Supplementary File of "Even Search in a Promising Region for Constrained Multi-objective Optimization"

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This file is the supplementary file of "Search in a Promising Region for Constrained Multi-objective Optimization Problems". It contains the experimental results of all experiments in Section IV of the main text and discussions on these results. All experiments were conducted on PlatEMO [1].

I. Results on Benchmark Comparison Studies

This section presents the results and discussions on benchmark comparison studies of Section IV-B in the main text.

A. Results on DAS-CMOPs

DAS-CMOPs [2] are featured as adjustable difficulties on convergence, diversity, and feasibility. DAS-CMOP1-9 contains all three difficulties and they are of different degrees. For example, DAS-CMOP4 has larger difficulties in convergence and feasibility than DAS-CMOP1. DAS-CMOP9 has larger difficulties in diversity and feasibility than DAS-CMOP8. These comprehensive features of the DAS-CMOP test suite propose a challenge to the versatility of algorithms.

1) *Indicator Results on DAS-CMOPs:* Tables S-I and S-II report the statistical results of HV and IGD+ obtained by CMOES and other methods on DAS-CMOPs. It is apparent that CMOES outperformed all other methods on DAS-CMOP1-6. On DAS-CMOP7-9, it performed worse than some methods, but referring to the indicator values, it can be found that CMOES finally approximated the CPFs of DAS-CMOP7-9.

2) *CPF Results on DAS-CMOPs:* Fig. S-1 presents the feasible and non-dominated solution sets obtained by CMOES on DAS-CMOP benchmark problems with the median IGD+ value among 30 runs. It is apparent that CMOES finally approximated the CPFs and achieved good degrees of diversity performances in all the instances, revealing that CMOES has excellent versatility. Further, Figs. S-2 and S-3 present the feasible and non-dominated solution sets obtained by CMOES and other methods on DAS-CMOP3 and DAS-CMOP9. It can be found that DSPCMDE [3] performed well on DAS-CMOP3 but performed poorly on DAS-CMOP9. Similarly, URCMO [4] performed well on DAS-CMOP9 but poorly on DAS-CMOP3. However, CMOES performed well in both of these two instances. Therefore, our methods achieve the best versatility in these instances.

B. Results on LIR-CMOPs

LIR-CMOPs [5] are featured as large infeasible regions, *i.e.,* small feasible regions, which propose great challenges for an algorithm on crossing infeasible barriers and locating feasible regions.

1) *Indicator Results on LIR-CMOPs:* Tables S-III and S-IV report the statistical results of HV and IGD+ obtained by CMOES and other methods on LIR-CMOPs. On LIR-CMOP1-4, CMOES performed worse than ShiP-A [6], revealing that the ε-constrained technique in this work is not effective enough in dealing with these LIR-CMOPs with very small feasible regions. On LIR-CMOP5-6, CMOES only performed worse than DSPCMDE. However, referring to the indicator values, CMOES finally approximated the CPFs and obtained good degrees of diversity. On LIR-CMOP7-12, CMOES outperformed all other methods. On LIR-CMOP13-14, CMOES performed worse than some SPEA2-based CMOEAs (CMOEA-MS [7] and CCMO [8]) and decomposition-based CMOEA (CCEA [9]). The reason is that we use the strategy of NSGA-II [34] to update the archive (the final output), and this strategy is less effective than SPEA2 [10] or decomposition-based approaches.

2) *CPF Results on LIR-CMOPs:* Then, we present the feasible and non-dominated solution sets obtained by CMOES on LIR-CMOP benchmark problems with the median IGD+ value among 30 runs in Fig. S-4. The results reflect that CMOES could not find all the segments of CPFs on LIR-CMOP1-4. On LIR-CMOP5-6, some extreme points are preserved due to the strategy of NSGA-II (protection for extreme points). On LIR-CMOP13-14, the distributions on the CPFs are poor, resulting in worse indicator values. Nevertheless, CMOES finally found the CPFs of LIR-CMOP5-14. To further compare different methods, we present the feasible and non-dominated solution sets obtained by CMOES and other methods on LIR-CMOP8 in Fig. S-5. It can be found that URCMO and DSPCMDE performed well on this instance, but they performed very poorly on other instances of LIR-CMOPs as shown in the tables. Therefore, they lack versatility but CMOES could achieve much more instances.

C. Results on LYOs

LYOs [9] have an interesting feature, the initial population arises in the complex infeasible regions below the CPF. This makes the popular unconstrained helper problem-assisted approaches ineffective because the UPF is very far below the CPF, and the unconstrained helper problem will guide the population search inward while the CPF needs a search backward in the objective space.

1) Indicator Results on LYOs: Tables S-V and S-VI report the statistical results of HV and IGD+ obtained by CMOES and other methods on LYOs. The results clearly show that our proposed CMOES is competitive with CCEA, an algorithm proposed for LYOs. CCEA performed better on LYO3, LYO5, and LYO7, while CMOES performed better on LYO2, LYO4, and LYO6. Referring to other benchmark test suites, we can find that CCEA performed worse than CMOES in most instances, demonstrating that an overly fine-tuned technique is less generic than our method.

2) CPF Results on LYOs: Then, we present the feasible and non-dominated solution sets obtained by CMOES on LIR-CMOP benchmark problems with the median IGD+ value among 30 runs in Fig. S-6. The results show that CMOES performed well on LYO1-6, but performed poorly on LYO7-8. The poor performances on LYO7-8 might be caused by the ε-constrained technique, which will be discussed in the parameter analyses. Also, we depict the feasible and non-dominated solution sets obtained by CMOES and other methods on LYO6 in Fig. S-7. The results show that CMOES and BiCo [11] performed the best, and CCEA is slightly worse in terms of diversity.

D. Results on MWs

MWs [12] contain four relationships between the CPF and the UPF, which can test the generic ability of an algorithm. According to our practice, ignoring constraints in a helper problem can achieve very good performance on Type-I to Type-III problems, but is less effective on Type-IV problems.

1) Indicator Results on MWs: Tables S-VII and S-VIII report the statistical results of HV and IGD+ obtained by CMOES and other methods on MWs. CMOES generally performed not the best on this benchmark test suite. Some other methods using an unconstrained helper problem (BiCo and MFO-SPEA2 [13]) performed better on Type-I to Type-III problems. Nevertheless, referring to the specific indicator values, it can be found that CMOES finally obtained the CPFs in all instances.

2) CPF Results on MWs: Fig. S-6 presents the feasible and non-dominated solution sets obtained by CMOES on MW benchmark problems with the median IGD+ value among 30 runs. It is apparent that CMOES finally obtained the CPFs on all instances. On MW10, the corner segment of the CPF is missed, revealing that CMOES failed to find the very small feasible region. On MW14, the diversity performance needs improvement. Since our method and many other methods performed very well on this test suite (the CPFs can be approximated and well covered), no further comparison is conducted.

II. Results on Real-world CMOPs

This section presents the results and discussions on real-world comparison studies of Section IV-C in the main text. We test all the methods on the IEEE CEC 2021 Competition on Real World Multiobjective Constrained Optimization test suite RWMOPs [32]. Specifically, the former 14 two-objective CMOPs are tested. Since real-world problems are subject to unknown features and challenges, they propose very great challenges to the generic ability of an algorithm.

The results of the HV indicator are reported in Table S-IX. From the results we can find that Top and CMOES generally performed the best, they obtained better results in more instances than others. We can have the following conclusions:

- The performances of algorithms on real-world test problems vary significantly, some methods that performed poor on benchmark test problems may perform well on real-world problems;
- ToP that adopts feasibility first (constrained dominance principle CDP) and CMOES using the Even Search in the promising region perform well in most instances.

III. Results of Ablation Studies

This section presents the results and discussions on ablation studies of Section IV-D in the main text. In the ablation studies, we designed two variants CMOESP1 and CMOESP2. CMOESP1 only preserves the first proportion of the population, while CMOESP2 only preserves the second proportion of the population. The results on DAS-CMOPs, LIR-CMOPs, LYOs, and MWs are reported in Tables S-X to S-XVII.

On DAS-CMOPs, CMOESP1 performed better on DAS-CMOP7-8 but CMOESP2 performed better on DAS-CMOP9. This is because DAS-CMOP9 has larger difficulties in diversity and feasibility, so the ε-constrained technique can lead to better performance. For other instances, CMOES generally performed the best.

On LIR-CMOPs, CMOESP1 performed better on LIR-CMOP6-12, revealing that using well-distributed non-dominated solutions in the promising region can help to search the CPF. However, CMOES outperformed both of the variants in other instances, revealing that our method generally has the best versatility.

On LYOs, CMOESP1 performed significantly worse in most instances, demonstrating that ignoring constraints has no help in dealing with such a kind of special problem. CMOESP2 generally performed the same as CMOES, revealing that the second proportion of the population indeed enhance the performance of our method on LYOs.

On MWs, CMOESP1 which uses non-dominated solutions (ignoring constraints) performed better on Type-I to Type-III problems, while CMOESP2 which uses relaxed feasible solutions performed better on Type-IV problems.

IV. Results of Parameter Analyses

This section presents the results and discussions on parameter analyses of Section IV-E in the main text. In the parameter analyses, we also created two variants named CMOESeta1 and CMOESeta2. CMOESeta1 set η to $1/2$, and CMOESeta2 set η to 1. $\eta = 1/2$ provides an increasing gradient for Equation (5), while $\eta = 1$ provides a steady gradient. The results on DAS-CMOPs, LIR-CMOPs, LYOs, and MWs are reported in Tables S-XVIII to S-XXV.

On DAS-CMOPs and LIR-CMOPs, $\eta = 2$ is the best setting. The reason can be that a decreasing gradient makes ε a larger value at the early stage to enhance the exploration ability. While in the latter stage, ε is smaller to enhance the exploitation ability. When dealing with DAS-CMOPs and LIR-CMOPs with complex infeasible regions, such a setting of ε is more suitable.

On LYOs, the differences are mainly on LYO2 and LYO7-8. For these instances, a smaller η value results in better performance, and the smaller, the better. The reason is that $\eta = 1/2$ provides the largest ε value during the evolutionary process, so more segments of the CPF can be detected. Therefore, for LYO2 and LYO7-8 that contain objective space regions of large constraint violation value, a small η can be more suitable.

On MWs, a smaller η value leads to better results on Type-III and Type-IV problems. On the contrary, a larger η value leads to better results on Type-I and Type-II problems. The reason is that for Type-I and Type-II problems, ignoring constraints can get very good results. A larger η leads to a small ε, which has a similar effect as CDP. Since the first proportion of the population contains non-dominated solutions that ignore constraints, if the second proportion has a larger preference for feasibility, the CPF can be better exploited. On the contrary, a smaller η value leads to a larger ε. Based on a larger degree of constraint relaxation, the CPF can be better explored since it partially overlaps the UPF or has no overlap with the UPF.

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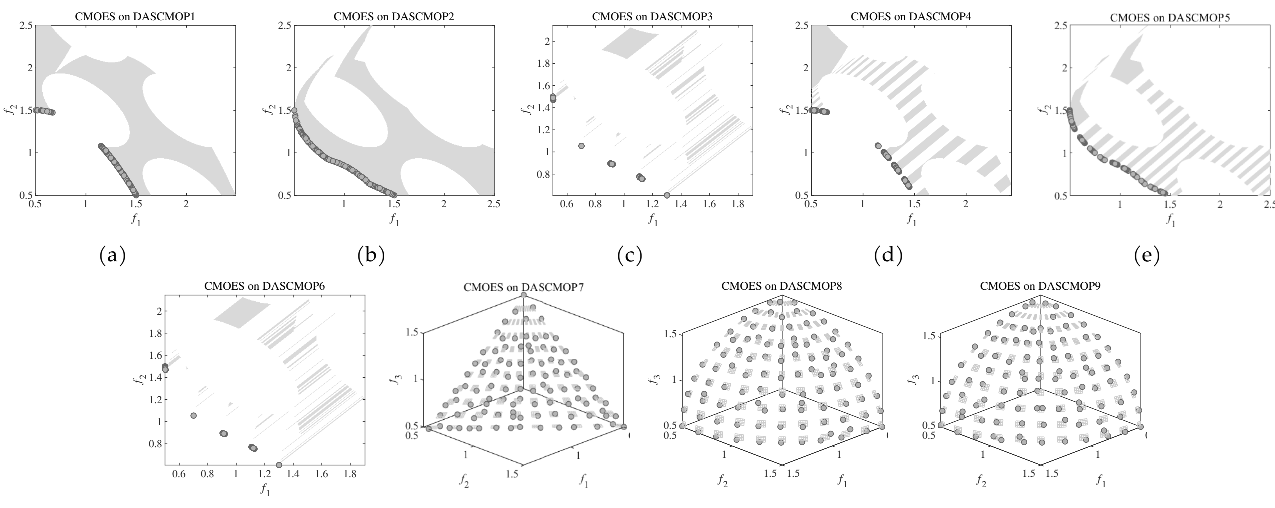


(a) (b) (c) (d) (e)

(f) (g) (h) (i)

Fig. S-1. Feasible and non-dominated solution set obtained by CMOES on DAS-CMOP benchmark problems with the median IGD+ value among 30 runs. Fig. 5(a) to Fig. 5(i) represents the results on DAS-CMOP1 to DAS-CMOP9.

TABLE S-I

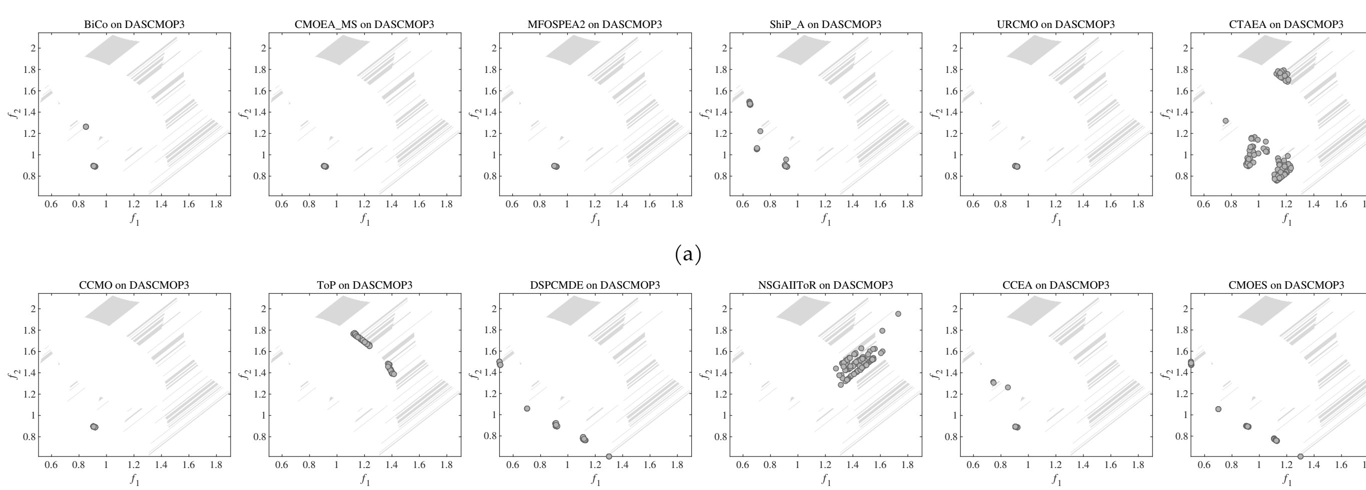
Statistical results of HV obtained by CMOES and other methods on DAS-CMOP benchmark problems. The best result in each row is highlighted.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
DASCMOP1	8.5403e-3 (5.25e-3) −	1.3256e-2 (1.84e-2) −	7.9933e-3 (7.24e-3) −	2.1105e-1 (1.01e-3) −	1.8887e-1 (5.23e-2) ≈	1.6717e-1 (2.50e-3) −	1.0862e-2 (1.14e-2) −	4.3883e-3 (7.43e-3) −	2.1103e-1 (6.23e-4) −	1.8232e-3 (2.73e-3) −	4.6001e-2 (2.78e-2) −	2.1165e-1 (5.03e-4)
DASCMOP2	2.4959e-1 (3.91e-3) −	2.5356e-1 (3.51e-3) −	2.5683e-1 (2.48e-3) −	3.3541e-1 (1.10e-2) −	3.5006e-1 (1.76e-2) −	3.0587e-1 (1.05e-2) −	2.5855e-1 (4.25e-3) −	8.0273e-2 (9.59e-2) −	3.5410e-1 (2.07e-4) −	9.0594e-2 (9.34e-2) −	2.7372e-1 (3.33e-3) −	3.5455e-1 (1.25e-4)
DASCMOP3	2.1542e-1 (1.08e-2) −	2.0846e-1 (3.32e-4) −	2.1326e-1 (1.23e-2) −	2.5847e-1 (6.81e-3) −	2.2547e-1 (3.05e-2) −	2.4892e-1 (9.85e-3) −	2.1357e-1 (1.36e-2) −	3.5298e-2 (4.44e-2) −	3.1109e-1 (5.34e-4) −	1.2990e-2 (1.13e-2) −	2.2542e-1 (1.28e-2) −	3.1148e-1 (4.01e-4)
DASCMOP4	1.4849e-1 (5.73e-2) −	1.7660e-1 (4.56e-2) ≈	2.0168e-1 (3.34e-3) −	1.9546e-1 (8.39e-3) −	1.6408e-1 (5.16e-2) −	1.9617e-1 (4.89e-3) −	2.0208e-1 (3.55e-3) ≈	NaN (NaN)	3.4586e-2 (6.03e-2) −	NaN (NaN)	1.9861e-1 (2.08e-2) −	2.0370e-1 (1.55e-3)
DASCMOP5	3.1712e-1 (8.64e-2) −	3.1691e-1 (8.68e-2) −	3.5110e-1 (2.57e-4) −	3.5009e-1 (1.20e-3) −	2.9057e-1 (8.32e-2) −	3.4790e-1 (4.49e-4) −	3.5132e-1 (1.99e-4) ≈	NaN (NaN)	8.2995e-2 (7.70e-2) −	NaN (NaN)	2.9372e-1 (9.48e-2) −	3.5141e-1 (1.40e-4)
DASCMOP6	2.4827e-1 (9.04e-2) −	1.8254e-1 (1.19e-1) −	3.0192e-1 (1.42e-2) −	3.0747e-1 (1.05e-2) −	1.5369e-1 (9.66e-2) −	3.0778e-1 (1.67e-3) −	3.0212e-1 (1.50e-2) −	NaN (NaN)	2.5652e-2 (1.97e-2) −	NaN (NaN)	2.7211e-1 (8.30e-2) −	3.0781e-1 (1.22e-2)
DASCMOP7	2.8720e-1 (1.63e-3) ≈	2.8894e-1 (1.56e-4) +	2.8713e-1 (5.98e-4) −	2.8238e-1 (6.90e-4) −	2.8465e-1 (4.01e-3) −	2.8664e-1 (3.05e-3) ≈	2.8848e-1 (4.07e-4) +	NaN (NaN)	4.8666e-2 (7.62e-2) −	NaN (NaN)	2.8835e-1 (2.03e-4) +	2.8765e-1 (4.71e-4)
DASCMOP8	2.0655e-1 (7.04e-4) ≈	2.0526e-1 (1.37e-2) −	2.0603e-1 (5.62e-4) −	2.0053e-1 (1.06e-3) −	2.0436e-1 (1.69e-3) −	2.0318e-1 (2.46e-3) −	2.0717e-1 (3.93e-4) +	NaN (NaN)	4.8830e-2 (7.67e-2) −	NaN (NaN)	2.0674e-1 (4.09e-3) +	2.0660e-1 (4.09e-4)
DASCMOP9	1.2700e-1 (1.02e-2) −	1.2357e-1 (1.26e-2) −	1.2077e-1 (1.54e-2) −	1.6356e-1 (1.58e-2) −	2.0415e-1 (6.33e-4) +	1.3980e-1 (1.39e-2) −	1.2574e-1 (1.06e-2) −	6.2920e-2 (2.85e-2) −	2.0158e-1 (1.04e-3) −	5.6832e-2 (9.18e-3) −	1.3267e-1 (1.64e-2) −	2.0350e-1 (5.36e-4)
+/ − / ≈	0/7/2	1/7/1	0/9/0	0/9/0	1/7/1	0/8/1	2/5/2	0/9/0	0/9/0	0/9/0	2/7/0	

TABLE S-II

Statistical results of IGD+ obtained by CMOES and other methods on DAS-CMOP benchmark problems. The best result in each row is highlighted.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
DASCMOP1	7.2139e-1 (2.60e-2) −	7.0174e-1 (7.76e-2) −	7.1995e-1 (3.70e-2) −	2.8509e-3 (7.13e-4) −	8.0365e-2 (1.78e-1) −	1.6565e-1 (3.41e-3) −	7.0814e-1 (4.99e-2) −	7.7189e-1 (5.50e-2) −	2.7064e-3 (2.60e-4) −	7.9552e-1 (3.50e-2) −	5.5031e-1 (9.76e-2) −	2.4430e-3 (1.31e-4)
DASCMOP2	1.4888e-1 (6.75e-3) −	1.4981e-1 (1.05e-2) −	1.4049e-1 (7.35e-3) −	3.3733e-2 (1.97e-2) −	9.4140e-3 (2.14e-2) −	5.8163e-2 (2.10e-2) −	1.4186e-1 (8.02e-3) −	6.2290e-1 (2.74e-1) −	4.5754e-3 (2.37e-4) −	5.7546e-1 (2.75e-1) −	1.1568e-1 (1.70e-2) −	4.1126e-3 (1.69e-4)
DASCMOP3	1.8294e-1 (2.55e-2) −	1.9836e-1 (1.67e-2) −	1.8200e-1 (2.08e-2) −	1.0448e-1 (1.40e-2) −	1.6335e-1 (4.94e-2) −	1.0701e-1 (2.03e-2) −	1.8468e-1 (2.51e-2) −	6.8775e-1 (1.34e-1) −	6.7509e-3 (5.94e-4) −	7.7386e-1 (5.78e-2) −	1.6163e-1 (2.76e-2) −	6.0116e-3 (3.48e-4)
DASCMOP4	1.3282e-1 (1.44e-1) −	7.7680e-2 (1.23e-1) ≈	1.3392e-3 (8.02e-4) −	4.8103e-3 (8.60e-3) −	9.1062e-2 (1.29e-1) −	7.2817e-3 (1.50e-3) −	1.0780e-3 (7.34e-4) ≈	NaN (NaN)	6.3185e-1 (3.74e-1) −	NaN (NaN)	1.0407e-2 (5.05e-2) −	7.5728e-4 (3.21e-4)
DASCMOP5	5.9776e-2 (1.49e-1) −	5.9653e-2 (1.47e-1) −	2.1072e-3 (1.28e-4) −	3.3701e-3 (1.70e-3) −	1.0151e-1 (1.46e-1) −	5.5624e-3 (5.51e-4) −	1.9160e-3 (1.42e-4) ≈	NaN (NaN)	5.3508e-1 (2.17e-1) −	NaN (NaN)	9.2968e-2 (1.55e-1) −	1.8832e-3 (1.14e-4)
DASCMOP6	1.2937e-1 (2.18e-1) −	2.6198e-1 (2.40e-1) −	2.1435e-2 (2.26e-2) −	1.3644e-2 (1.61e-2) −	3.0731e-1 (1.86e-1) −	1.1953e-2 (4.18e-3) −	1.6485e-2 (2.06e-2) −	NaN (NaN)	7.0912e-1 (1.41e-1) −	NaN (NaN)	7.6348e-2 (1.54e-1) −	1.0814e-2 (1.72e-2)
DASCMOP7	2.4962e-2 (1.67e-3) ≈	2.2876e-2 (5.02e-4) +	2.5099e-2 (9.67e-4) ≈	3.7977e-2 (1.70e-3) −	2.9564e-2 (8.80e-3) −	2.9060e-2 (6.33e-3) −	2.3101e-2 (5.61e-4) +	NaN (NaN)	7.9080e-1 (3.02e-1) −	NaN (NaN)	2.4593e-2 (7.21e-4) ≈	2.4628e-2 (8.49e-4)
DASCMOP8	1.9008e-2 (1.23e-3) ≈	2.3167e-2 (2.64e-2) ≈	1.9643e-2 (9.47e-4) −	2.8550e-2 (1.69e-3) −	2.1667e-2 (2.61e-3) −	2.2275e-2 (3.87e-3) −	1.8581e-2 (9.48e-4) ≈	NaN (NaN)	5.4138e-1 (3.28e-1) −	NaN (NaN)	1.7793e-2 (8.15e-3) +	1.8734e-2 (6.85e-4)
DASCMOP9	2.4400e-1 (3.50e-2) −	2.5744e-1 (4.40e-2) −	2.6747e-1 (5.47e-2) −	1.3372e-1 (4.86e-2) −	2.1407e-2 (8.96e-4) +	1.9680e-1 (4.37e-2) −	2.5143e-1 (3.58e-2) −	4.6139e-1 (1.01e-1) −	2.7554e-2 (1.75e-3) −	4.7193e-1 (4.31e-2) −	2.3097e-1 (5.29e-2) −	2.3415e-2 (9.81e-4)
+/ − / ≈	0/7/2	1/6/2	0/8/1	0/9/0	1/8/0	0/9/0	1/5/3	0/9/0	0/9/0	0/9/0	1/7/1	



(a)

(b)

Fig. S-2. Feasible and non-dominated solution sets obtained by CMOES and other methods on DAS-CMOP3 with the median IGD+ value among 30 runs. Each sub-figure corresponds to the result of the algorithm in its title.

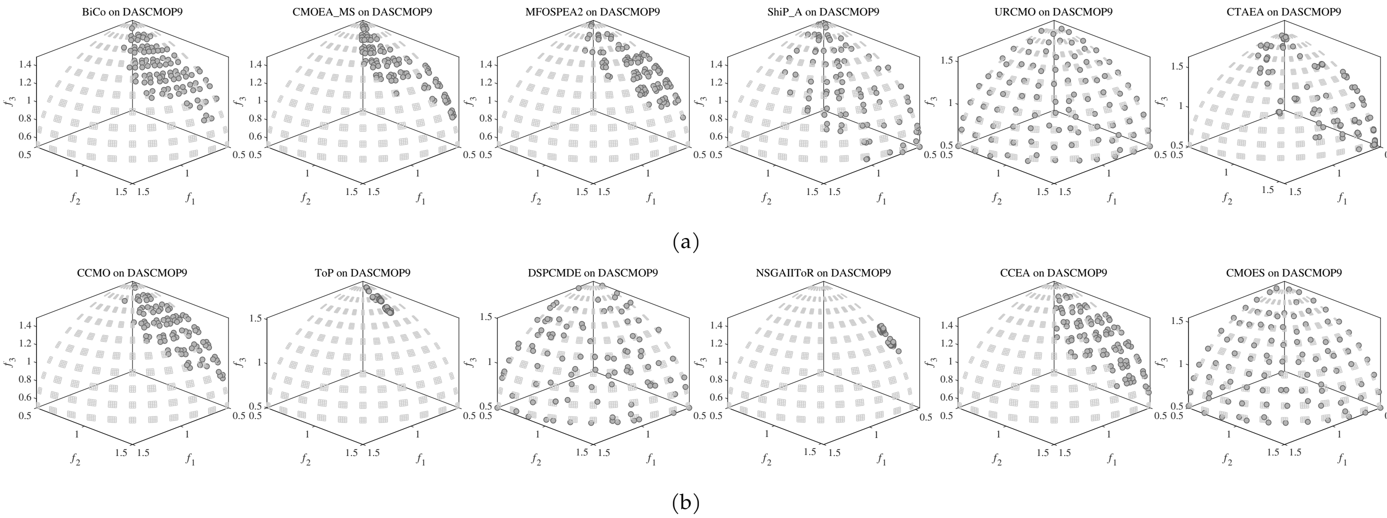


Fig. S-3. Feasible and non-dominated solution sets obtained by CMOES and other methods on DAS-CMOP9 with the median IGD+ value among 30 runs. Each sub-figure corresponds to the result of the algorithm in its title.

TABLE S-III

Statistical results of HV obtained by CMOES and other methods on LIR-CMOP benchmark problems. The best result in each row is highlighted.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
LIRCMOP1	1.4027e-1 (7.02e-3) −	1.0819e-1 (1.50e-2) −	1.3586e-1 (1.40e-2) −	2.3101e-1 (6.92e-4) +	1.6625e-1 (2.47e-2) −	1.2510e-1 (2.40e-2) −	1.2572e-1 (1.88e-2) −	1.0655e-1 (8.40e-3) −	1.9406e-1 (2.55e-2) ≈	9.6113e-2 (4.47e-3) −	1.7208e-1 (1.10e-2) −	2.0189e-1 (1.87e-2)
LIRCMOP2	2.6202e-1 (1.12e-2) −	2.2263e-1 (2.15e-2) −	2.5504e-1 (1.39e-2) −	3.5187e-1 (1.44e-3) +	3.4161e-1 (3.02e-2) +	2.6171e-1 (3.75e-2) −	2.2792e-1 (1.40e-2) −	2.1997e-1 (1.25e-2) −	3.3085e-1 (8.78e-3) ≈	2.0180e-1 (9.48e-3) −	2.9740e-1 (1.25e-2) −	3.3046e-1 (1.37e-2)
LIRCMOP3	1.2521e-1 (7.83e-3) −	1.0133e-1 (1.25e-2) −	1.2644e-1 (1.13e-2) −	1.9053e-1 (5.34e-3) +	1.6997e-1 (2.53e-2) ≈	9.5834e-2 (1.66e-2) −	1.0417e-1 (1.52e-2) −	9.3227e-2 (3.62e-3) −	1.6082e-1 (2.39e-2) ≈	8.7797e-2 (4.94e-3) −	1.5669e-1 (1.08e-2) −	1.7226e-1 (1.59e-2)
LIRCMOP4	2.2382e-1 (1.34e-2) −	1.9165e-1 (1.40e-2) −	2.1756e-1 (1.33e-2) −	2.9160e-1 (9.30e-3) +	2.6527e-1 (3.86e-2) ≈	1.9417e-1 (3.63e-2) −	2.0105e-1 (2.29e-2) −	1.8003e-1 (1.06e-2) −	2.7495e-1 (1.42e-2) ≈	1.7756e-1 (1.04e-2) −	2.5396e-1 (1.38e-2) −	2.7422e-1 (1.94e-2)
LIRCMOP5	0.0000e+0 (0.00e+0) −	1.3898e-1 (4.24e-2) −	1.5879e-1 (2.24e-2) −	1.5354e-1 (1.72e-2) −	2.6056e-1 (5.73e-2) ≈	9.3847e-3 (3.60e-2) −	1.5516e-1 (2.49e-2) −	0.0000e+0 (0.00e+0) −	2.7596e-1 (3.75e-2) +	0.0000e+0 (0.00e+0) −	1.3140e-1 (3.88e-2) −	2.6883e-1 (2.89e-2)
LIRCMOP6	0.0000e+0 (0.00e+0) −	9.4899e-2 (2.75e-2) −	1.0992e-1 (1.31e-2) −	1.0470e-1 (1.05e-2) −	1.5983e-1 (5.07e-2) ≈	6.1486e-3 (2.34e-2) −	1.1174e-1 (1.37e-2) −	0.0000e+0 (0.00e+0) −	1.8819e-1 (2.08e-2) +	0.0000e+0 (0.00e+0) −	8.2855e-2 (3.32e-2) −	1.7426e-1 (4.36e-2)
LIRCMOP7	1.2928e-1 (1.23e-1) −	2.4677e-1 (8.08e-3) −	2.4997e-1 (7.65e-3) −	2.4673e-1 (9.36e-3) −	2.9175e-1 (6.57e-3) −	2.1308e-1 (7.59e-2) −	2.5200e-1 (9.17e-3) −	3.5277e-2 (8.31e-2) −	2.9166e-1 (8.60e-3) −	0.0000e+0 (0.00e+0) −	2.4376e-1 (6.47e-3) −	2.9359e-1 (3.44e-4)
LIRCMOP8	9.6164e-2 (1.12e-1) −	2.2917e-1 (1.35e-2) −	2.3641e-1 (1.06e-2) −	2.3137e-1 (8.21e-3) −	2.9212e-1 (4.99e-3) ≈	1.3777e-1 (1.08e-1) −	2.3785e-1 (1.41e-2) −	1.3424e-2 (5.11e-2) −	2.9335e-1 (2.39e-4) ≈	0.0000e+0 (0.00e+0) −	2.2508e-1 (4.60e-3) −	2.8927e-1 (1.51e-2)
LIRCMOP9	1.2748e-1 (5.53e-2) −	2.9736e-1 (8.37e-2) −	3.4751e-1 (7.31e-2) −	3.7231e-1 (4.47e-2) −	4.4302e-1 (6.85e-2) ≈	3.3315e-1 (5.51e-2) −	3.6223e-1 (6.42e-2) −	3.0868e-1 (7.38e-2) −	3.7025e-1 (2.49e-2) −	3.8976e-2 (1.31e-2) −	2.2199e-1 (5.87e-2) −	4.4864e-1 (2.81e-2)
LIRCMOP10	6.7782e-2 (2.56e-2) −	4.3586e-1 (1.21e-1) −	5.4886e-1 (5.29e-2) −	4.3167e-1 (8.23e-2) −	6.5173e-1 (3.57e-2) −	5.2893e-1 (3.38e-2) −	6.1063e-1 (3.45e-2) −	4.7075e-1 (7.35e-2) −	6.3697e-1 (4.45e-2) −	6.1694e-2 (2.39e-2) −	1.1777e-1 (1.05e-1) −	6.9288e-1 (1.79e-2)
LIRCMOP11	2.6485e-1 (1.02e-1) −	5.0998e-1 (8.53e-2) −	6.2809e-1 (5.30e-2) −	4.9437e-1 (9.91e-2) −	6.0165e-1 (5.55e-2) −	6.0811e-1 (2.46e-2) −	6.5373e-1 (3.04e-2) −	3.9009e-1 (8.18e-2) −	6.4792e-1 (5.29e-2) −	6.2924e-2 (3.22e-2) −	3.3776e-1 (1.62e-1) −	6.8237e-1 (9.71e-3)
LIRCMOP12	3.3278e-1 (1.16e-1) −	4.3117e-1 (8.48e-2) −	5.2499e-1 (3.92e-2) −	5.0544e-1 (2.88e-2) −	5.3022e-1 (3.43e-2) −	4.8594e-1 (5.03e-2) −	5.2580e-1 (3.93e-2) −	4.6189e-1 (4.32e-2) −	5.3235e-1 (5.96e-2) −	8.4393e-2 (1.33e-2) −	4.1472e-1 (7.76e-2) −	5.7845e-1 (1.54e-2)
LIRCMOP13	9.4655e-5 (1.32e-4) −	5.5599e-1 (1.30e-3) +	1.0630e-4 (1.07e-4) −	5.3188e-1 (2.06e-3) −	5.3452e-1 (4.30e-3) −	5.4601e-1 (1.34e-3) −	5.5421e-1 (1.74e-3) +	3.3536e-3 (1.82e-2) −	5.0391e-1 (3.25e-3) −	7.1341e-7 (3.91e-6) −	5.5914e-1 (1.09e-3) +	5.5223e-1 (1.82e-3)
LIRCMOP14	5.2070e-4 (2.82e-4) −	5.5501e-1 (1.32e-3) +	5.1591e-4 (3.43e-4) −	5.4160e-1 (2.98e-3) −	5.4946e-1 (8.98e-4) −	5.4604e-1 (1.12e-3) −	5.5397e-1 (1.34e-3) ≈	2.2451e-3 (1.12e-2) −	5.3019e-1 (3.29e-3) −	4.0638e-5 (1.30e-4) −	5.5845e-1 (1.03e-3) +	5.5340e-1 (1.17e-3)
+/ − / ≈	0/14/0	2/12/0	0/14/0	4/10/0	1/7/6	0/14/0	1/12/1	0/14/0	2/7/5	0/14/0	2/12/0	

TABLE S-IV

Statistical results of IGD+ obtained by CMOES and other methods on DAS benchmark problems. The best result in each row is highlighted.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
LIRCMOP1	1.8038e-1 (1.40e-2) −	2.6663e-1 (3.15e-2) −	1.8459e-1 (3.25e-2) −	1.2281e-2 (8.86e-4) +	1.3320e-1 (4.62e-2) −	2.1301e-1 (6.68e-2) −	2.1262e-1 (5.19e-2) −	2.6885e-1 (1.21e-2) −	7.5675e-2 (5.10e-2) ≈	2.9254e-1 (6.46e-3) −	1.0876e-1 (2.52e-2) −	5.5760e-2 (3.33e-2)
LIRCMOP2	1.1052e-1 (1.43e-2) −	1.7646e-1 (3.25e-2) −	1.2564e-1 (1.76e-2) −	1.4351e-2 (1.44e-3) +	2.1114e-2 (3.01e-2) +	1.3832e-1 (6.98e-2) −	1.6332e-1 (2.14e-2) −	1.8164e-1 (1.43e-2) −	3.8874e-2 (1.44e-2) ≈	2.0918e-1 (1.10e-2) −	6.4989e-2 (1.42e-2) −	3.6954e-2 (1.52e-2)
LIRCMOP3	1.8708e-1 (1.70e-2) −	2.4970e-1 (3.38e-2) −	1.8512e-1 (2.84e-2) −	3.2675e-2 (1.30e-2) +	7.5753e-2 (4.83e-2) ≈	2.8145e-1 (5.81e-2) −	2.4781e-1 (3.66e-2) −	2.8111e-1 (1.03e-2) −	1.0799e-1 (7.73e-2) −	2.8724e-1 (4.99e-3) −	1.0546e-1 (2.18e-2) −	6.4610e-2 (3.82e-2)
LIRCMOP4	1.3167e-1 (2.09e-2) −	1.8896e-1 (2.45e-2) −	1.4390e-1 (2.12e-2) −	3.1837e-2 (1.07e-2) +	7.1667e-2 (5.56e-2) ≈	1.9789e-1 (7.12e-2) −	1.7289e-1 (3.72e-2) −	2.0905e-1 (1.53e-2) −	6.0866e-2 (2.44e-2) ≈	2.1352e-1 (1.58e-2) −	8.3053e-2 (1.88e-2) −	5.4773e-2 (2.67e-2)
LIRCMOP5	1.2210e+0 (6.99e-3) −	3.0520e-1 (2.54e-1) −	2.1771e-1 (4.97e-2) −	2.2903e-1 (3.75e-2) −	8.0928e-2 (2.09e-1) ≈	1.1643e+0 (2.47e-1) −	2.2640e-1 (5.80e-2) −	1.2026e+0 (2.07e-2) −	3.4510e-2 (7.51e-2) +	2.6749e+0 (7.68e-2) −	3.2199e-1 (2.48e-1) −	5.4460e-2 (7.82e-2)
LIRCMOP6	1.3453e+0 (1.90e-4) −	3.5552e-1 (2.72e-1) −	2.5949e-1 (5.21e-2) −	2.8348e-1 (4.15e-2) −	1.6045e-1 (3.36e-1) −	1.2780e+0 (2.60e-1) −	2.4640e-1 (4.61e-2) −	1.3467e+0 (5.29e-4) −	2.2415e-2 (4.21e-2) +	2.9017e+0 (9.80e-2) −	4.4354e-1 (3.60e-1) −	8.7892e-2 (2.55e-1)
LIRCMOP7	8.4700e-1 (7.94e-1) −	1.0567e-1 (2.04e-2) −	9.6160e-2 (1.91e-2) −	1.0474e-1 (2.30e-2) −	1.0132e-2 (1.32e-2) −	2.9620e-1 (4.80e-1) −	9.0975e-2 (2.28e-2) −	1.4368e+0 (5.63e-1) −	1.1149e-2 (1.85e-2) −	2.7055e+0 (5.92e-1) −	1.1273e-1 (1.49e-2) −	7.2208e-3 (4.89e-4)
LIRCMOP8	1.0394e+0 (7.47e-1) −	1.7334e-1 (3.78e-2) −	1.5441e-1 (4.29e-2) −	1.6104e-1 (3.47e-2) −	9.4279e-3 (8.46e-3) ≈	7.5671e-1 (7.23e-1) −	1.4508e-1 (4.59e-2) −	1.5928e+0 (3.43e-1) −	7.7937e-3 (4.50e-4) +	2.9891e+0 (6.86e-1) −	1.9483e-1 (2.74e-2) −	1.6304e-2 (3.30e-2)
LIRCMOP9	9.1276e-1 (1.59e-1) −	4.6100e-1 (1.53e-1) −	4.0316e-1 (1.62e-1) −	2.8587e-1 (7.57e-2) −	1.9143e-1 (9.26e-2) ≈	3.4664e-1 (8.60e-2) −	3.7535e-1 (1.29e-1) −	4.0251e-1 (1.49e-1) −	2.6061e-1 (3.91e-2) −	1.2581e+0 (6.95e-2) −	7.0174e-1 (2.24e-1) −	1.5964e-1 (2.86e-2)
LIRCMOP10	9.3833e-1 (8.29e-2) −	3.7401e-1 (1.39e-1) −	2.2449e-1 (7.34e-2) −	3.7108e-1 (9.12e-2) −	9.5934e-2 (5.68e-2) −	2.7117e-1 (5.35e-2) −	1.4480e-1 (5.00e-2) −	3.3398e-1 (7.71e-2) −	1.1691e-1 (6.79e-2) −	9.8763e-1 (1.04e-1) −	8.7167e-1 (1.79e-1) −	2.6742e-2 (2.95e-2)
LIRCMOP11	7.0337e-1 (2.23e-1) −	2.5151e-1 (1.20e-1) −	1.0133e-1 (6.86e-2) −	2.6114e-1 (1.22e-1) −	1.1759e-1 (6.74e-2) −	1.7279e-1 (4.03e-2) −	6.9381e-2 (4.63e-2) −	3.8803e-1 (1.10e-1) −	6.4967e-2 (6.66e-2) −	1.2570e+0 (8.23e-2) −	5.6422e-1 (2.82e-1) −	1.7171e-2 (1.45e-2)
LIRCMOP12	5.9247e-1 (2.48e-1) −	3.1777e-1 (1.61e-1) −	1.6369e-1 (7.72e-2) −	1.8610e-1 (3.60e-2) −	1.4556e-1 (4.88e-2) −	2.5403e-1 (1.20e-1) −	1.5599e-1 (5.50e-2) −	2.3902e-1 (5.57e-2) −	1.4510e-1 (1.02e-1) −	1.3583e+0 (7.20e-2) −	4.3664e-1 (1.97e-1) −	7.6654e-2 (2.15e-2)
LIRCMOP13	1.3173e+0 (1.81e-3) −	4.3066e-2 (1.18e-3) +	1.3153e+0 (2.00e-3) −	4.4522e-2 (9.33e-4) +	6.3452e-2 (4.35e-3) −	4.7115e-2 (1.02e-3) ≈	4.5164e-2 (1.73e-3) +	1.3243e+0 (1.02e-1) −	8.6298e-2 (2.24e-3) −	1.4548e+0 (2.58e-2) −	4.0498e-2 (9.58e-4) +	4.7071e-2 (1.99e-3)
LIRCMOP14	1.2738e+0 (1.61e-3) −	4.5148e-2 (1.36e-3) +	1.2720e+0 (1.85e-3) −	5.4478e-2 (2.06e-3) −	5.0475e-2 (9.95e-4) −	4.8684e-2 (9.51e-4) −	4.6608e-2 (1.36e-3) ≈	1.2880e+0 (5.94e-2) −	6.1998e-2 (2.13e-3) −	1.4236e+0 (2.40e-2) −	4.2174e-2 (8.54e-4) +	4.7087e-2 (1.28e-3)
+/ − / ≈	0/14/0	2/12/0	0/14/0	5/9/0	1/8/5	0/13/1	1/12/1	0/14/0	3/8/3	0/14/0	2/12/0	

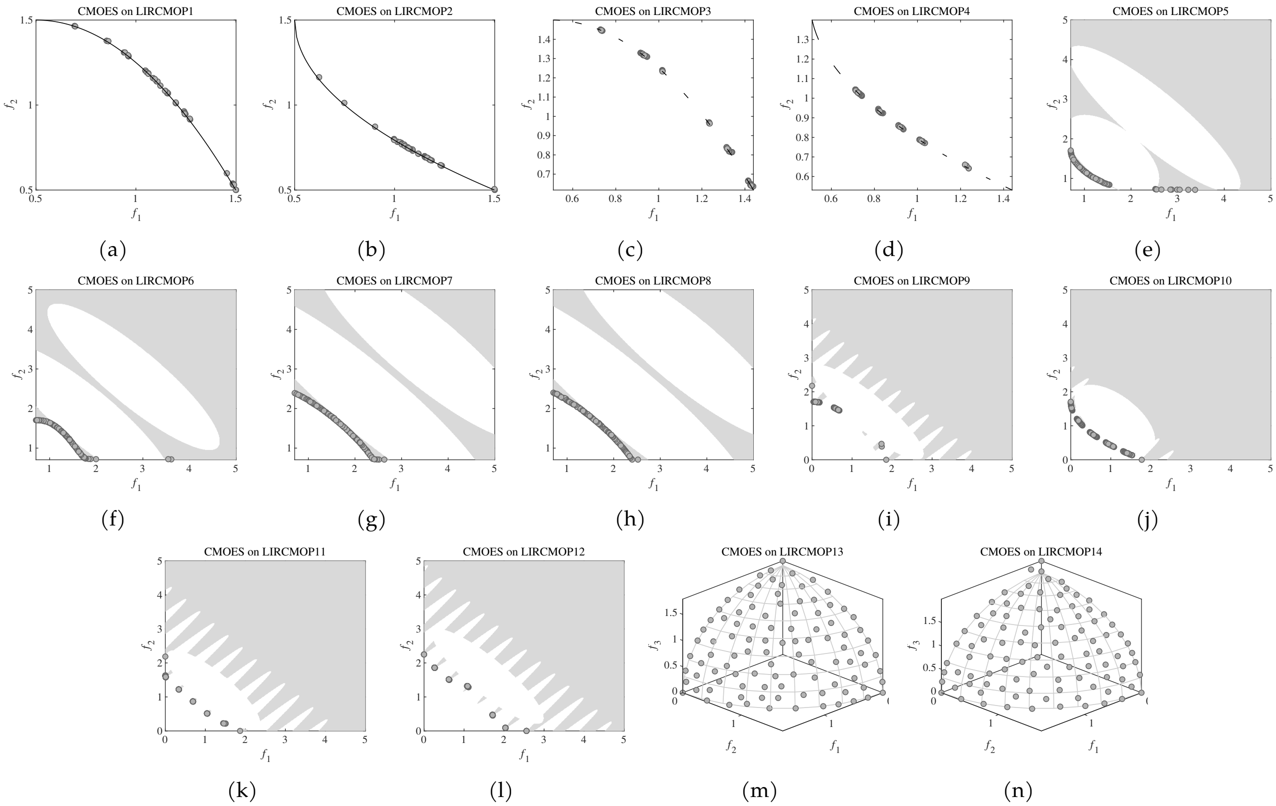


Fig. S-4. Feasible and non-dominated solution set obtained by CMOES on LIR-CMOP benchmark problems with the median IGD+ value among 30 runs. Each sub-figure corresponds to the result of CMOES on the instance whose name is given in its title.

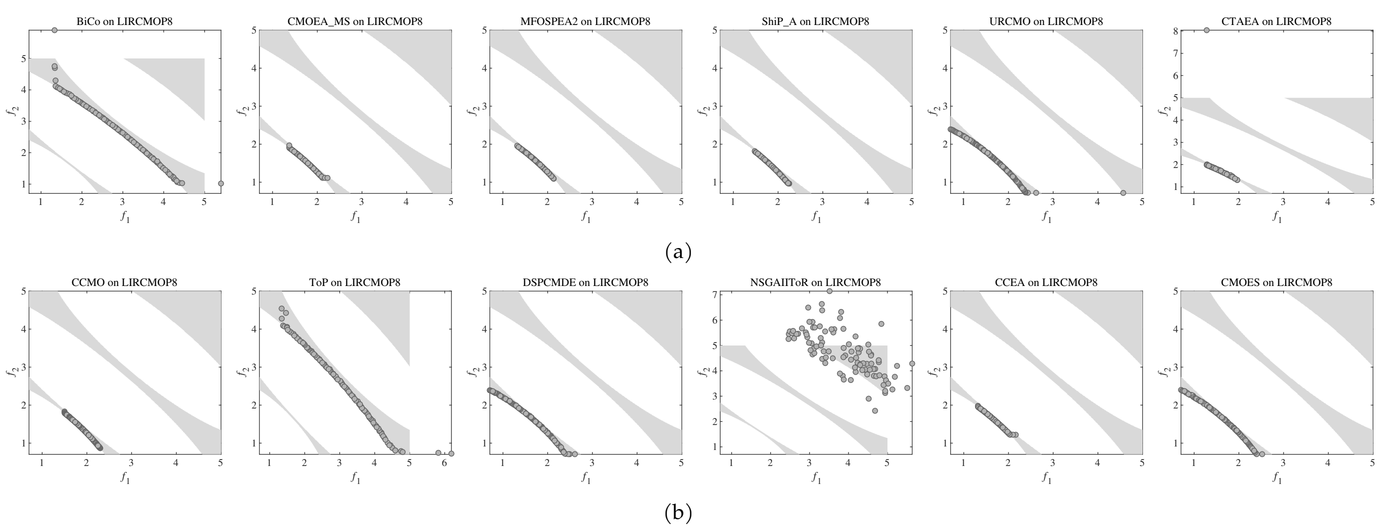


Fig. S-5. Feasible and non-dominated solution sets obtained by CMOES and other methods on LIR-CMOP8 with the median IGD+ value among 30 runs. Fig. 5(a) contains the results of BiCo, CMOEA-MS, MFO-SPEA2, ShiP-A, URCMO, and C-TAEA; Fig. 5(b) contains the results of CCMO, ToP, DSPCMDE, NSGA-II-ToR, CCEA, and CMOES.

TABLE S-V
STATISTICAL RESULTS OF HV OBTAINED BY CMOES AND OTHER METHODS ON LYO BENCHMARK PROBLEMS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
LYO1	3.4612e-1 (4.96e-4) ≈	3.4590e-1 (6.03e-4) ≈	3.4597e-1 (5.04e-4) ≈	3.4505e-1 (6.77e-4) −	3.4453e-1 (7.39e-4) −	3.2407e-1 (3.14e-3) −	3.4565e-1 (3.60e-4) −	3.2493e-1 (6.58e-2) −	NaN (NaN)	0.0000e+0 (0.00e+0) −	3.4611e-1 (2.77e-4) ≈	3.4616e-1 (3.20e-4)
LYO2	3.6049e-1 (9.92e-2) −	4.2582e-1 (7.18e-2) −	4.2112e-1 (5.75e-2) −	2.3345e-1 (1.15e-1) −	5.7669e-1 (3.11e-3) +	4.4100e-1 (9.84e-2) −	5.7043e-1 (2.86e-3) +	2.1732e-2 (6.06e-2) −	2.0390e-1 (2.36e-1) −	0.0000e+0 (0.00e+0) −	2.9143e-1 (1.21e-1) −	5.6528e-1 (1.16e-2)
LYO3	3.5150e-1 (3.40e-1) −	8.5056e-1 (1.49e-2) −	8.5784e-1 (1.68e-4) ≈	7.4946e-1 (1.11e-1) −	8.3991e-1 (4.70e-2) −	8.4910e-1 (2.01e-3) −	8.5736e-1 (2.86e-4) −	3.0028e-1 (3.76e-1) −	8.5220e-1 (1.71e-2) −	0.0000e+0 (0.00e+0) −	8.5790e-1 (1.02e-4) +	8.5776e-1 (2.66e-4)
LYO4	4.9021e-1 (1.10e-1) −	3.5681e-1 (1.35e-1) −	5.5441e-1 (5.98e-4) −	4.3123e-1 (7.92e-2) −	5.5272e-1 (1.34e-3) −	5.4725e-1 (1.27e-3) −	5.5429e-1 (2.23e-4) −	1.4425e-1 (2.44e-1) −	5.4433e-1 (4.93e-3) −	0.0000e+0 (0.00e+0) −	5.5415e-1 (1.64e-4) −	5.5462e-1 (2.22e-4)
LYO5	5.7810e-1 (1.11e-2) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	4.3940e-1 (1.85e-1) −	NaN (NaN)	5.7991e-1 (5.12e-4) +	5.6669e-1 (4.10e-2)
LYO6	8.5834e-1 (2.86e-4) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	4.1976e-1 (2.68e-1) −	NaN (NaN)	NaN (NaN)	8.5807e-1 (1.14e-4) −	8.5844e-1 (1.30e-4)
LYO7	1.4115e-1 (4.64e-2) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	9.3755e-2 (0.00e+0) ≈	NaN (NaN)	3.3307e-1 (1.03e-2) +	1.3868e-1 (4.83e-2)
LYO8	4.5451e-1 (1.11e-1) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	1.4290e-1 (0.00e+0) ≈	NaN (NaN)	NaN (NaN)	5.5424e-1 (3.34e-4) ≈	4.8481e-1 (1.21e-1)
+/ − / ≈	0/3/5	0/7/1	0/6/2	0/8/0	1/7/0	0/8/0	1/7/0	0/7/1	0/7/1	0/8/0	3/3/2	

TABLE S-VI
STATISTICAL RESULTS OF IGD+ OBTAINED BY CMOES AND OTHER METHODS ON LYO BENCHMARK PROBLEMS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
LYO1	1.1823e-2 (1.38e-3) ≈	1.2562e-2 (1.53e-3) ≈	1.2132e-2 (1.27e-3) ≈	1.4521e-2 (1.68e-3) −	1.6080e-2 (1.98e-3) −	6.8454e-2 (1.02e-2) −	1.3170e-2 (1.01e-3) −	1.4033e-1 (5.12e-1) −	NaN (NaN)	1.2546e+2 (4.45e+1) −	1.1994e-2 (7.87e-4) ≈	1.1832e-2 (8.43e-4)
LYO2	1.2866e+0 (1.04e+0) −	7.1120e-1 (6.14e-1) −	6.1988e-1 (4.68e-1) −	2.4382e+0 (1.26e+0) −	3.3366e-2 (1.06e-2) +	5.1022e-1 (4.06e-1) −	5.3524e-2 (9.20e-3) +	1.8354e+1 (1.08e+1) −	3.7746e+1 (4.37e+1) −	1.0452e+4 (5.73e+3) −	2.2562e+0 (1.03e+0) −	7.0123e-2 (3.73e-2)
LYO3	1.4862e+1 (1.01e+1) −	2.4154e-1 (5.35e-1) −	8.9728e-2 (5.22e-3) ≈	2.6585e+0 (2.74e+0) −	5.7569e-1 (1.27e+0) −	1.5547e-1 (1.50e-2) −	1.0089e-1 (7.79e-3) −	1.7978e+1 (1.29e+1) −	1.9598e-1 (5.68e-1) −	2.5862e+2 (4.85e+1) −	8.2559e-2 (3.19e-3) +	9.1690e-2 (7.64e-3)
LYO4	1.8561e+0 (3.48e+0) −	4.2606e+0 (2.80e+0) −	5.6669e-2 (2.43e-2) ≈	3.8958e+0 (3.26e+0) −	1.5741e-1 (5.42e-2) −	3.7310e-1 (5.90e-2) −	8.0251e-2 (2.41e-2) −	5.8907e+1 (4.27e+1) −	4.3483e-1 (1.72e-1) −	4.1918e+2 (1.14e+2) −	9.0618e-2 (1.84e-2) −	4.9169e-2 (1.75e-2)
LYO5	7.0795e-2 (9.12e-2) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	1.9251e+0 (2.86e+0) −	NaN (NaN)	5.9907e-2 (4.69e-3) +	2.0129e-1 (4.41e-1)
LYO6	1.7092e-2 (1.03e-3) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	4.5747e+0 (7.76e+0) −	NaN (NaN)	NaN (NaN)	1.7922e-2 (7.86e-4) −	1.6813e-2 (6.89e-4)
LYO7	1.4991e+1 (3.27e+0) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	1.7847e+1 (0.00e+0) ≈	NaN (NaN)	5.7266e-1 (6.10e-1) +	1.5153e+1 (3.21e+0)
LYO8	9.9038e-1 (1.13e+0) ≈	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	NaN (NaN)	4.3972e+0 (0.00e+0) ≈	NaN (NaN)	NaN (NaN)	2.2840e-2 (6.63e-3) ≈	7.4180e-1 (1.29e+0)
+/ − / ≈	0/3/5	0/7/1	0/5/3	0/8/0	1/7/0	0/8/0	1/7/0	0/7/1	0/7/1	0/8/0	3/3/2	

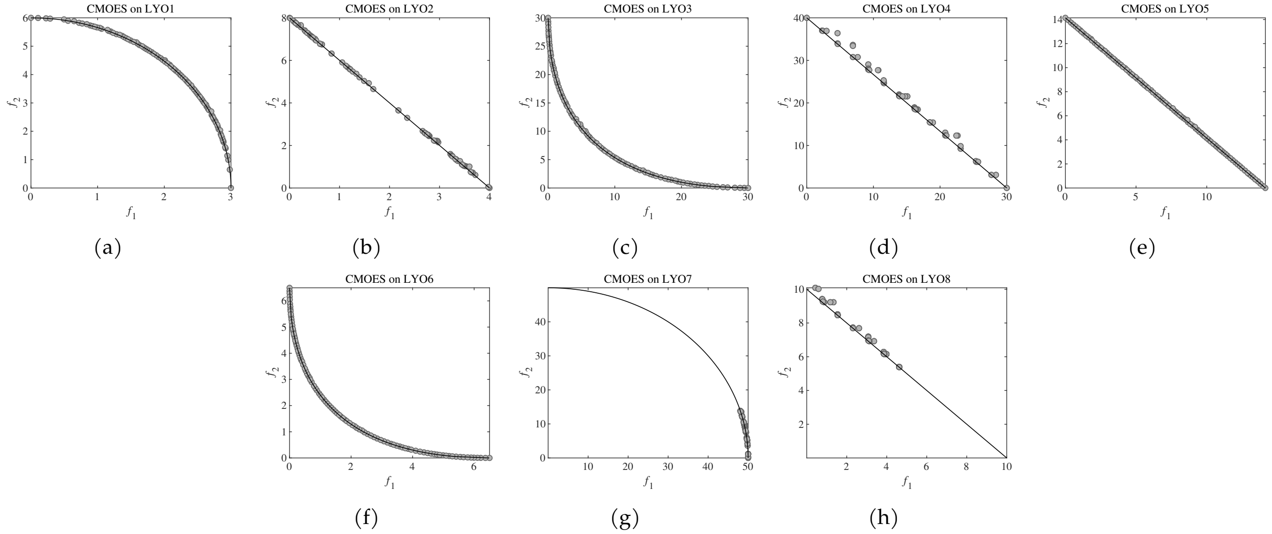


Fig. S-6. Feasible and non-dominated solution set obtained by CMOES on LYO benchmark problems with the median IGD+ value among 30 runs. Each sub-figure corresponds to the result of CMOES on the instance whose name is given in its title.

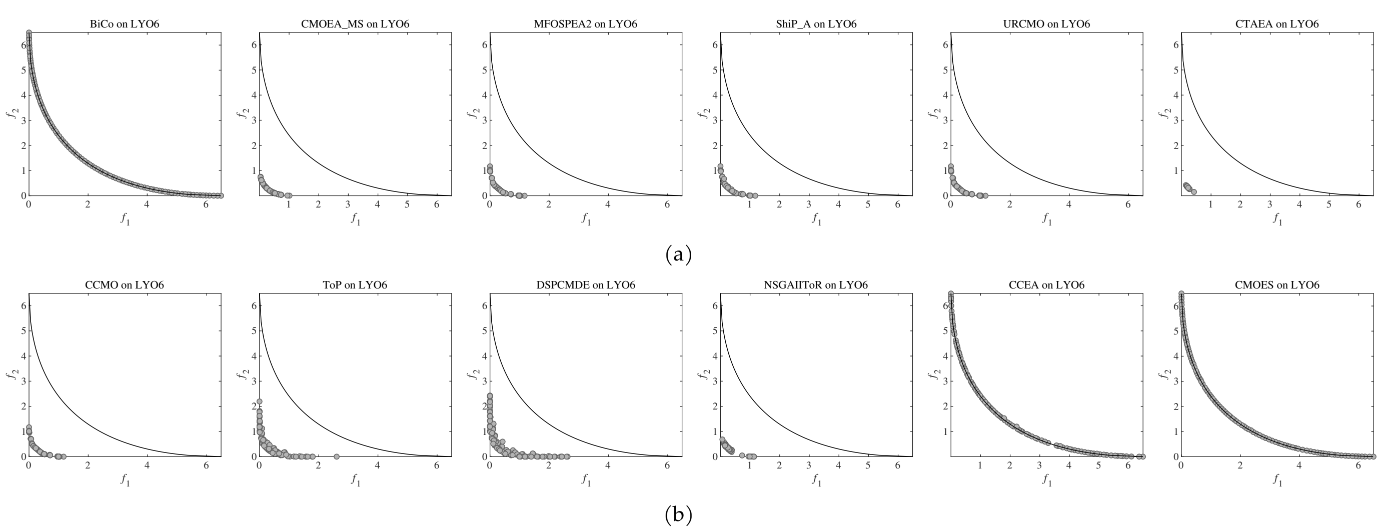


Fig. S-7. Feasible and non-dominated solution sets obtained by CMOES and other methods on LYO6 with the median IGD+ value among 30 runs. Fig. 7(a) contains the results of BiCo, CMOEA-MS, MFO-SPEA2, ShiP-A, URCMO, and C-TAEA; Fig. 7(b) contains the results of CCMO, ToP, DSPCMDE, NSGA-II-ToR, CCEA, and CMOES.

TABLE S-VII

Statistical results of HV obtained by CMOES and other methods on MW benchmark problems. The best result in each row is highlighted.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
MW1	4.9004e-1 (5.23e-5) ≈	4.8933e-1 (2.78e-3) ≈	4.9006e-1 (3.87e-5) ≈	4.8938e-1 (2.14e-4) −	4.8970e-1 (3.40e-4) −	4.7639e-1 (6.84e-2) −	4.9007e-1 (3.54e-5) ≈	NaN (NaN)	4.8844e-1 (3.16e-3) −	2.7787e-2 (3.31e-2) −	4.8806e-1 (2.25e-3) −	4.9005e-1 (4.49e-5)
MW2	5.6305e-1 (1.17e-2) +	5.4915e-1 (1.58e-2) ≈	5.5936e-1 (1.35e-2) ≈	5.6150e-1 (2.31e-2) +	5.5845e-1 (1.61e-2) ≈	5.6135e-1 (1.21e-2) ≈	5.5313e-1 (1.18e-2) ≈	3.9520e-1 (1.22e-1) −	5.1290e-1 (2.73e-2) −	4.3908e-1 (5.70e-2) −	5.5366e-1 (1.31e-2) ≈	5.5442e-1 (1.47e-2)
MW3	5.4372e-1 (6.62e-4) −	5.4404e-1 (6.30e-4) −	5.4441e-1 (4.85e-4) ≈	5.4424e-1 (3.29e-4) −	5.4461e-1 (1.72e-4) +	5.4486e-1 (3.83e-4) +	5.4440e-1 (4.97e-4) ≈	1.2147e-1 (1.75e-1) −	5.4372e-1 (2.42e-4) −	2.9494e-1 (1.36e-1) −	5.4351e-1 (4.76e-4) −	5.4429e-1 (7.06e-4)
MW4	8.4134e-1 (5.92e-4) ≈	8.3919e-1 (7.15e-4) −	8.4166e-1 (3.65e-4) +	8.0739e-1 (3.87e-3) −	8.3829e-1 (3.16e-3) −	8.3812e-1 (2.00e-4) −	8.4153e-1 (3.54e-4) +	0.0000e+0 (0.00e+0) ≈	8.1140e-1 (4.63e-3) −	3.0928e-1 (3.73e-2) −	8.3975e-1 (6.10e-4) −	8.4117e-1 (5.66e-4)
MW5	3.2391e-1 (1.05e-3) −	2.9253e-1 (4.57e-2) −	3.2117e-1 (1.81e-2) −	3.2242e-1 (6.27e-4) −	3.2449e-1 (6.99e-5) +	3.1639e-1 (3.64e-3) −	3.2397e-1 (1.30e-3) ≈	6.3142e-2 (2.65e-2) −	3.0708e-1 (2.21e-2) −	2.2394e-3 (8.15e-3) −	3.2171e-1 (1.41e-2) −	3.2434e-1 (2.37e-4)
MW6	3.1539e-1 (1.31e-2) +	2.9776e-1 (3.65e-2) ≈	3.0976e-1 (1.99e-2) +	3.2181e-1 (6.66e-3) +	2.9923e-1 (1.86e-2) ≈	3.1009e-1 (1.62e-2) +	3.0261e-1 (1.58e-2) ≈	8.3913e-2 (6.62e-2) −	2.0033e-1 (6.30e-2) −	1.5635e-1 (3.07e-2) −	2.9811e-1 (3.70e-2) ≈	3.0216e-1 (1.22e-2)
MW7	4.1171e-1 (5.22e-4) −	4.0845e-1 (4.03e-3) −	4.1234e-1 (5.30e-4) +	4.1223e-1 (3.01e-4) ≈	4.1248e-1 (1.78e-4) +	4.0950e-1 (6.78e-4) −	4.1235e-1 (5.10e-4) +	3.7495e-1 (3.49e-2) −	4.1266e-1 (1.48e-4) +	2.7870e-1 (6.24e-2) −	4.0955e-1 (1.06e-3) −	4.1206e-1 (5.30e-4)
MW8	5.4453e-1 (8.04e-3) +	5.2700e-1 (1.35e-2) ≈	5.3621e-1 (1.31e-2) +	5.2521e-1 (7.42e-3) ≈	5.2591e-1 (2.14e-2) ≈	5.1890e-1 (1.33e-2) −	5.3080e-1 (1.28e-2) ≈	1.0531e-1 (1.19e-1) −	4.2331e-1 (4.10e-2) −	3.1035e-1 (7.51e-2) −	5.3300e-1 (1.81e-2) ≈	5.2543e-1 (2.86e-2)
MW9	3.9338e-1 (3.76e-3) −	2.6530e-1 (1.43e-1) −	3.9930e-1 (1.58e-3) ≈	3.9797e-1 (1.62e-3) ≈	3.9662e-1 (1.67e-3) −	3.9270e-1 (1.90e-3) −	3.9923e-1 (1.83e-3) ≈	4.4316e-2 (8.86e-2) −	1.4914e-1 (9.03e-2) −	1.1611e-1 (4.69e-2) −	3.9493e-1 (1.70e-2) ≈	3.9875e-1 (2.40e-3)
MW10	4.1315e-1 (3.53e-2) ≈	4.0945e-1 (2.33e-2) −	4.3441e-1 (1.18e-2) +	4.4335e-1 (1.16e-2) +	4.2106e-1 (2.02e-2) ≈	4.4100e-1 (1.42e-2) +	4.1576e-1 (2.85e-2) ≈	NaN (NaN)	2.9277e-1 (8.99e-2) −	2.6479e-1 (8.57e-2) −	4.3325e-1 (1.30e-2) ≈	4.2378e-1 (2.19e-2)
MW11	4.4780e-1 (1.64e-4) +	4.3439e-1 (4.04e-2) −	4.4731e-1 (2.90e-4) −	4.4765e-1 (1.78e-4) ≈	4.4751e-1 (2.60e-4) −	4.4272e-1 (1.16e-3) −	4.4717e-1 (1.41e-3) −	2.7720e-1 (3.32e-2) −	3.1024e-1 (6.08e-17) −	2.5356e-1 (5.05e-3) −	4.4734e-1 (2.30e-4) −	4.4769e-1 (2.18e-4)
MW12	6.0513e-1 (1.70e-4) +	6.0411e-1 (3.35e-4) −	5.9611e-1 (4.80e-2) ≈	6.0410e-1 (3.93e-4) −	6.0444e-1 (1.58e-4) −	6.0086e-1 (6.20e-4) −	6.0471e-1 (2.22e-4) −	8.4023e-2 (1.88e-1) −	6.0408e-1 (4.36e-4) −	3.2921e-3 (8.43e-3) −	5.8544e-1 (1.05e-1) −	6.0497e-1 (1.94e-4)
MW13	4.6206e-1 (9.34e-3) +	4.2515e-1 (3.91e-2) −	4.5597e-1 (1.18e-2) +	4.6674e-1 (9.34e-3) +	4.4646e-1 (1.79e-2) ≈	4.5798e-1 (1.50e-2) +	4.5135e-1 (1.57e-2) ≈	2.2657e-1 (1.06e-1) −	3.9391e-1 (1.61e-2) −	1.9084e-1 (5.98e-2) −	4.4108e-1 (2.40e-2) ≈	4.4442e-1 (2.51e-2)
MW14	4.6859e-1 (2.07e-3) −	4.6610e-1 (4.79e-3) −	4.7319e-1 (1.74e-3) +	4.5496e-1 (5.50e-3) −	4.7341e-1 (1.36e-3) +	4.6647e-1 (2.76e-3) −	4.7320e-1 (1.54e-3) ≈	3.7949e-1 (1.40e-1) −	4.5171e-1 (3.56e-3) −	4.9157e-2 (1.67e-2) −	4.6991e-1 (2.77e-3) −	4.7222e-1 (2.26e-3)
+/ − / ≈	6/5/3	0/10/4	7/2/5	4/6/4	4/5/5	4/9/1	2/2/10	0/13/1	1/13/0	0/14/0	0/8/6	

TABLE S-VIII

Statistical results of IGD+ obtained by CMOES and other methods on MW benchmark problems. The best result in each row is highlighted.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
MW1	1.1711e-3 (2.47e-5) ≈	1.4260e-3 (8.84e-4) −	1.1552e-3 (1.81e-5) ≈	1.2820e-3 (3.19e-5) −	1.5175e-3 (3.23e-4) −	1.2229e-2 (5.92e-2) −	1.1539e-3 (1.84e-5) ≈	NaN (NaN)	2.3494e-3 (1.91e-3) −	4.8669e-1 (1.06e-1) −	1.4386e-3 (6.73e-4) −	1.1601e-3 (2.10e-5)
MW2	1.4025e-2 (7.00e-3) +	2.2731e-2 (1.09e-2) ≈	1.6202e-2 (8.38e-3) ≈	1.5077e-2 (1.59e-2) +	1.6995e-2 (1.02e-2) ≈	1.4871e-2 (7.07e-3) ≈	2.0000e-2 (7.80e-3) ≈	1.5848e-1 (1.67e-1) −	4.8470e-2 (2.01e-2) −	9.9680e-2 (4.89e-2) −	1.9604e-2 (8.21e-3) ≈	1.9621e-2 (9.37e-3)
MW3	3.2627e-3 (3.55e-4) −	3.1404e-3 (3.91e-4) −	2.8887e-3 (2.67e-4) ≈	2.5087e-3 (1.87e-4) +	2.8100e-3 (1.11e-4) ≈	2.5645e-3 (2.14e-4) +	2.9324e-3 (3.19e-4) ≈	5.5906e-1 (2.83e-1) −	3.4080e-3 (1.60e-4) −	2.5447e-1 (2.16e-1) −	3.3689e-3 (3.34e-4) −	2.9912e-3 (4.19e-4)
MW4	2.9313e-2 (3.76e-4) +	2.9769e-2 (4.79e-4) ≈	2.9130e-2 (2.85e-4) +	2.8383e-2 (5.81e-4) +	3.2044e-2 (2.76e-3) −	3.2671e-2 (2.09e-4) −	2.9237e-2 (3.07e-4) +	8.1301e-1 (0.00e+0) ≈	5.3144e-2 (2.90e-3) −	3.5536e-1 (4.24e-2) −	3.0851e-2 (6.07e-4) −	2.9529e-2 (3.91e-4)
MW5	1.2705e-3 (1.74e-3) −	3.5248e-2 (5.03e-2) −	3.5398e-3 (1.70e-2) −	2.5858e-3 (6.85e-4) −	3.5828e-4 (9.79e-5) +	1.2556e-2 (4.82e-3) −	1.3582e-3 (2.28e-3) ≈	3.5086e-1 (4.49e-2) −	1.9391e-2 (1.79e-2) −	4.7837e-1 (4.24e-2) −	3.3814e-3 (1.51e-2) ≈	6.8107e-4 (4.50e-4)
MW6	1.0622e-2 (9.65e-3) +	3.4242e-2 (8.43e-2) ≈	1.5042e-2 (1.55e-2) +	5.4647e-3 (4.80e-3) +	2.2933e-2 (1.54e-2) ≈	1.2524e-2 (1.23e-2) +	2.0006e-2 (1.17e-2) ≈	5.7200e-1 (2.15e-1) −	1.9923e-1 (1.85e-1) −	3.7047e-1 (1.31e-1) −	3.2605e-2 (8.37e-2) ≈	2.0342e-2 (9.00e-3)
MW7	2.2278e-3 (2.30e-4) −	4.5830e-3 (2.71e-3) −	2.0014e-3 (2.37e-4) ≈	2.0076e-3 (1.28e-4) ≈	1.9578e-3 (7.60e-5) +	3.5933e-3 (3.04e-4) −	1.9911e-3 (2.42e-4) +	3.4709e-2 (6.27e-2) −	2.0164e-3 (1.34e-4) ≈	2.0823e-1 (1.38e-1) −	2.9380e-3 (4.66e-4) −	2.1215e-3 (2.66e-4)
MW8	2.3640e-2 (4.31e-3) +	3.2895e-2 (8.14e-3) ≈	2.7769e-2 (7.44e-3) +	2.6513e-2 (3.91e-3) +	3.3436e-2 (1.21e-2) ≈	3.2112e-2 (7.61e-3) ≈	3.0668e-2 (7.25e-3) ≈	5.0731e-1 (2.01e-1) −	8.4900e-2 (2.40e-2) −	2.1349e-1 (1.06e-1) −	2.5922e-2 (1.05e-2) +	3.3714e-2 (1.60e-2)
MW9	4.3965e-3 (1.31e-3) −	1.3483e-1 (1.85e-1) −	2.7491e-3 (1.23e-4) ≈	2.9529e-3 (2.39e-4) ≈	3.5674e-3 (3.91e-4) −	6.4388e-3 (5.02e-4) −	2.9612e-3 (2.42e-4) −	6.5228e-1 (2.64e-1) −	2.5868e-1 (9.87e-2) −	3.9196e-1 (2.02e-1) −	5.5766e-3 (1.34e-2) −	2.9111e-3 (3.75e-4)
MW10	4.4602e-2 (4.99e-2) ≈	4.6432e-2 (3.13e-2) −	1.7557e-2 (1.15e-2) +	9.7326e-3 (1.02e-2) +	3.2669e-2 (2.42e-2) ≈	1.1700e-2 (1.30e-2) +	4.0596e-2 (3.60e-2) ≈	NaN (NaN)	2.2979e-1 (1.56e-1) −	2.6799e-1 (1.54e-1) −	1.8486e-2 (1.28e-2) +	3.0534e-2 (2.46e-2)
MW11	2.5967e-3 (1.34e-4) ≈	2.8976e-2 (9.50e-2) −	2.6285e-3 (1.07e-4) ≈	2.7152e-3 (1.33e-4) −	3.0078e-3 (1.30e-4) −	7.1573e-3 (7.92e-4) −	2.6234e-3 (2.36e-4) ≈	5.1270e-1 (1.11e-1) −	4.3563e-1 (0.00e+0) −	5.7099e-1 (1.11e-2) −	2.9905e-3 (1.36e-4) −	2.5839e-3 (1.48e-4)
MW12	2.8412e-3 (8.55e-5) ≈	2.9954e-3 (1.45e-4) −	1.0537e-2 (4.19e-2) ≈	3.1736e-3 (1.74e-4) −	3.2793e-3 (1.22e-4) −	5.6839e-3 (4.38e-4) −	3.0534e-3 (1.44e-4) −	7.3258e-1 (3.46e-1) −	3.1789e-3 (1.34e-4) −	7.1300e-1 (1.04e-1) −	2.4120e-2 (1.14e-1) −	2.8734e-3 (1.01e-4)
MW13	1.9155e-2 (1.12e-2) +	7.5943e-2 (6.78e-2) −	2.6876e-2 (1.47e-2) +	1.3572e-2 (1.02e-2) +	4.0177e-2 (2.43e-2) ≈	2.4203e-2 (1.98e-2) +	3.3206e-2 (2.11e-2) ≈	7.5812e-1 (4.18e-1) −	1.1423e-1 (2.84e-2) −	1.0594e+0 (5.31e-1) −	4.8284e-2 (3.97e-2) ≈	4.4284e-2 (4.19e-2)
MW14	6.3326e-2 (2.24e-3) +	8.1606e-2 (9.68e-3) −	6.4867e-2 (2.31e-3) ≈	7.1328e-2 (3.66e-3) −	6.3322e-2 (1.77e-3) +	6.1242e-2 (2.21e-3) +	6.4789e-2 (2.12e-3) ≈	2.5122e-1 (3.37e-1) −	8.3535e-2 (6.07e-3) −	1.1030e+0 (9.25e-2) −	5.8491e-2 (2.48e-3) +	6.5757e-2 (3.36e-3)
+/ − / ≈	6/4/4	0/10/4	5/1/8	7/5/2	3/5/6	5/7/2	2/2/10	0/13/1	0/13/1	0/14/0	3/7/4	

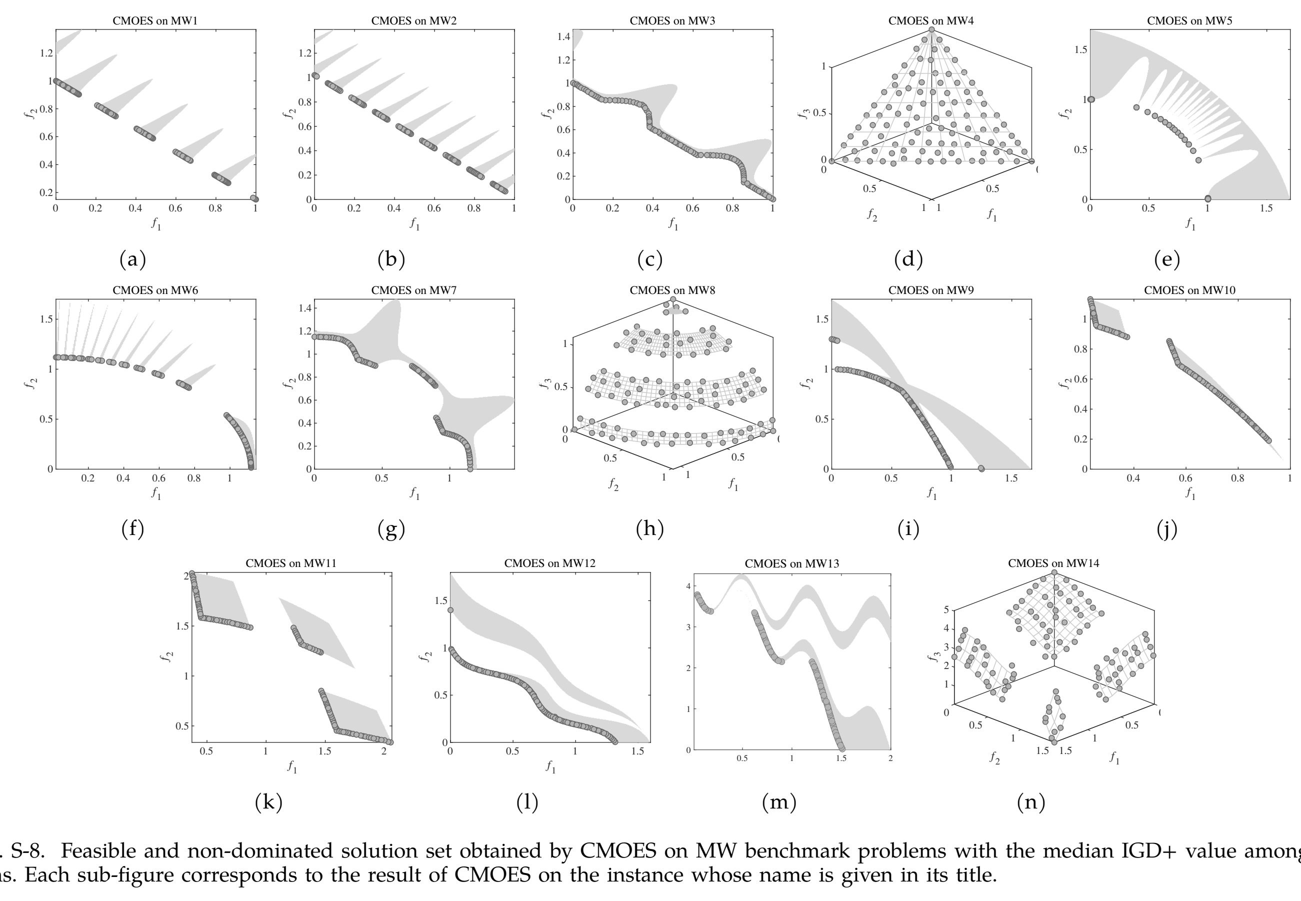


Fig. S-8. Feasible and non-dominated solution set obtained by CMOES on MW benchmark problems with the median IGD+ value among 30 runs. Each sub-figure corresponds to the result of CMOES on the instance whose name is given in its title.

TABLE S-IX

STATISTICAL RESULTS OF HV OBTAINED BY CMOES AND OTHER METHODS ON REAL-WORLD PROBLEMS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	BiCo	CMOEA-MS	MFO-SPEA2	ShiP-A	URCMO	C-TAEA	CCMO	ToP	DSPCMDE	NSGA-II-ToR	CCEA	CMOES
RWMOP1	6.0899e-1 (2.16e-4) +	7.0257e-1 (1.98e-1) ≈	6.0723e-1 (4.90e-4) +	6.0700e-1 (6.58e-4) +	6.0785e-1 (3.34e-4) +	6.0693e-1 (1.21e-3) +	6.0639e-1 (5.71e-4) +	6.0787e-1 (3.39e-4) +	6.3363e-1 (9.95e-2) +	9.4760e-1 (5.23e-2) +	6.0882e-1 (2.48e-4) +	6.0600e-1 (3.39e-4)
RWMOP2	1.0306e+0 (3.83e-3) ≈	1.0333e+0 (8.04e-3) ≈	1.0303e+0 (3.82e-3) ≈	1.0660e+0 (1.97e-2) +	1.0282e+0 (7.54e-5) ≈	1.0346e+0 (8.15e-3) ≈	2.8855e-1 (1.37e-1) −	1.0284e+0 (5.58e-4) ≈	1.0294e+0 (7.13e-3) −	1.0499e+0 (9.76e-3) +	1.0323e+0 (5.72e-3) +	1.0321e+0 (6.87e-3)
RWMOP3	1.3358e+1 (6.06e-2) −	1.2589e+1 (2.22e+0) −	1.3399e+1 (7.83e-3) ≈	1.3378e+1 (2.30e-2) −	1.3396e+1 (6.03e-3) ≈	1.0187e+1 (2.05e+0) −	1.3395e+1 (8.30e-3) ≈	1.3060e+1 (2.60e-1) −	1.3171e+1 (1.82e-1) −	7.1432e+0 (3.02e+0) −	1.2746e+1 (1.10e-1) −	1.3397e+1 (8.78e-3)
RWMOP4	1.0000e+0 (1.29e-6) −	9.9999e-1 (3.28e-6) −	1.0000e+0 (8.71e-7) ≈	1.0000e+0 (4.68e-7) ≈	1.0000e+0 (7.15e-8) +	9.9999e-1 (2.09e-6) −	1.0000e+0 (2.91e+1) =	1.0000e+0 (9.88e-8) +	9.9999e-1 (1.27e-6) −	9.9998e-1 (4.47e-6) −	1.0000e+0 (3.37e-7) ≈	1.0000e+0 (5.03e-7)
RWMOP5	1.0004e+0 (4.29e-11) ≈	1.0003e+0 (1.13e-5) −	1.0004e+0 (1.30e-5) −	1.0004e+0 (9.06e-6) ≈	1.0004e+0 (1.57e-8) ≈	1.0004e+0 (1.07e-4) +	1.0004e+0 (1.47e-5) −	1.0004e+0 (6.78e-16) ≈	1.0001e+0 (2.59e-8) −	1.0003e+0 (1.59e-5) −	1.0004e+0 (7.58e-9) −	1.0004e+0 (6.78e-16)
RWMOP6	1.1523e+0 (1.94e-4) −	1.1525e+0 (5.36e-5) ≈	1.1524e+0 (1.45e-4) −	1.1525e+0 (3.06e-5) ≈	1.1523e+0 (2.46e-4) −	1.1422e+0 (8.67e-3) −	1.1524e+0 (2.17e-4) −	1.1522e+0 (5.64e-4) −	1.1524e+0 (2.88e-4) −	1.1398e+0 (1.71e-2) −	1.1525e+0 (4.51e-5) −	1.1525e+0 (2.29e-5)
RWMOP7	1.0038e+0 (1.64e-4) ≈	1.0039e+0 (1.47e-4) +	1.0038e+0 (9.49e-5) ≈	1.0038e+0 (1.32e-4) ≈	1.0038e+0 (1.03e-4) −	1.0041e+0 (6.63e-4) +	1.0039e+0 (6.18e-1) +	1.0039e+0 (1.93e-4) ≈	1.0038e+0 (8.83e-5) −	1.0041e+0 (3.36e-4) +	1.0038e+0 (1.35e-4) ≈	1.0038e+0 (7.03e-5)
RWMOP9	9.9647e-1 (3.39e-16) ≈	9.9569e-1 (2.04e-4) −	9.9647e-1 (3.39e-16) ≈	9.9646e-1 (1.44e-6) −	9.9647e-1 (3.39e-16) ≈	9.9641e-1 (3.38e-5) −	9.9647e-1 (3.39e-16) ≈	9.9647e-1 (3.39e-16) ≈	9.9647e-1 (3.39e-16) ≈	9.9584e-1 (2.73e-4) −	9.9647e-1 (3.68e-7) ≈	9.9647e-1 (3.39e-16)
RWMOP10	9.9993e-1 (5.33e-16) ≈	9.9993e-1 (6.28e-11) −	9.9993e-1 (5.33e-16) ≈	9.9993e-1 (1.45e-9) −	9.9993e-1 (5.04e-16) −	9.9992e-1 (2.30e-6) −	9.9993e-1 (5.19e-16) ≈	9.9993e-1 (5.15e-16) ≈	9.9993e-1 (5.08e-16) ≈	9.9992e-1 (4.14e-6) −	9.9993e-1 (9.38e-13) −	9.9993e-1 (5.26e-16)
RWMOP12	9.9968e-1 (1.82e-6) ≈	9.9964e-1 (4.63e-5) −	9.9968e-1 (3.18e-6) ≈	9.9968e-1 (3.15e-6) ≈	9.9968e-1 (2.86e-6) ≈	9.9965e-1 (1.70e-5) −	9.9968e-1 (3.04e-6) −	9.9968e-1 (6.04e-7) +	9.9967e-1 (3.73e-6) −	9.9965e-1 (1.39e-5) −	9.9968e-1 (2.97e-6) −	9.9968e-1 (1.54e-6)
RWMOP14	1.0000e+0 (5.85e-7) ≈	1.0000e+0 (1.19e-6) −	1.0000e+0 (5.63e-8) +	1.0000e+0 (1.69e-5) +	1.0000e+0 (5.39e-8) ≈	1.0000e+0 (8.71e-8) −	1.0000e+0 (7.14e-8) −	1.0000e+0 (7.84e-8) ≈	1.0000e+0 (2.74e-9) −	1.0000e+0 (1.74e-7) −	1.0000e+0 (3.51e-10) −	1.0000e+0 (7.18e-9)
RWMOP15	2.4140e+1 (3.02e-1) ≈	2.3875e+1 (4.63e-1) −	2.4260e+1 (1.39e-1) ≈	1.8806e+1 (3.39e+0) −	2.4320e+1 (6.38e-3) +	2.4095e+1 (5.34e-1) ≈	2.4119e+1 (3.82e-1) ≈	2.4332e+1 (1.87e-2) +	2.4304e+1 (1.10e-1) +	2.1383e+1 (1.68e+0) −	2.3688e+1 (4.31e-1) −	2.4212e+1 (2.87e-1)
RWMOP16	1.0000e+0 (1.81e-10) −	1.0000e+0 (2.12e-11) +	1.0000e+0 (2.34e-10) ≈	1.0000e+0 (3.08e-10) ≈	1.0000e+0 (2.29e-10) −	1.0000e+0 (3.65e-8) −	1.0000e+0 (1.89e-10) −	1.0000e+0 (1.43e-10) −	1.0000e+0 (1.99e-10) −	1.0000e+0 (9.70e-8) −	1.0000e+0 (3.44e-10) −	1.0000e+0 (7.47e-11)
RWMOP18	1.0001e+0 (9.65e-9) −	1.0001e+0 (1.36e-9) −	1.0001e+0 (1.75e-9) −	1.0001e+0 (4.09e-7) −	1.0001e+0 (2.15e-9) −	1.0001e+0 (4.63e-7) −	1.0001e+0 (5.89e-3) −	1.0001e+0 (2.07e-9) −	1.0001e+0 (3.28e-9) −	1.0001e+0 (1.66e-6) −	1.0001e+0 (9.05e-9) −	1.0001e+0 (4.06e-10)
+/ − / ≈	1/5/8	2/9/3	2/3/9	3/5/6	3/5/6	3/9/2	2/7/5	4/4/6	2/10/2	3/11/0	2/9/3	

TABLE S-X

STATISTICAL RESULTS OF HV OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON DAS-CMOPS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
DASCMOP1	2.1101e-1 (9.06e-4) −	1.9214e-1 (5.96e-2) ≈	2.1165e-1 (5.03e-4)
DASCMOP2	3.5420e-1 (3.58e-4) −	3.3992e-1 (3.02e-2) −	3.5455e-1 (1.25e-4)
DASCMOP3	3.0449e-1 (1.50e-2) −	3.0727e-1 (1.35e-2) ≈	3.1148e-1 (4.01e-4)
DASCMOP4	2.0237e-1 (3.42e-3) −	1.5107e-1 (5.99e-2) −	2.0370e-1 (1.55e-3)
DASCMOP5	3.5148e-1 (1.50e-4) +	2.7344e-1 (1.22e-1) ≈	3.5141e-1 (1.40e-4)
DASCMOP6	3.0460e-1 (1.09e-2) −	1.3865e-1 (9.82e-2) −	3.0781e-1 (1.22e-2)
DASCMOP7	2.8822e-1 (4.83e-4) +	2.8821e-1 (4.28e-4) +	2.8765e-1 (4.71e-4)
DASCMOP8	2.0720e-1 (5.80e-4) +	2.0716e-1 (5.02e-4) +	2.0660e-1 (4.09e-4)
DASCMOP9	2.0319e-1 (5.95e-4) ≈	2.0383e-1 (6.50e-4) +	2.0350e-1 (5.36e-4)
+/ − / ≈	3/5/1	3/3/3	

TABLE S-XI

STATISTICAL RESULTS OF IGD+ OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON DAS-CMOPS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
DASCMOP1	2.5943e-3 (1.93e-4) −	6.9283e-2 (2.05e-1) −	2.4430e-3 (1.31e-4)
DASCMOP2	4.3886e-3 (3.16e-4) −	2.4299e-2 (4.21e-2) −	4.1126e-3 (1.69e-4)
DASCMOP3	1.6105e-2 (2.55e-2) −	1.2630e-2 (2.42e-2) ≈	6.0116e-3 (3.48e-4)
DASCMOP4	1.0708e-3 (8.18e-4) −	1.2430e-1 (1.51e-1) −	7.5728e-4 (3.21e-4)
DASCMOP5	1.8538e-3 (1.03e-4) ≈	1.4050e-1 (2.22e-1) ≈	1.8832e-3 (1.14e-4)
DASCMOP6	1.5195e-2 (1.64e-2) −	3.3706e-1 (2.01e-1) −	1.0814e-2 (1.72e-2)
DASCMOP7	2.3579e-2 (1.03e-3) +	2.3947e-2 (1.08e-3) +	2.4628e-2 (8.49e-4)
DASCMOP8	1.8328e-2 (7.77e-4) +	1.8402e-2 (1.06e-3) ≈	1.8734e-2 (6.85e-4)
DASCMOP9	2.4183e-2 (1.02e-3) −	2.3066e-2 (1.41e-3) ≈	2.3415e-2 (9.81e-4)
+/ − / ≈	2/6/1	1/4/4	

TABLE S-XII

STATISTICAL RESULTS OF HV OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON LIR-CMOPS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
LIRCMOP1	1.7292e-1 (2.88e-2) −	1.7742e-1 (2.93e-2) −	2.0189e-1 (1.87e-2)
LIRCMOP2	2.8610e-1 (2.61e-2) −	2.9591e-1 (3.44e-2) −	3.3046e-1 (1.37e-2)
LIRCMOP3	1.5450e-1 (2.48e-2) −	1.5746e-1 (2.46e-2) −	1.7226e-1 (1.59e-2)
LIRCMOP4	2.4139e-1 (2.95e-2) −	2.5437e-1 (2.13e-2) −	2.7422e-1 (1.94e-2)
LIRCMOP5	2.4060e-1 (9.93e-2) −	6.0073e-2 (1.11e-1) −	2.6883e-1 (2.89e-2)
LIRCMOP6	1.8516e-1 (1.58e-2) ≈	2.1128e-2 (3.33e-2) −	1.7426e-1 (4.36e-2)
LIRCMOP7	2.8628e-1 (1.72e-2) ≈	1.9036e-1 (1.19e-1) −	2.9359e-1 (3.44e-4)
LIRCMOP8	2.9356e-1 (6.77e-4) +	9.7470e-2 (1.14e-1) −	2.8927e-1 (1.51e-2)
LIRCMOP9	4.4192e-1 (1.70e-2) ≈	3.5752e-1 (2.42e-2) −	4.4864e-1 (2.81e-2)
LIRCMOP10	6.9391e-1 (9.70e-3) ≈	4.9915e-1 (7.34e-2) −	6.9288e-1 (1.79e-2)
LIRCMOP11	6.8726e-1 (5.85e-3) +	5.5577e-1 (5.20e-2) −	6.8237e-1 (9.71e-3)
LIRCMOP12	6.0492e-1 (1.22e-2) +	4.9236e-1 (3.33e-2) −	5.7845e-1 (1.54e-2)
LIRCMOP13	5.0758e-1 (3.04e-3) −	3.5389e-1 (1.21e-1) −	5.5223e-1 (1.82e-3)
LIRCMOP14	5.3884e-1 (1.82e-3) −	3.9608e-1 (1.47e-1) −	5.5340e-1 (1.17e-3)
+/ − / ≈	3/7/4	0/14/0	

TABLE S-XIII

STATISTICAL RESULTS OF IGD+ OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON LIR-CMOPS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
LIRCMOP1	1.0674e-1 (5.66e-2) −	1.0036e-1 (5.66e-2) −	5.5760e-2 (3.33e-2)
LIRCMOP2	7.9056e-2 (3.01e-2) −	6.9365e-2 (3.89e-2) −	3.6954e-2 (1.52e-2)
LIRCMOP3	1.0886e-1 (5.81e-2) −	1.0400e-1 (6.02e-2) −	6.4610e-2 (3.82e-2)
LIRCMOP4	1.0294e-1 (4.54e-2) −	8.3365e-2 (3.06e-2) −	5.4773e-2 (2.67e-2)
LIRCMOP5	1.8514e-1 (3.95e-1) −	9.3020e-1 (4.78e-1) −	5.4460e-2 (7.82e-2)
LIRCMOP6	3.0277e-2 (4.18e-2) ≈	1.0304e+0 (4.91e-1) −	8.7892e-2 (2.55e-1)
LIRCMOP7	2.2745e-2 (3.73e-2) −	5.1206e-1 (7.20e-1) −	7.2208e-3 (4.89e-4)
LIRCMOP8	7.2825e-3 (1.19e-3) +	1.0739e+0 (7.13e-1) −	1.6304e-2 (3.30e-2)
LIRCMOP9	1.6648e-1 (2.19e-2) ≈	2.8396e-1 (2.20e-2) −	1.5964e-1 (2.86e-2)
LIRCMOP10	2.6539e-2 (1.91e-2) ≈	3.0007e-1 (8.28e-2) −	2.6742e-2 (2.95e-2)
LIRCMOP11	1.0173e-2 (8.57e-3) +	1.7813e-1 (7.06e-2) −	1.7171e-2 (1.45e-2)
LIRCMOP12	3.0985e-2 (2.36e-2) +	1.9922e-1 (4.53e-2) −	7.6654e-2 (2.15e-2)
LIRCMOP13	9.4074e-2 (3.41e-3) −	2.8633e-1 (1.73e-1) −	4.7071e-2 (1.99e-3)
LIRCMOP14	6.2287e-2 (2.05e-3) −	2.6003e-1 (2.34e-1) −	4.7087e-2 (1.28e-3)
+/ − / ≈	3/8/3	0/14/0	

TABLE S-XIV

STATISTICAL RESULTS OF HV OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON LYOS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
LYO1	3.4548e-1 (4.87e-4) −	3.4640e-1 (3.44e-4) +	3.4616e-1 (3.20e-4)
LYO2	5.6842e-1 (4.24e-3) ≈	4.4712e-1 (4.63e-2) −	5.6528e-1 (1.16e-2)
LYO3	8.5732e-1 (3.58e-4) −	8.5782e-1 (3.14e-4) ≈	8.5776e-1 (2.66e-4)
LYO4	5.5438e-1 (3.46e-4) −	5.5457e-1 (9.30e-4) ≈	5.5462e-1 (2.22e-4)
LYO5	5.7561e-1 (2.23e-2) +	5.7903e-1 (9.93e-3) ≈	5.6669e-1 (4.10e-2)
LYO6	8.5847e-1 (1.36e-4) ≈	8.5847e-1 (1.01e-4) ≈	8.5844e-1 (1.30e-4)
LYO7	1.2078e-1 (4.39e-2) −	1.3837e-1 (5.69e-2) ≈	1.3868e-1 (4.83e-2)
LYO8	4.4612e-1 (1.19e-1) −	5.1104e-1 (9.29e-2) ≈	4.8481e-1 (1.21e-1)
+/ − / ≈	1/5/2	1/1/6	

TABLE S-XV

STATISTICAL RESULTS OF IGD+ OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON LYOS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
LYO1	1.3545e-2 (1.18e-3) −	1.1220e-2 (8.95e-4) +	1.1832e-2 (8.43e-4)
LYO2	6.0071e-2 (1.37e-2) ≈	4.5089e-1 (1.49e-1) −	7.0123e-2 (3.73e-2)
LYO3	1.0251e-1 (9.55e-3) −	9.0846e-2 (1.15e-2) ≈	9.1690e-2 (7.64e-3)
LYO4	6.6238e-2 (2.19e-2) −	4.5840e-2 (3.31e-2) ≈	4.9169e-2 (1.75e-2)
LYO5	1.0115e-1 (2.28e-1) +	6.2288e-2 (7.34e-2) ≈	2.0129e-1 (4.41e-1)
LYO6	1.6726e-2 (7.29e-4) ≈	1.6812e-2 (5.10e-4) ≈	1.6813e-2 (6.89e-4)
LYO7	1.6270e+1 (2.91e+0) −	1.5116e+1 (3.80e+0) ≈	1.5153e+1 (3.21e+0)
LYO8	1.1067e+0 (1.26e+0) −	4.3830e-1 (9.95e-1) ≈	7.4180e-1 (1.29e+0)
+/ − / ≈	1/5/2	1/1/6	

TABLE S-XVI
STATISTICAL RESULTS OF HV OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON MWS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
MW1	4.9005e-1 (4.10e-5) ≈	4.8970e-1 (2.01e-3) ≈	4.9005e-1 (4.49e-5)
MW2	5.6628e-1 (1.28e-2) +	5.6526e-1 (1.17e-2) +	5.5442e-1 (1.47e-2)
MW3	5.4440e-1 (3.22e-4) ≈	5.4424e-1 (5.50e-4) ≈	5.4429e-1 (7.06e-4)
MW4	8.4122e-1 (4.59e-4) ≈	8.4084e-1 (5.66e-4) −	8.4117e-1 (5.66e-4)
MW5	3.2417e-1 (5.34e-4) ≈	3.2290e-1 (4.45e-3) ≈	3.2434e-1 (2.37e-4)
MW6	3.1251e-1 (1.54e-2) +	3.1505e-1 (9.86e-3) +	3.0216e-1 (1.22e-2)
MW7	4.1245e-1 (4.59e-4) +	4.1225e-1 (4.82e-4) ≈	4.1206e-1 (5.30e-4)
MW8	5.3787e-1 (1.22e-2) +	5.3734e-1 (9.78e-3) +	5.2543e-1 (2.86e-2)
MW9	3.9816e-1 (1.82e-3) ≈	3.9519e-1 (3.00e-3) −	3.9875e-1 (2.40e-3)
MW10	4.3591e-1 (1.38e-2) +	4.3121e-1 (1.55e-2) ≈	4.2378e-1 (2.19e-2)
MW11	4.4721e-1 (1.43e-3) −	4.4781e-1 (1.61e-4) +	4.4769e-1 (2.18e-4)
MW12	6.0470e-1 (1.89e-4) −	5.8499e-1 (1.10e-1) −	6.0497e-1 (1.94e-4)
MW13	4.5691e-1 (1.54e-2) +	4.5722e-1 (1.17e-2) +	4.4442e-1 (2.51e-2)
MW14	4.7318e-1 (1.55e-3) ≈	4.7152e-1 (1.57e-3) −	4.7222e-1 (2.26e-3)
+/ − / ≈	6/2/6	5/4/5	

TABLE S-XVII
STATISTICAL RESULTS OF IGD+ OBTAINED BY CMOES AND ITS VARIANTS FOR ABLATION STUDIES ON THE EFFECTIVENESS OF THE PROPOSED EVEN SEARCH METHOD ON MWS. THE BEST RESULT IN EACH ROW IS HIGHLIGHTED.

Problem	CMOESP1	CMOESP2	CMOES
MW1	1.1601e-3 (1.49e-5) ≈	1.2861e-3 (6.41e-4) ≈	1.1601e-3 (2.10e-5)
MW2	1.2030e-2 (7.55e-3) +	1.2474e-2 (6.76e-3) +	1.9621e-2 (9.37e-3)
MW3	2.9231e-3 (2.05e-4) ≈	3.0087e-3 (3.16e-4) ≈	2.9912e-3 (4.19e-4)
MW4	2.9399e-2 (3.13e-4) ≈	2.9677e-2 (4.96e-4) ≈	2.9529e-2 (3.91e-4)
MW5	1.0216e-3 (1.05e-3) ≈	2.3876e-3 (4.60e-3) ≈	6.8107e-4 (4.50e-4)
MW6	1.2761e-2 (1.13e-2) +	1.0854e-2 (7.21e-3) +	2.0342e-2 (9.00e-3)
MW7	1.9382e-3 (2.06e-4) +	2.0038e-3 (2.10e-4) ≈	2.1215e-3 (2.66e-4)
MW8	2.6585e-2 (6.96e-3) +	2.6939e-2 (5.41e-3) +	3.3714e-2 (1.60e-2)
MW9	3.0973e-3 (2.23e-4) −	3.5236e-3 (9.58e-4) −	2.9111e-3 (3.75e-4)
MW10	1.6662e-2 (1.34e-2) +	2.1432e-2 (1.57e-2) ≈	3.0534e-2 (2.46e-2)
MW11	2.6356e-3 (1.45e-4) ≈	2.4597e-3 (1.48e-4) +	2.5839e-3 (1.48e-4)
MW12	3.0352e-3 (1.18e-4) −	2.6964e-2 (1.33e-1) −	2.8734e-3 (1.01e-4)
MW13	2.6379e-2 (2.00e-2) +	2.5544e-2 (1.42e-2) +	4.4284e-2 (4.19e-2)
MW14	6.4892e-2 (2.22e-3) ≈	6.7092e-2 (2.51e-3) −	6.5757e-2 (3.36e-3)
+/ − / ≈	6/2/6	5/3/6	

TABLE S-XVIII

Statistical results of HV obtained by CMOES and its variants with different settings on η on DAS-CMOPs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
DASCMOP1	2.1157e-1 (6.49e-4) ≈	2.1157e-1 (5.80e-4) ≈	2.1165e-1 (5.03e-4)
DASCMOP2	3.5450e-1 (1.87e-4) ≈	3.5453e-1 (1.47e-4) ≈	3.5455e-1 (1.25e-4)
DASCMOP3	3.1144e-1 (5.52e-4) ≈	3.1144e-1 (6.21e-4) ≈	3.1148e-1 (4.01e-4)
DASCMOP4	1.8839e-1 (4.22e-2) −	1.9507e-1 (2.27e-2) −	2.0370e-1 (1.55e-3)
DASCMOP5	3.4017e-1 (3.89e-2) −	3.3432e-1 (6.90e-2) −	3.5141e-1 (1.40e-4)
DASCMOP6	2.3251e-1 (1.20e-1) −	2.6416e-1 (8.55e-2) −	3.0781e-1 (1.22e-2)
DASCMOP7	2.5013e-1 (7.67e-2) −	2.6995e-1 (4.35e-2) −	2.8765e-1 (4.71e-4)
DASCMOP8	1.7019e-1 (6.23e-2) −	1.7879e-1 (5.43e-2) −	2.0660e-1 (4.09e-4)
DASCMOP9	2.0346e-1 (4.79e-4) ≈	2.0349e-1 (4.64e-4) ≈	2.0350e-1 (5.36e-4)
+/ − / ≈	0/5/4	0/5/4	

TABLE S-XIX

Statistical results of IGD+ obtained by CMOES and its variants with different settings on η on DAS-CMOPs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
DASCMOP1	2.6437e-3 (1.67e-4) −	2.5333e-3 (1.61e-4) ≈	2.4430e-3 (1.31e-4)
DASCMOP2	4.2147e-3 (2.61e-4) ≈	4.1669e-3 (1.92e-4) ≈	4.1126e-3 (1.69e-4)
DASCMOP3	6.0738e-3 (5.64e-4) ≈	6.1852e-3 (5.72e-4) ≈	6.0116e-3 (3.48e-4)
DASCMOP4	3.5356e-2 (1.23e-1) −	1.3523e-2 (5.55e-2) −	7.5728e-4 (3.21e-4)
DASCMOP5	1.8409e-2 (6.34e-2) −	4.0895e-2 (1.77e-1) −	1.8832e-3 (1.14e-4)
DASCMOP6	1.8592e-1 (2.97e-1) −	9.2451e-2 (1.65e-1) −	1.0814e-2 (1.72e-2)
DASCMOP7	1.3489e-1 (2.80e-1) −	6.5807e-2 (1.17e-1) −	2.4628e-2 (8.49e-4)
DASCMOP8	1.2927e-1 (2.54e-1) −	1.0916e-1 (2.45e-1) −	1.8734e-2 (6.85e-4)
DASCMOP9	2.3678e-2 (1.10e-3) ≈	2.3758e-2 (8.78e-4) ≈	2.3415e-2 (9.81e-4)
+/ − / ≈	0/6/3	0/5/4	

TABLE S-XX

Statistical results of HV obtained by CMOES and its variants with different settings on η on LIR-CMOPs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
LIRCMOP1	1.9437e-1 (2.05e-2) ≈	1.9910e-1 (2.07e-2) ≈	2.0189e-1 (1.87e-2)
LIRCMOP2	3.1696e-1 (2.55e-2) ≈	3.1948e-1 (2.29e-2) ≈	3.3046e-1 (1.37e-2)
LIRCMOP3	1.5656e-1 (1.98e-2) −	1.6031e-1 (2.03e-2) −	1.7226e-1 (1.59e-2)
LIRCMOP4	2.5673e-1 (2.28e-2) −	2.6466e-1 (2.09e-2) −	2.7422e-1 (1.94e-2)
LIRCMOP5	2.5362e-1 (7.60e-2) ≈	2.3484e-1 (9.57e-2) ≈	2.6883e-1 (2.89e-2)
LIRCMOP6	1.8996e-1 (6.08e-3) ≈	1.8150e-1 (3.33e-2) ≈	1.7426e-1 (4.36e-2)
LIRCMOP7	2.9219e-1 (5.83e-3) ≈	2.8723e-1 (1.61e-2) −	2.9359e-1 (3.44e-4)
LIRCMOP8	2.9231e-1 (4.60e-3) ≈	2.9167e-1 (9.21e-3) ≈	2.8927e-1 (1.51e-2)
LIRCMOP9	4.3954e-1 (2.03e-2) ≈	4.4945e-1 (2.66e-2) ≈	4.4864e-1 (2.81e-2)
LIRCMOP10	6.9205e-1 (1.90e-2) ≈	6.9539e-1 (7.91e-3) ≈	6.9288e-1 (1.79e-2)
LIRCMOP11	6.8059e-1 (1.75e-2) ≈	6.7238e-1 (3.32e-2) ≈	6.8237e-1 (9.71e-3)
LIRCMOP12	5.8279e-1 (1.25e-2) ≈	5.8090e-1 (1.54e-2) ≈	5.7845e-1 (1.54e-2)
LIRCMOP13	5.0650e-1 (3.26e-3) −	5.0624e-1 (2.69e-3) −	5.5223e-1 (1.82e-3)
LIRCMOP14	5.3797e-1 (2.21e-3) −	5.3694e-1 (2.22e-3) −	5.5340e-1 (1.17e-3)
+/ − / ≈	0/4/10	0/5/9	

TABLE S-XXI

Statistical results of IGD+ obtained by CMOES and its variants with different settings on η on LIR-CMOPs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
LIRCMOP1	7.2185e-2 (4.20e-2) ≈	6.1741e-2 (4.32e-2) ≈	5.5760e-2 (3.33e-2)
LIRCMOP2	4.7615e-2 (2.40e-2) ≈	4.3871e-2 (2.11e-2) ≈	3.6954e-2 (1.52e-2)
LIRCMOP3	1.0741e-1 (4.77e-2) −	9.3417e-2 (4.41e-2) −	6.4610e-2 (3.82e-2)
LIRCMOP4	7.8844e-2 (3.30e-2) −	6.9143e-2 (2.98e-2) −	5.4773e-2 (2.67e-2)
LIRCMOP5	1.1914e-1 (2.95e-1) ≈	1.9219e-1 (3.91e-1) ≈	5.4460e-2 (7.82e-2)
LIRCMOP6	1.8164e-2 (1.14e-2) ≈	4.1985e-2 (1.12e-1) ≈	8.7892e-2 (2.55e-1)
LIRCMOP7	9.7017e-3 (1.10e-2) ≈	2.0249e-2 (3.43e-2) −	7.2208e-3 (4.89e-4)
LIRCMOP8	9.1134e-3 (7.35e-3) ≈	1.1315e-2 (1.99e-2) ≈	1.6304e-2 (3.30e-2)
LIRCMOP9	1.6940e-1 (2.54e-2) ≈	1.5737e-1 (2.89e-2) ≈	1.5964e-1 (2.86e-2)
LIRCMOP10	2.8636e-2 (3.18e-2) ≈	2.3042e-2 (1.59e-2) ≈	2.6742e-2 (2.95e-2)
LIRCMOP11	1.9568e-2 (2.37e-2) ≈	2.9866e-2 (4.24e-2) ≈	1.7171e-2 (1.45e-2)
LIRCMOP12	7.1027e-2 (2.05e-2) ≈	7.3922e-2 (2.26e-2) ≈	7.6654e-2 (2.15e-2)
LIRCMOP13	9.4807e-2 (3.32e-3) −	9.4666e-2 (2.53e-3) −	4.7071e-2 (1.99e-3)
LIRCMOP14	6.2827e-2 (2.04e-3) −	6.4180e-2 (2.33e-3) −	4.7087e-2 (1.28e-3)
+/ − / ≈	0/4/10	0/5/9	

TABLE S-XXII

Statistical results of HV obtained by CMOES and its variants with different settings on η on LYOs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
LYO1	3.4582e-1 (2.45e-4) −	3.4591e-1 (3.76e-4) −	3.4616e-1 (3.20e-4)
LYO2	5.7237e-1 (4.02e-3) +	5.6925e-1 (6.35e-3) ≈	5.6528e-1 (1.16e-2)
LYO3	8.5759e-1 (2.45e-4) −	8.5754e-1 (2.56e-4) −	8.5776e-1 (2.66e-4)
LYO4	5.5430e-1 (2.52e-4) −	5.5438e-1 (1.90e-4) −	5.5462e-1 (2.22e-4)
LYO5	5.8030e-1 (7.01e-3) ≈	5.7442e-1 (2.70e-2) ≈	5.6669e-1 (4.10e-2)
LYO6	8.5836e-1 (1.21e-4) −	8.5840e-1 (1.47e-4) ≈	8.5844e-1 (1.30e-4)
LYO7	2.6460e-1 (4.69e-2) +	2.5734e-1 (5.45e-2) +	1.3868e-1 (4.83e-2)
LYO8	5.4068e-1 (3.85e-2) ≈	5.0035e-1 (9.76e-2) ≈	4.8481e-1 (1.21e-1)
+/ − / ≈	2/4/2	1/3/4	

TABLE S-XXIII

Statistical results of IGD+ obtained by CMOES and its variants with different settings on η on LYOs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
LYO1	1.2713e-2 (6.68e-4) −	1.2464e-2 (1.03e-3) −	1.1832e-2 (8.43e-4)
LYO2	4.7069e-2 (1.32e-2) +	5.7187e-2 (2.07e-2) ≈	7.0123e-2 (3.73e-2)
LYO3	9.4957e-2 (6.72e-3) −	9.5721e-2 (6.12e-3) ≈	9.1690e-2 (7.64e-3)
LYO4	7.9409e-2 (1.99e-2) −	7.4240e-2 (1.86e-2) −	4.9169e-2 (1.75e-2)
LYO5	5.6327e-2 (6.36e-2) ≈	1.1397e-1 (2.85e-1) ≈	2.0129e-1 (4.41e-1)
LYO6	1.7272e-2 (6.86e-4) −	1.7098e-2 (8.31e-4) ≈	1.6813e-2 (6.89e-4)
LYO7	5.6860e+0 (3.85e+0) +	6.3387e+0 (4.28e+0) +	1.5153e+1 (3.21e+0)
LYO8	1.2314e-1 (2.52e-1) ≈	5.7488e-1 (1.04e+0) ≈	7.4180e-1 (1.29e+0)
+/ − / ≈	2/4/2	1/2/5	

TABLE S-XXIV

Statistical results of HV obtained by CMOES and its variants with different settings on η on MWs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
MW1	4.9003e-1 (3.79e-5) $-$	4.9002e-1 (3.54e-5) $-$	4.9005e-1 (4.49e-5)
MW2	5.6478e-1 (9.84e-3) $+$	5.5904e-1 (1.31e-2) $\approx$	5.5442e-1 (1.47e-2)
MW3	5.4404e-1 (4.56e-4) $-$	5.4399e-1 (5.97e-4) $-$	5.4429e-1 (7.06e-4)
MW4	8.4044e-1 (6.79e-4) $-$	8.4070e-1 (5.20e-4) $-$	8.4117e-1 (5.66e-4)
MW5	3.2439e-1 (1.37e-4) $\approx$	3.2439e-1 (1.18e-4) $\approx$	3.2434e-1 (2.37e-4)
MW6	3.1154e-1 (1.10e-2) $+$	3.1044e-1 (1.39e-2) $+$	3.0216e-1 (1.22e-2)
MW7	4.1217e-1 (5.03e-4) $\approx$	4.1211e-1 (4.46e-4) $\approx$	4.1206e-1 (5.30e-4)
MW8	5.3676e-1 (1.22e-2) $+$	5.3802e-1 (9.56e-3) $+$	5.2543e-1 (2.86e-2)
MW9	3.8634e-1 (7.30e-2) $\approx$	3.9942e-1 (1.36e-3) $\approx$	3.9875e-1 (2.40e-3)
MW10	4.3554e-1 (1.49e-2) $+$	4.2776e-1 (1.88e-2) $\approx$	4.2378e-1 (2.19e-2)
MW11	4.4763e-1 (1.88e-4) $\approx$	4.4762e-1 (2.12e-4) $\approx$	4.4769e-1 (2.18e-4)
MW12	6.0472e-1 (5.13e-4) $-$	6.0485e-1 (1.70e-4) $-$	6.0497e-1 (1.94e-4)
MW13	4.5706e-1 (1.52e-2) $+$	4.5546e-1 (1.36e-2) $+$	4.4442e-1 (2.51e-2)
MW14	4.7034e-1 (2.07e-3) $-$	4.7095e-1 (2.77e-3) $-$	4.7222e-1 (2.26e-3)
$+/-/\approx$	5/5/4	3/5/6	

TABLE S-XXV

Statistical results of IGD+ obtained by CMOES and its variants with different settings on η on MWs. The best result in each row is highlighted.

Problem	CMOESeta1	CMOESeta2	CMOES
MW1	1.1824e-3 (1.74e-5) $-$	1.1839e-3 (1.81e-5) $-$	1.1601e-3 (2.10e-5)
MW2	1.2768e-2 (5.58e-3) $+$	1.6377e-2 (8.17e-3) $\approx$	1.9621e-2 (9.37e-3)
MW3	3.1431e-3 (2.74e-4) $-$	3.1823e-3 (3.33e-4) $-$	2.9912e-3 (4.19e-4)
MW4	2.9977e-2 (6.04e-4) $-$	2.9770e-2 (4.40e-4) $\approx$	2.9529e-2 (3.91e-4)
MW5	5.6978e-4 (2.66e-4) $\approx$	5.2519e-4 (1.87e-4) $\approx$	6.8107e-4 (4.50e-4)
MW6	1.3427e-2 (8.05e-3) $+$	1.4249e-2 (1.02e-2) $+$	2.0342e-2 (9.00e-3)
MW7	2.0627e-3 (2.43e-4) $\approx$	2.1072e-3 (2.30e-4) $\approx$	2.1215e-3 (2.66e-4)
MW8	2.7136e-2 (6.77e-3) $+$	2.6673e-2 (5.42e-3) $+$	3.3714e-2 (1.60e-2)
MW9	2.4691e-2 (1.19e-1) $\approx$	2.9513e-3 (1.15e-4) $-$	2.9111e-3 (3.75e-4)
MW10	1.7425e-2 (1.41e-2) $+$	2.5378e-2 (2.13e-2) $\approx$	3.0534e-2 (2.46e-2)
MW11	2.6690e-3 (1.05e-4) $-$	2.6952e-3 (1.53e-4) $-$	2.5839e-3 (1.48e-4)
MW12	3.0719e-3 (2.50e-4) $-$	3.0147e-3 (1.27e-4) $-$	2.8734e-3 (1.01e-4)
MW13	2.6257e-2 (1.94e-2) $+$	2.7755e-2 (1.82e-2) $+$	4.4284e-2 (4.19e-2)
MW14	6.7771e-2 (2.63e-3) $-$	6.7747e-2 (3.53e-3) $-$	6.5757e-2 (3.36e-3)
$+/-/\approx$	5/6/3	3/6/5	