818e-2	RCM36	2	28	0	24	0.0000e+0	0.0000e+0	0.0000e+0	RCM43	2	34	0	26	0.0000e+0	0.0000e+0	6.6288e-1
RCM28-re	2	5	2	2	3.4195e-2	3.8602e-2	3.5209e-2	RCM36-re	2	24	8	20	0.0000e+0	0.0000e+0	0.0000e+0	RCM43-re	2	26	16	18	0.0000e+0	0.0000e+0	1.6893e-1
RCM30	2	25	24	0	6.3510e-1	6.9337e-1	8.1071e-1	RCM37	2	28	0	24	0.0000e+0	0.0000e+0	0.0000e+0	RCM44	3	34	0	26	0.0000e+0	0.0000e+0	7.2941e-1
RCM30-re	2	26	0	0	8.0764e-1	8.0523e-1	8.9924e-1	RCM37-re	2	24	8	20	0.0000e+0	0.0000e+0	---	RCM44-re	3	26	16	18	0.0000e+0	0.0000e+0	1.7504e-1
RCM31	2	25	24	0	4.6880e-1	4.6856e-1	7.4721e-1	RCM38	2	28	0	24	6.5554e-1	0.0000e+0	---	RCM45	3	34	0	26	0.0000e+0	0.0000e+0	3.1084e-1
RCM31-re	2	26	0	0	8.7926e-1	8.8632e-1	8.9645e-1	RCM38-re	2	24	8	20	5.8413e-1	0.0000e+0	---	RCM45-re	3	26	16	18	0.0000e+0	0.0000e+0	5.9263e-2
RCM32	2	25	24	0	8.0951e-1	8.1391e-1	8.3902e-1	RCM39	3	28	0	24	0.0000e+0	0.0000e+0	0.0000e+0	RCM46	4	34	0	26	0.0000e+0	0.0000e+0	7.2747e-1
RCM32-re	2	26	0	0	8.4433e-1	8.6238e-1	8.8111e-1	RCM39-re	3	24	8	20	0.0000e+0	0.0000e+0	0.0000e+0	RCM46-re	4	26	16	18	0.0000e+0	0.0000e+0	1.9581e-1