TABLE I

Spread results of seven CMOEAs on LIRCMOP test suite. "+", "-", or "≈" indicates that the corresponding algorithm is significantly better than, worse than, or comparable to DPPCMO. The best average Spread value on each test problem is highlighted in gray.

Problem	dpACS	PPS	CMOES	ToP	BiCo	CCMO	DPPCMO
MW1	6.0947e-1 (5.65e-2) −	9.5484e-1 (1.15e-1) −	1.3459e-1 (1.43e-2) −	9.4114e-1 (0.00e+0) ≈	1.1924e-1 (5.58e-2) ≈	1.1782e-1 (1.89e-2) ≈	1.1297e-1 (1.46e-2)
MW2	3.5646e-1 (3.57e-1) ≈	1.0432e+0 (6.83e-2) −	2.2966e-1 (7.88e-2) ≈	1.0000e+0 (0.00e+0) ≈	2.0418e-1 (3.97e-2) +	2.3652e-1 (2.70e-2) ≈	2.2436e-1 (3.19e-2)
MW3	2.9541e-1 (3.23e-2) −	6.2137e-1 (6.19e-2) −	1.7129e-1 (2.20e-2) −	9.0584e-1 (1.59e-1) −	1.4674e-1 (2.18e-2) ≈	1.7088e-1 (2.70e-2) −	1.5448e-1 (1.51e-2)
MW4	6.5706e-2 (7.81e-3) +	5.0175e-1 (5.95e-2) −	7.8054e-2 (9.32e-3) ≈	9.0194e-1 (5.00e-2) −	8.8297e-2 (1.14e-2) −	7.8036e-2 (8.37e-3) ≈	7.7735e-2 (1.08e-2)
MW5	1.4958e+0 (1.67e-1) −	1.2158e+0 (2.96e-1) +	1.9368e+0 (5.49e-2) −	9.4958e-1 (7.13e-2) +	1.7162e+0 (5.79e-2) +	1.7755e+0 (6.07e-2) −	1.7385e+0 (4.33e-2)
MW6	7.0389e-1 (5.67e-2) −	9.8673e-1 (1.60e-2) −	1.9438e-1 (2.11e-2) −	1.0154e+0 (5.02e-2) −	2.0296e-1 (2.82e-2) −	1.9156e-1 (2.39e-2) −	1.6927e-1 (1.98e-2)
MW7	6.9187e-1 (5.75e-2) −	5.7467e-1 (6.62e-2) −	1.7225e-1 (2.17e-2) −	8.3971e-1 (1.55e-1) −	1.9444e-1 (3.30e-2) −	1.8086e-1 (2.58e-2) −	1.5018e-1 (1.82e-2)
MW8	5.6734e-1 (4.79e-2) −	5.5454e-1 (8.45e-2) −	1.1927e-1 (1.07e-2) ≈	7.6868e-1 (2.30e-1) −	1.5872e-1 (1.64e-2) −	1.1505e-1 (1.19e-2) ≈	1.1636e-1 (1.19e-2)
MW9	6.2443e-1 (9.08e-2) −	7.5598e-1 (1.94e-1) −	3.6098e-1 (9.96e-2) ≈	9.2470e-1 (6.29e-2) −	2.5665e-1 (4.44e-2) +	3.9310e-1 (6.54e-2) −	3.8462e-1 (7.06e-2)
MW10	6.5336e-1 (3.92e-2) −	8.5387e-1 (8.36e-2) −	2.6115e-1 (5.74e-2) ≈	NaN (NaN)	3.1087e-1 (9.33e-2) −	3.0816e-1 (9.61e-2) −	2.4847e-1 (6.47e-2)
MW11	7.3401e-1 (8.85e-2) −	4.2740e-1 (5.33e-2) −	1.7657e-1 (1.82e-2) −	9.5821e-1 (5.83e-2) −	1.5507e-1 (1.84e-2) −	1.8771e-1 (2.70e-2) −	1.4890e-1 (1.78e-2)
MW12	5.4579e-1 (9.37e-2) −	7.3612e-1 (2.08e-1) −	3.9755e-1 (4.68e-2) −	9.3058e-1 (4.19e-2) −	4.0601e-1 (1.29e-2) −	4.1471e-1 (1.25e-2) −	3.9120e-1 (4.85e-2)
MW13	7.3235e-1 (8.78e-2) −	7.8844e-1 (5.77e-2) −	2.4689e-1 (5.43e-2) −	8.4970e-1 (2.26e-1) −	2.0609e-1 (4.95e-2) +	2.7158e-1 (6.90e-2) −	2.3495e-1 (4.27e-2)
MW14	5.9655e-1 (6.07e-2) −	5.8753e-1 (5.86e-2) −	1.2300e-1 (1.50e-2) ≈	5.4720e-1 (9.30e-2) −	3.3296e-1 (2.38e-2) −	1.2164e-1 (1.02e-2) ≈	1.2397e-1 (1.53e-2)
LIRCMOP1	9.9600e-1 (6.07e-2) −	4.3722e-1 (8.69e-2) ≈	5.8352e-1 (2.29e-1) −	6.1769e-1 (2.18e-1) −	3.6239e-1 (7.79e-2) +	5.1155e-1 (1.54e-1) ≈	4.4811e-1 (1.25e-1)
LIRCMOP2	8.8589e-1 (1.82e-1) −	3.9002e-1 (7.48e-2) ≈	6.8410e-1 (2.03e-1) −	6.2769e-1 (2.18e-1) −	3.6194e-1 (7.22e-2) ≈	6.5879e-1 (1.38e-1) −	3.8900e-1 (1.52e-1)
LIRCMOP3	1.0529e+0 (6.29e-2) −	7.8758e-1 (5.60e-2) −	9.1242e-1 (1.95e-1) −	9.7863e-1 (1.84e-1) −	5.4022e-1 (1.58e-1) ≈	8.4499e-1 (6.37e-2) −	6.3515e-1 (2.46e-1)
LIRCMOP4	1.0630e+0 (7.82e-2) −	8.0953e-1 (4.75e-2) −	9.7104e-1 (2.52e-1) −	9.8347e-1 (1.30e-1) −	6.2015e-1 (1.87e-1) ≈	8.7031e-1 (7.87e-2) −	6.6797e-1 (2.03e-1)
LIRCMOP5	3.4498e-1 (2.88e-2) −	7.0950e-1 (8.02e-2) −	2.4884e-1 (2.31e-1) −	4.0869e-1 (1.55e-1) −	1.0135e+0 (4.04e-1) −	1.4123e-1 (1.36e-2) ≈	1.6418e-1 (1.07e-1)
LIRCMOP6	2.2145e-1 (5.81e-2) −	1.0580e+0 (1.40e-1) −	1.9353e-1 (6.41e-2) −	3.6441e-1 (1.87e-1) −	4.3966e-1 (3.51e-1) −	1.7526e-1 (4.95e-2) ≈	1.5344e-1 (3.22e-2)
LIRCMOP7	2.9634e-1 (6.54e-2) −	7.4734e-1 (9.86e-2) −	2.1604e-1 (2.31e-1) ≈	3.0523e-1 (5.70e-2) −	7.0426e-1 (5.83e-1) −	1.9464e-1 (2.36e-1) −	1.8629e-1 (2.09e-1)
LIRCMOP8	2.6582e-1 (6.36e-2) −	7.0213e-1 (9.89e-2) −	2.0452e-1 (2.13e-1) ≈	3.5630e-1 (1.91e-1) −	4.4701e-1 (4.31e-1) −	1.4175e-1 (3.27e-2) ≈	1.9323e-1 (2.41e-1)
LIRCMOP9	7.7153e-1 (2.10e-1) +	7.8022e-1 (8.69e-2) +	1.0359e+0 (5.46e-3) −	5.0610e-1 (1.76e-1) +	1.2396e+0 (9.26e-2) −	1.0337e+0 (3.95e-3) ≈	1.0336e+0 (4.39e-3)
LIRCMOP10	6.6369e-1 (8.76e-2) −	8.8659e-1 (1.01e-1) −	3.3643e-1 (8.62e-3) −	5.2540e-1 (4.91e-2) −	5.3050e-1 (2.86e-1) −	3.3318e-1 (9.46e-3) ≈	3.3173e-1 (6.72e-3)
LIRCMOP11	1.6776e+0 (3.10e-1) ≈	7.8371e-1 (3.89e-1) +	1.8005e+0 (4.63e-3) −	7.7677e-1 (4.84e-1) +	1.7944e+0 (1.04e-2) ≈	1.7979e+0 (4.29e-3) ≈	1.7989e+0 (3.07e-3)
LIRCMOP12	1.5336e+0 (2.45e-1) +	8.1528e-1 (2.68e-1) +	1.7436e+0 (3.34e-1) ≈	7.2078e-1 (7.26e-2) +	1.8231e+0 (2.21e-2) +	1.8368e+0 (1.49e-2) −	1.8355e+0 (5.24e-3)
LIRCMOP13	1.7718e-1 (4.42e-3) −	5.8978e-2 (7.90e-2) ≈	1.0028e-1 (7.60e-3) ≈	3.9704e-2 (3.31e-2) ≈	9.9835e-2 (1.25e-2) ≈	1.0112e-1 (1.01e-2) ≈	9.4796e-2 (1.08e-2)
LIRCMOP14	1.9182e-1 (9.73e-3) −	4.4209e-2 (4.82e-2) ≈	9.5814e-2 (1.23e-2) −	4.2512e-2 (3.80e-2) −	9.7268e-2 (1.30e-2) −	9.8561e-2 (1.49e-2) −	8.6942e-2 (1.11e-2)
DASCMOP1	8.5500e-1 (1.12e-1) −	6.5902e-1 (2.04e-1) −	1.9024e-1 (2.38e-2) −	9.7486e-1 (4.71e-2) −	8.9401e-1 (1.38e-2) −	2.0014e-1 (2.57e-2) −	1.7109e-1 (2.56e-2)
DASCMOP2	4.2971e-1 (5.88e-2) −	4.7632e-1 (7.29e-2) −	1.6488e-1 (2.20e-2) ≈	9.3997e-1 (1.44e-1) −	8.6449e-1 (1.51e-2) −	1.7097e-1 (1.79e-2) −	1.5593e-1 (1.69e-2)
DASCMOP3	1.2551e+0 (2.17e-1) −	9.9000e-1 (2.27e-2) +	1.0589e+0 (1.45e-1) ≈	9.8173e-1 (3.18e-2) +	1.0713e+0 (1.11e-1) −	1.1107e+0 (1.75e-1) −	1.0575e+0 (1.55e-1)
DASCMOP4	8.5191e-1 (9.28e-2) −	9.1769e-1 (5.72e-2) −	4.2150e-1 (1.37e-1) −	NaN (NaN)	3.2614e-1 (3.67e-2) −	2.9572e-1 (3.56e-2) ≈	2.8839e-1 (1.14e-2)
DASCMOP5	1.1452e+0 (2.29e-1) −	1.0566e+0 (7.78e-2) −	3.3080e-1 (7.49e-2) −	NaN (NaN)	1.7854e-1 (1.55e-2) −	1.6681e-1 (1.46e-2) −	1.5761e-1 (1.47e-2)
DASCMOP6	1.2732e+0 (2.28e-1) +	9.9216e-1 (9.58e-2) +	1.4047e+0 (2.06e-1) ≈	NaN (NaN)	1.4690e+0 (1.70e-1) ≈	1.5061e+0 (8.48e-2) +	1.5079e+0 (6.03e-2)
DASCMOP7	9.1571e-1 (1.88e-1) −	6.1824e-1 (7.58e-2) −	2.4664e-1 (1.66e-1) −	NaN (NaN)	1.2393e-1 (1.36e-2) ≈	1.1973e-1 (1.23e-2) ≈	1.1774e-1 (1.23e-2)
DASCMOP8	1.0204e+0 (1.71e-1) −	6.3290e-1 (8.12e-2) −	2.4001e-1 (8.30e-2) −	NaN (NaN)	1.6173e-1 (1.54e-2) −	1.4601e-1 (1.97e-2) ≈	1.4163e-1 (1.46e-2)
DASCMOP9	5.0194e-1 (6.47e-2) −	7.1989e-1 (8.40e-2) −	1.8372e-1 (1.35e-2) ≈	8.8504e-1 (1.57e-1) −	3.3979e-1 (5.80e-2) −	1.9028e-1 (1.46e-2) −	1.7669e-1 (1.77e-2)
DOC1	6.1188e-1 (6.91e-2) −	1.2118e+0 (1.23e-1) −	3.7031e-1 (7.04e-2) −	3.4785e-1 (4.31e-2) −	4.8582e-1 (4.67e-2) −	2.0523e-1 (2.63e-2) ≈	1.9884e-1 (2.49e-2)
DOC2	9.1353e-1 (5.17e-2) −	1.0163e+0 (1.22e-2) −	NaN (NaN)	9.3187e-1 (2.90e-2) −	NaN (NaN)	2.1149e-1 (1.44e-1) ≈	1.7570e-1 (3.34e-2)
DOC3	9.4091e-1 (9.99e-2) ≈	1.0089e+0 (2.43e-2) −	9.7259e-1 (7.43e-2) ≈	9.4255e-1 (9.25e-2) +	9.9856e-1 (5.34e-4) ≈	9.1223e-1 (1.85e-2) +	9.7900e-1 (1.09e-1)
DOC4	1.3977e+0 (1.53e-1) +	1.2114e+0 (2.02e-1) +	1.2984e+0 (2.39e-1) +	1.2911e+0 (2.44e-1) +	1.0339e+0 (3.00e-1) +	1.5683e+0 (1.36e-1) −	1.4790e+0 (2.47e-1)
DOC5	1.0248e+0 (1.61e-1) +	1.1860e+0 (2.73e-1) +	1.2439e+0 (2.69e-1) ≈	1.0167e+0 (1.21e-1) +	NaN (NaN)	1.4754e+0 (1.69e-1) −	1.3243e+0 (2.01e-1)
DOC6	1.2443e+0 (2.38e-1) −	1.5492e+0 (3.16e-1) −	9.9801e-1 (2.66e-1) −	1.4328e+0 (2.21e-1) −	7.8865e-1 (1.15e-1) ≈	7.9128e-1 (6.75e-2) ≈	7.8909e-1 (2.14e-2)
DOC7	8.7847e-1 (1.13e-1) ≈	1.0470e+0 (5.21e-2) −	8.3089e-1 (8.81e-2) +	8.9463e-1 (9.73e-2) ≈	9.5200e-1 (2.32e-2) −	8.5121e-1 (3.34e-2) ≈	8.4839e-1 (2.41e-2)
DOC8	4.9182e-1 (6.56e-2) −	1.3960e+0 (1.19e-1) −	2.3061e-1 (3.23e-1) −	5.3200e-1 (5.98e-2) −	2.6752e-1 (2.53e-2) −	1.5743e-1 (1.76e-2) +	1.7134e-1 (2.83e-1)
DOC9	6.2887e-1 (8.42e-2) −	8.3559e-1 (1.47e-1) −	1.4083e-1 (1.51e-2) ≈	4.5788e-1 (4.83e-2) −	1.5191e-1 (2.68e-2) −	1.4193e-1 (1.89e-2) ≈	1.3640e-1 (1.93e-2)
+/ − /≈	7/35/4	8/36/2	2/24/19	8/30/2	7/25/12	3/19/24	