Evolutionary Alternating Direction Method of Multipliers for Constrained Multi-Objective Optimization with Unknown Constraints

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APPENDIX A
MATHEMATICAL DEFINITIONS OF BENCHMARK PROBLEMS

In our experiments, we consider the following synthetic test problems and real-world engineering challenges.

A. Synthetic Test Problems

As pointed out in Remark 2 of the main paper, the prevalent test problems are hardly adequate to benchmark the existing CHTs of EMO for dealing with CMOP/UC. Inspired by the C-DTLZ benchmark suite developed in [1], we design a set of new benchmark test problems, whose name consists of three components: "UC*", "C*", and "DTLZ*". Among them, UC1 to UC5 serve to denote the following five types of distinctive characteristics respectively.

- `Type-I`: As the illustrative example shown in Fig. 1, the feasible region of this type of problem is a narrow area adjacent to the PF, making most of the search space infeasible. Constrained EMO algorithms relying on the CV information may struggle to navigate towards the PF through this predominantly infeasible space.
- `Type-II`: An extension of `Type-I`, this category includes additional feasible regions distant from the PF, as shown in Fig. 2. The large gap between these disparate feasible areas often diminishes the selection pressure necessary for evolutionary populations to traverse the regions using binary CV signals.
- `Type-III`: Building upon `Type-I`, this type intersperses the infeasible space with two narrowly spaced feasible regions, as depicted in Fig. 3. Without access to CV information, evolutionary populations may become impeded by these narrow feasible areas.
- `Type-IV`: Inspired by C3-DTLZ problems, the PF here is overshadowed by a 'pseudo' PF when constraints are disregarded, as in Fig. 4. This presents additional complexities that can misguide an evolutionary population towards the infeasible region above the PF.
- `Type-V`: Sharing the same PF and feasible regions as `Type-I`, this category introduces the complexity of a 'pseudo' PF similar to `Type-IV`, as shown in Fig. 5, elevating the challenge.

Moreover, C1 to C3 serve to denote the wedge-shaped feasible region, belt-shaped feasible region, and disparately distributed feasible region respectively. DTLZ1 to DTLZ3 serve to denote the corresponding objective functions, whose definitions are given as follows:

- The definitions of objective functions of DTLZ1:

$$\left.\begin{array}{rl} \min f_1(\mathbf{x}) & = 0.5x_1x_2\cdots x_{m-1}\left(1+g\left(\mathbf{x}_m\right)\right) \\ \min f_2(\mathbf{x}) & = 0.5x_1x_2\cdots\left(1-x_{m-1}\right)\left(1+g\left(\mathbf{x}_m\right)\right) \\ & \vdots \\ \min f_{m-1}(\mathbf{x}) & = 0.5x_1\left(1-x_2\right)\left(1+g\left(\mathbf{x}_m\right)\right) \\ \min f_m(\mathbf{x}) & = 0.5\left(1-x_1\right)\left(1+g\left(\mathbf{x}_m\right)\right) \end{array}\right\}, \tag{1}$$

  where $\mathbf{x}\in\mathbb{R}^n$,$\mathbf{x}_m=\{x_m,\ldots,x_n\}$,

$$g\left(\mathbf{x}_m\right)=100\left[\left|\mathbf{x}_m\right|+\sum_{x_i\in\mathbf{x}_m}\left(x_i-0.5\right)^2-\cos\left(20\pi\left(x_i-0.5\right)\right)\right]. \tag{2}$$

- The definitions of objective functions of DTLZ2:

$$\left.\begin{array}{rl} \min f_1(\mathbf{x}) & = \left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(\frac{\pi}{2}x_1\right)\cdots\cos\left(\frac{\pi}{2}x_{m-2}\right)\cos\left(\frac{\pi}{2}x_{m-1}\right) \\ \min f_2(\mathbf{x}) & = \left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(\frac{\pi}{2}x_1\right)\cdots\cos\left(\frac{\pi}{2}x_{m-2}\right)\sin\left(\frac{\pi}{2}x_{m-1}\right) \\ \min f_3(\mathbf{x}) & = \left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(\frac{\pi}{2}x_1\right)\cdots\sin\left(\frac{\pi}{2}x_{m-2}\right), \\ & \vdots \\ \min f_m(\mathbf{x}) & = \left(1+g\left(\mathbf{x}_m\right)\right)\sin\left(\frac{\pi}{2}x_1\right) \end{array}\right\}, \tag{3}$$

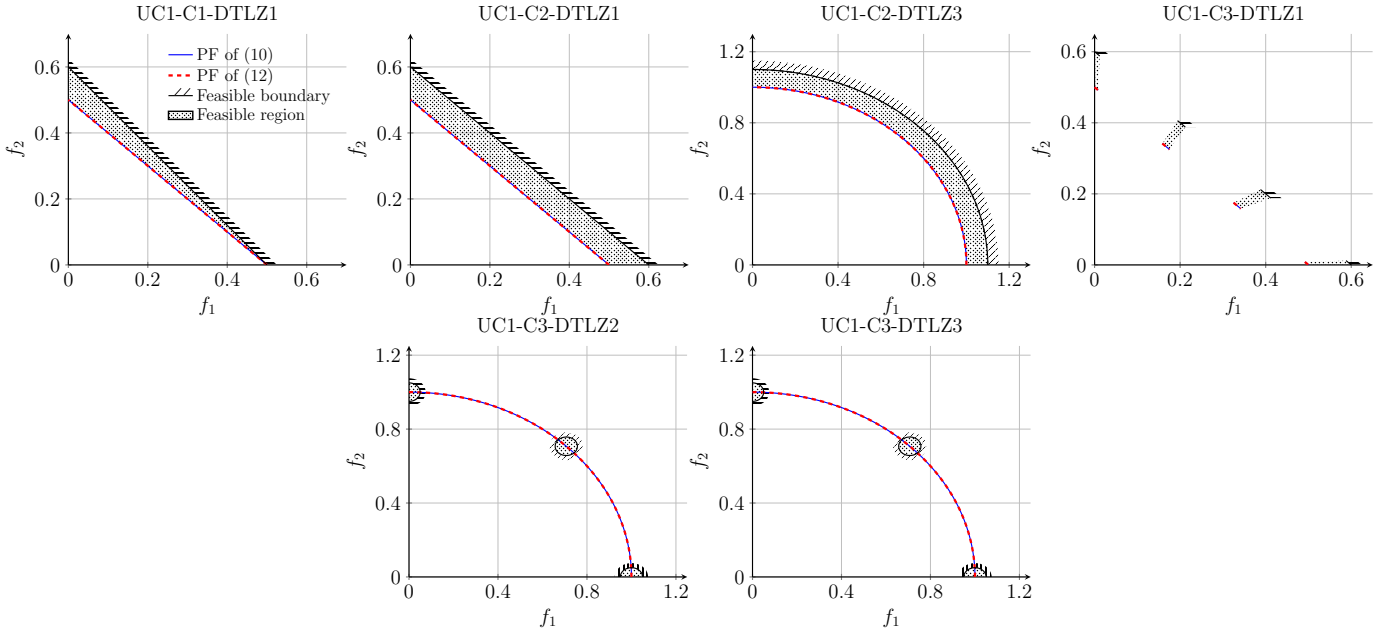

Fig. 1. The illustrations of the feasible regions of UC1-C1-DTLZ1 to UC1-C3-DTLZ3 benchmark problems.

where $\mathbf{x}_m = \{x_m, \ldots, x_n\}$, $g(\mathbf{x}_m) = \sum_{x_i \in \mathbf{x}_m} (x_i - 0.5)^2$.

- The definitions of objective functions of DTLZ3 are same as equation (3), where the definition of $g(\mathbf{x}_m)$ is same as equation (2).

1) Definitions of UC1 Benchmark Suit: The illustrations of UC1-C1-DTLZ1, UC1-C2-DTLZ1, UC1-C2-DTLZ3, UC1-C3-DTLZ1, UC1-C3-DTLZ2 and UC1-C3-DTLZ3 are given in Fig. 1, the definitions of them are given as follows:

- UC1-C1-DTLZ1: The definitions of objective functions of UC1-C1-DTLZ1 are same as DTLZ1, the definition of constraint function of UC1-C1-DTLZ1 is given as follows:

$$c(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{0.6} - \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{0.5} \leq 0), \tag{4}$$

  where $\mathbb{1}(\cdot)$ is an indicator function that returns 1 for infeasible solutions when its argument is true, otherwise it returns 0 for feasible solutions.
- UC1-C2-DTLZ1: The definitions of objective functions of UC1-C2-DTLZ1 are same as DTLZ1, the definition of constraint function of UC1-C2-DTLZ1 is given as follows:

$$c(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{0.6} - \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{0.6} \leq 0) \tag{5}$$

- UC1-C2-DTLZ3: The definitions of objective functions of UC1-C2-DTLZ3 are same as DTLZ3, the definition of constraint function of UC1-C2-DTLZ3 is given as follows:

$$c(\mathbf{x}) = \mathbb{1}(r^2 - \sum_{i=1}^{m} f_i(\mathbf{x})^2 \leq 0), \tag{6}$$

  where r is designed to control the range of the feasible region. In this paper, we set it as $r = 1.1$.
- UC1-C3-DTLZ1: The definitions of objective functions of UC1-C3-DTLZ1 are same as DTLZ1, the definitions of constraint functions of UC1-C3-DTLZ1 are given as follows:

$$c_1(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{0.6} - \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{0.6} \leq 0), \tag{7}$$

$$c_2(\mathbf{x}) = \mathbb{1}(\cos(a\pi * x_1) - b \leq 0), \tag{8}$$

  where a is used to control the number of segments of the feasible region on PF and $b \in [0, 1]$ is used to control the width of each segment of the feasible region. The larger b is, the wider the feasible region is. In this paper, we set $a = 6$, $b = 0.95$.

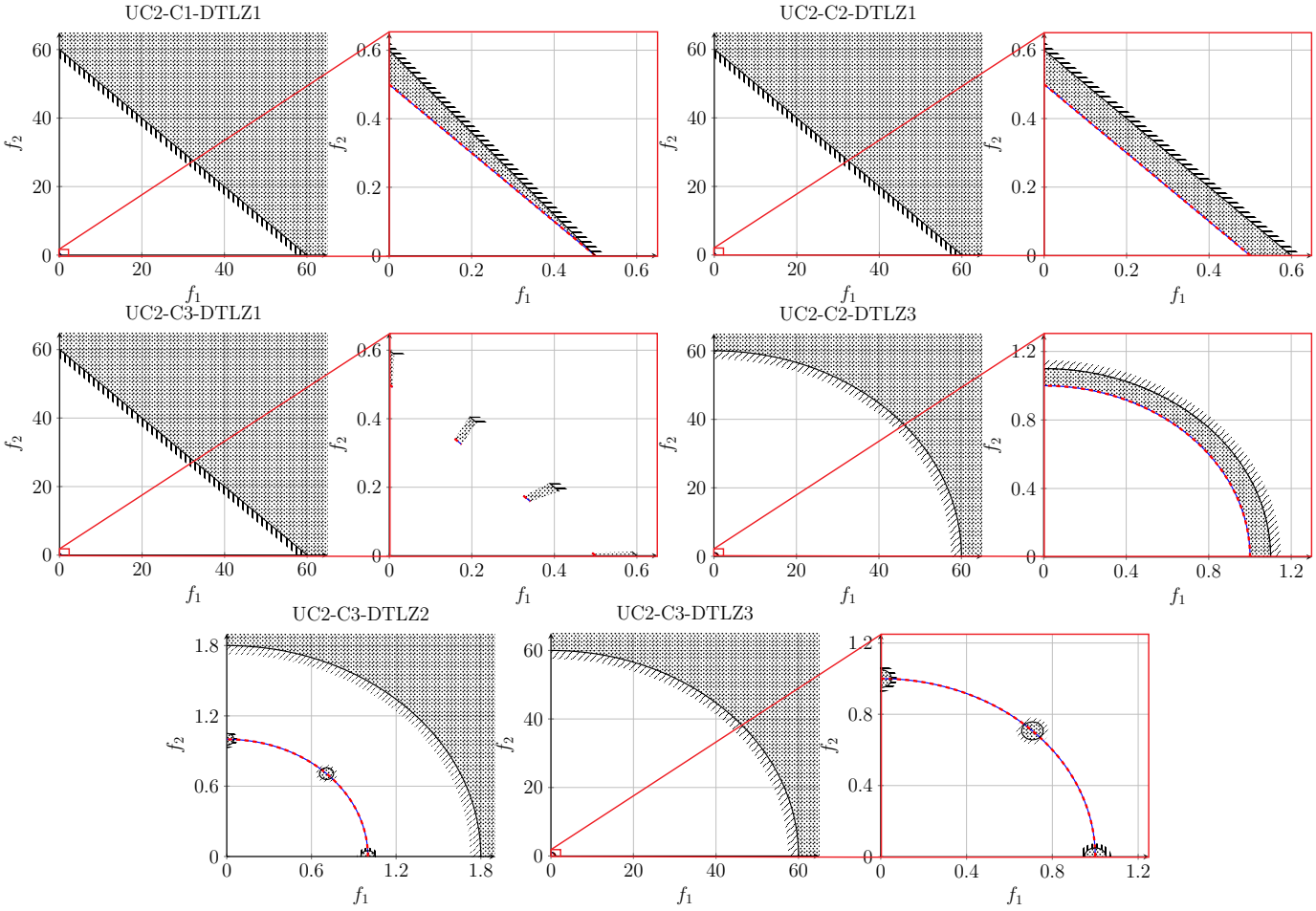

Fig. 2. The illustrations of the feasible regions of UC2-C1-DTLZ1 to UC2-C3-DTLZ3 benchmark problems.

- UC1-C3-DTLZ2 and UC1-C3-DTLZ3: The definitions of objective functions of UC1-C3-DTLZ2 and UC1-C3-DTLZ3 are the same as DTLZ2 and DTLZ3 respectively, the definitions of constraint functions of them are given as follows:

$$c(\mathbf{x}) = \mathbb{1}(\max\left\{\min_{i=1}^{m}\left[r^2 - (f_i(\mathbf{x})-1)^2 - \sum_{j=1,j\neq i}^{m} f_j^2\right], \left[r^2 - \sum_{i=1}^{m}\left(f_i(\mathbf{x}) - \frac{1}{\sqrt{m}}\right)^2\right]\right\} \leq 0), \tag{9}$$

  where r is designed to control the range of the feasible region. In this paper, we set $r = 0.05$ for $m = 2$ and set $r = 0.1$ for $m = \{3, 5, 10\}$.

2) Definitions of UC2 Benchmark Suit: The illustrations of UC2-C1-DTLZ1, UC2-C2-DTLZ1, UC2-C2-DTLZ3, UC2-C3-DTLZ1, UC2-C3-DTLZ2 and UC2-C3-DTLZ3 are given in Fig. 2, the definitions of them are given as follows:

- UC2-C1-DTLZ1, UC2-C2-DTLZ1 and UC2-C3-DTLZ1: The UC2-C1-DTLZ1, UC2-C2-DTLZ1, and UC2-C3-DTLZ1 are defined as using the constraint functions of UC1-C1-DTLZ1, UC1-C2-DTLZ1, and UC1-C3-DTLZ1 to multiply the following constraint function, respectively.

$$c(\mathbf{x}) = \mathbb{1}(\frac{f_m(\mathbf{x})}{60} + \sum_{i=1}^{m-1}\frac{f_i(\mathbf{x})}{60} - 1 \leq 0). \tag{10}$$

- UC2-C2-DTLZ3 and UC2-C3-DTLZ2 and UC2-C3-DTLZ3: The UC2-C2-DTLZ3 and UC2-C3-DTLZ2 and UC2-C3-DTLZ3 are defined as using the constraint functions of UC1-C2-DTLZ3, UC1-C3-DTLZ2 and UC1-C3-DTLZ3 to multiply

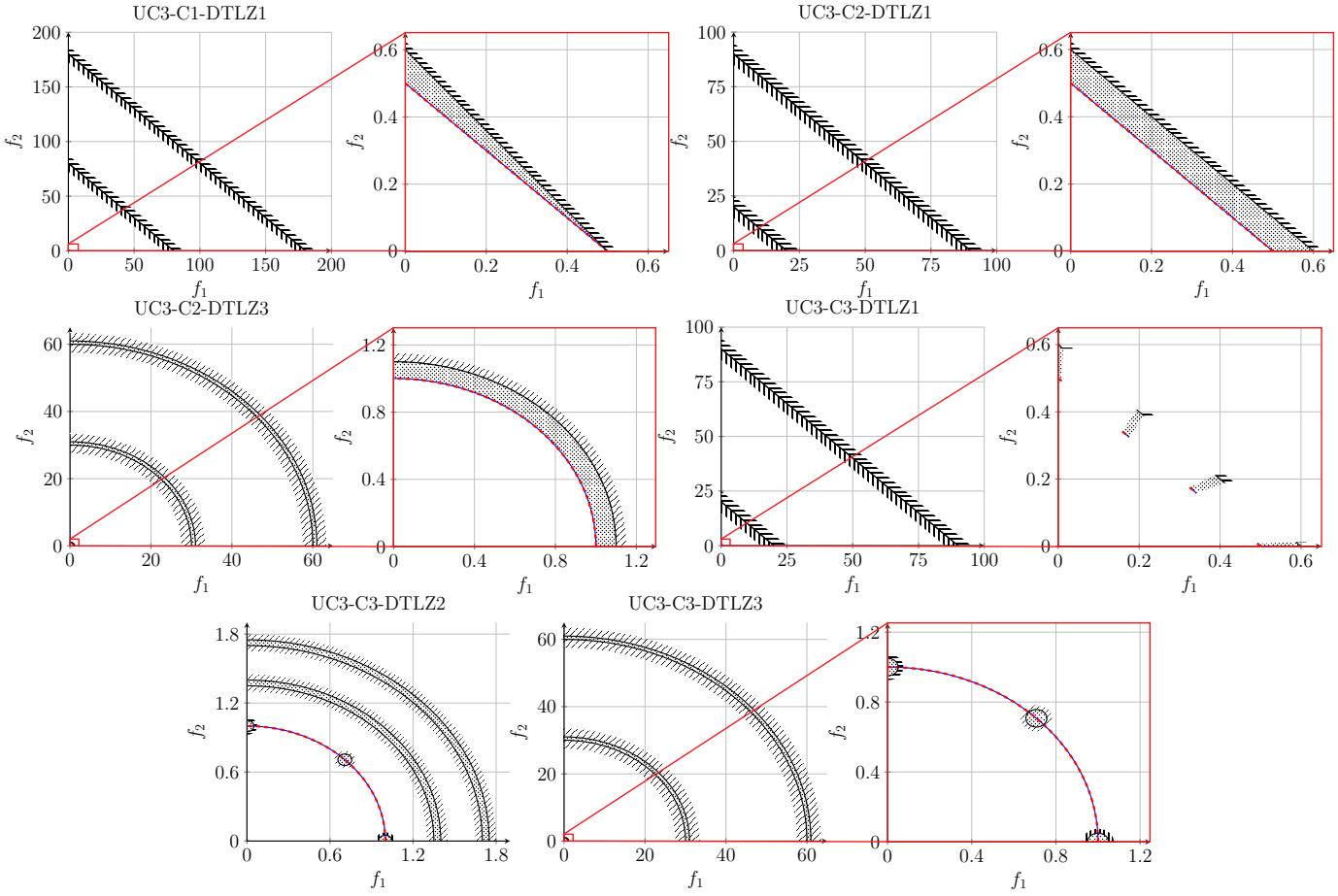

Fig. 3. The illustrations of the feasible regions of UC3-C1-DTLZ1 to UC3-C3-DTLZ3 benchmark problems.

the following constraint function, respectively.

$$c(\mathbf{x}) = \mathbb{1}((\sum_{i=1}^{m} f_i(\mathbf{x}))^2 - r^2 \leq 0). \tag{11}$$

In this paper, we set $r = 60$ for UC2-C2-DTLZ3 and UC2-C3-DTLZ3 with $m = 2$, set $r = 90$ for for UC2-C2-DTLZ3 and UC2-C3-DTLZ3 with $m \in \{3, 5, 10\}$, set $r = 1.8$ for UC2-C3-DTLZ2 with $m = 2$, set $r = 9$ for UC2-C3-DTLZ2 with $m \in \{3, 5, 10\}$.

3) Definitions of UC3 Benchmark Suit: The illustrations of UC3-C1-DTLZ1, UC3-C2-DTLZ1, UC3-C2-DTLZ3, UC3-C3-DTLZ1, UC3-C3-DTLZ2 and UC3-C3-DTLZ3 are given in Fig. 3, the definitions of them are given as follows:

- UC3-C1-DTLZ1, UC3-C2-DTLZ1 and UC3-C3-DTLZ1: The UC3-C1-DTLZ1, UC3-C2-DTLZ1, and UC3-C3-DTLZ1 are defined as using the constraint functions of UC1-C1-DTLZ1, UC1-C2-DTLZ1, and UC1-C3-DTLZ1 to multiply the following $c(\mathbf{x})$, respectively.

$$c(\mathbf{x}) = \mathbb{1}((c_1(\mathbf{x}) + c_2(\mathbf{x})) * (c_3(\mathbf{x}) + c_4(\mathbf{x})) \neq 0), \tag{12}$$

where $c_1(\mathbf{x})$, $c_2(\mathbf{x})$, $c_3(\mathbf{x})$,$c_4(\mathbf{x})$ are defined as follows:

$$c_1(\mathbf{x}) = \mathbb{1}(\frac{f_m(\mathbf{x})}{d_1} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{d_1} - 1 \leq 0), \tag{13}$$

$$c_2(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{d_2} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{d_2} \leq 0), \tag{14}$$

$$c_3(\mathbf{x}) = \mathbb{1}(\frac{f_m(\mathbf{x})}{d_3} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{d_3} - 1 \leq 0), \tag{15}$$

$$c_4(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{d_4} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{d_4} \leq 0), \tag{16}$$

where d_1,d_2,d_3, and d_4 are designed to control the position and width of feasible regions. In this paper, we set $d_1 = 80$,$d_2 = 80.25$,$d_3 = 180$ and $d_4 = 180.5$ for UC3-C1-DTLZ1, set $d_1 = 20$,$d_2 = 20.1$,$d_3 = 90$ and $d_4 = 90.1$ for UC3-C2-DTLZ1 and UC3-C3-DTLZ1.

- UC3-C2-DTLZ3, UC3-C3-DTLZ2 and UC3-C3-DTLZ3: The UC3-C2-DTLZ3, UC3-C3-DTLZ2 and UC3-C3-DTLZ3 are defined as using the constraint functions of UC1-C2-DTLZ3, UC1-C3-DTLZ2 and UC1-C3-DTLZ3 to multiply the following $c(\mathbf{x})$, respectively.

$$c(\mathbf{x}) = \mathbb{1}((c_1(\mathbf{x}) + c_2(\mathbf{x})) * (c_3(\mathbf{x}) + c_4(\mathbf{x})) \neq 0), \tag{17}$$

where $c_1(\mathbf{x})$, $c_2(\mathbf{x})$, $c_3(\mathbf{x})$,$c_4(\mathbf{x})$ are defined as follows:

$$c_1(\mathbf{x}) = \mathbb{1}((\sum_{i=1}^{m} f_i(\mathbf{x}))^2 - {r_1}^2 \leq 0), \tag{18}$$

$$c_2(\mathbf{x}) = \mathbb{1}({r_2}^2 - (\sum_{i=1}^{m} f_i(\mathbf{x}))^2 \leq 0), \tag{19}$$

$$c_3(\mathbf{x}) = \mathbb{1}((\sum_{i=1}^{m} f_i(\mathbf{x}))^2 - {r_3}^2 \leq 0), \tag{20}$$

$$c_4(\mathbf{x}) = \mathbb{1}({r_4}^2 - (\sum_{i=1}^{m} f_i(\mathbf{x}))^2 \leq 0). \tag{21}$$

In this paper, we set $r_1 = 30$, $r_2 = 31$, $r_3 = 60$, $r_4 = 90$ for UC3-C2-DTLZ3 and UC3-C3-DTLZ3 with $m = 2$, set $r_1 = 45$, $r_2 = 46$, $r_3 = 90$, $r_4 = 91$ for UC3-C2-DTLZ3 and UC3-C3-DTLZ3 with $m \in \{3, 5, 10\}$, set $r_1 = 1.35$, $r_2 = 1.4$, $r_3 = 1.7$, $r_4 = 1.75$ for UC3-C3-DTLZ2 with $m \in \{2, 3, 5, 10\}$.

4) Definitions of UC4 Benchmark Suit: The illustrations of UC4-C1-DTLZ1, UC4-C2-DTLZ1, UC4-C2-DTLZ3, UC4-C3-DTLZ1, UC4-C3-DTLZ2 and UC4-C3-DTLZ3 are given in Fig. 4, the definitions of them are given as follows:

- UC4-C1-DTLZ1: The UC4-C1-DTLZ1 is defined on the base of UC3-C1-DTLZ1, with modifications to equation (4) as follows:

$$c(\mathbf{x}) = \mathbb{1}(c_1(\mathbf{x}) + c_2(\mathbf{x}) \neq 0), \tag{22}$$

where $c_1(\mathbf{x})$ and $c_2(\mathbf{x})$ are defined as follows:

$$c_1(\mathbf{x}) = \mathbb{1}(\frac{f_m(\mathbf{x})}{10} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{10} - 1 \leq 0), \tag{23}$$

$$c_2(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{10} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{10.1} \leq 0). \tag{24}$$

- UC4-C2-DTLZ1: The UC4-C2-DTLZ1 is defined on the base of UC3-C2-DTLZ1, with modifications to equation (5) as follows:

$$c(\mathbf{x}) = \mathbb{1}(c_1(\mathbf{x}) + c_2(\mathbf{x}) \neq 0), \tag{25}$$

where $c_1(\mathbf{x})$ and $c_2(\mathbf{x})$ are defined as follows:

$$c_1(\mathbf{x}) = \mathbb{1}(\frac{f_m(\mathbf{x})}{10} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{10} - 1 \leq 0), \tag{26}$$

$$c_2(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{10.1} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{10.1} \leq 0). \tag{27}$$

- UC4-C2-DTLZ3: The UC4-C2-DTLZ3 is defined on the base of UC3-C2-DTLZ3, with modifications to equation (6) as follows:

$$c(\mathbf{x}) = \mathbb{1}(c_1(\mathbf{x}) + c_2(\mathbf{x}) \neq 0), \tag{28}$$

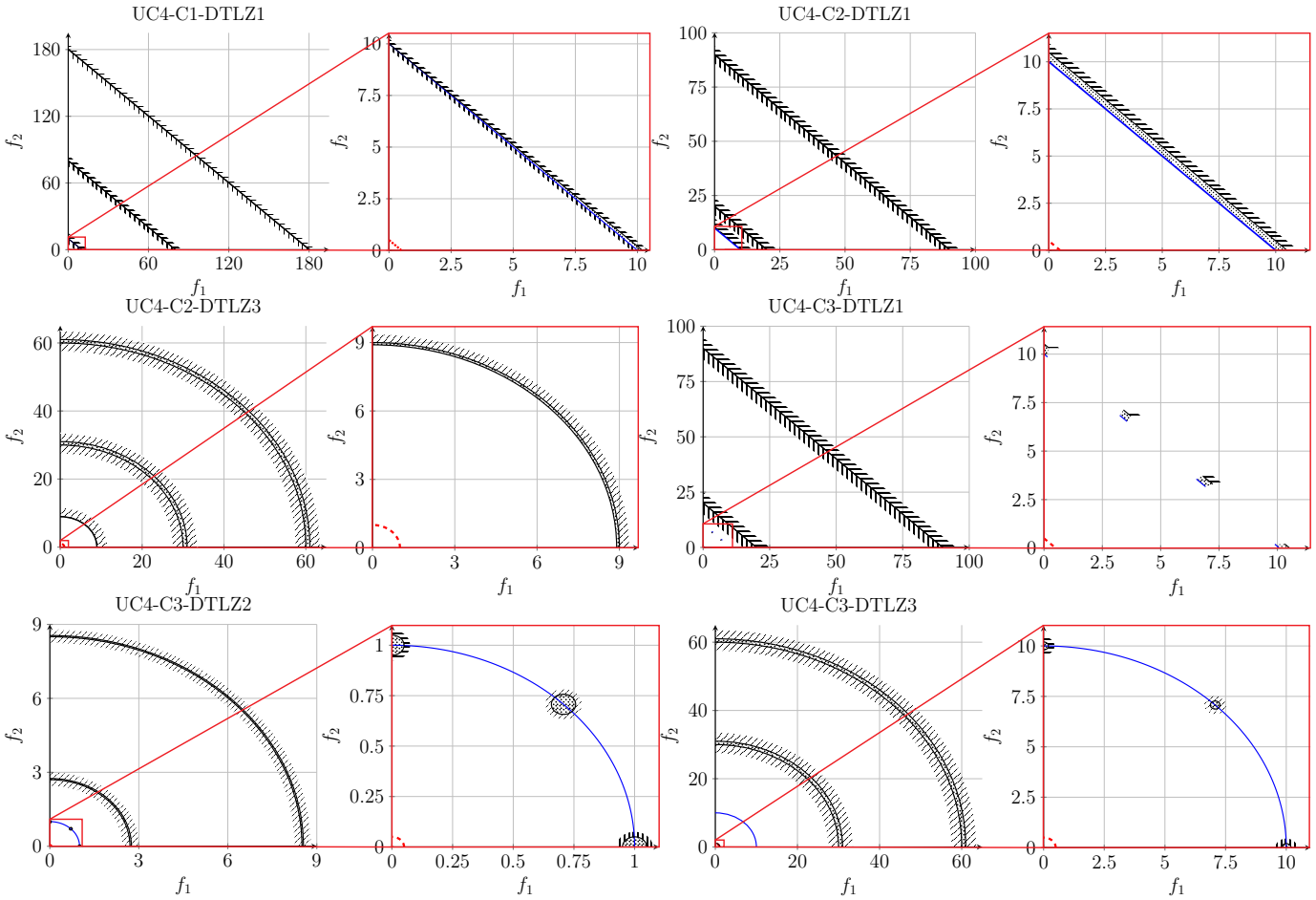

Fig. 4. The illustrations of the feasible regions of UC4-C1-DTLZ1 to UC4-C3-DTLZ3 benchmark problems.

where $c_1(\mathbf{x})$ and $c_2(\mathbf{x})$ are defined as follows:

$$c_1(\mathbf{x}) = \mathbb{1}(\sum_{i=1}^{m} f_i(\mathbf{x})^2 - {r_1}^2 \leq 0), \tag{29}$$

$$c_2(\mathbf{x}) = \mathbb{1}(\sum_{i=1}^{m} f_i({r_2}^2 - \mathbf{x})^2 \leq 0). \tag{30}$$

In this paper, we set $r_1 = 8.9$, $r_2 = 9$.

- UC4-C3-DTLZ1: The UC4-C3-DTLZ1 is defined on the base of UC3-C3-DTLZ1, with modifications to equation (7) as follows:

$$c(\mathbf{x}) = \mathbb{1}(c_1(\mathbf{x}) + c_2(\mathbf{x}) \neq 0), \tag{31}$$

where $c_1(\mathbf{x})$ and $c_2(\mathbf{x})$ are defined as follows:

$$c_1(\mathbf{x}) = \mathbb{1}(\frac{f_m(\mathbf{x})}{10} + \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{10} - 1 \leq 0), \tag{32}$$

$$c_2(\mathbf{x}) = \mathbb{1}(1 - \frac{f_m(\mathbf{x})}{10.5} - \sum_{i=1}^{m-1} \frac{f_i(\mathbf{x})}{10.5} \leq 0). \tag{33}$$

- UC4-C3-DTLZ2: The UC4-C3-DTLZ2 is defined on the base of UC3-C3-DTLZ2, with modifications to the objective

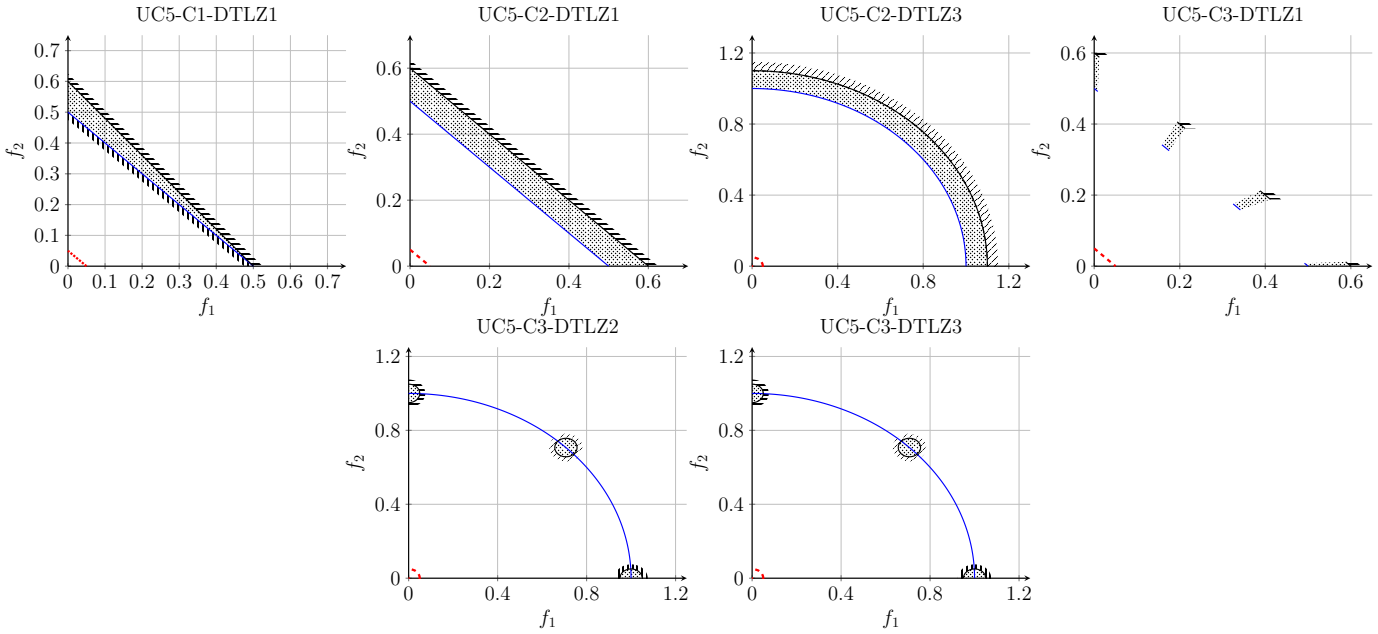

Fig. 5. The illustrations of the feasible regions of UC5-C1-DTLZ1 to UC5-C3-DTLZ3 benchmark problems.

functions of DTLZ2 as follows:

$$\left.\begin{array}{rl} \min f_1(\mathbf{x}) & = a\left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(x_1\pi/2\right)\cdots\cos\left(x_{m-2}\pi/2\right)\cos\left(x_{m-1}\pi/2\right) \\ \min f_2(\mathbf{x}) & = a\left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(x_1\pi/2\right)\cdots\cos\left(x_{m-2}\pi/2\right)\sin\left(x_{m-1}\pi/2\right) \\ \min f_3(\mathbf{x}) & = a\left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(x_1\pi/2\right)\cdots\sin\left(x_{m-2}\pi/2\right) \\ \vdots & \\ \min f_m(\mathbf{x}) & = a\left(1+g\left(\mathbf{x}_m\right)\right)\sin\left(x_1\pi/2\right) \end{array}\right\}, \tag{34}$$

where $g\left(\mathbf{x}_m\right)$ is defined as follows:

$$g\left(\mathbf{x}_m\right) = b\sum_{x_i\in\mathbf{x}_m}\left(x_i-0.5\right)^2. \tag{35}$$

In this paper, we set $r_1 = 2.7$, $r_2 = 2.75$, $r_3 = 8.5$, $r_4 = 8.55$, $a = 0.05$, $b = 10000$ for UC4-C3-DTLZ2 with $m \in \{2, 3, 5, 10\}$.

- UC4-C3-DTLZ3: The UC4-C3-DTLZ3 is defined on the base of UC3-C3-DTLZ3, with modifications to equation (9) as follows:

$$c(\mathbf{x}) = \mathbb{1}(\max\left\{\max_{i=1}^{m}\left[r^2-\left(f_i(\mathbf{x})-1\right)^2-\sum_{j=1,j\neq i}^{m}f_j^2\right],\left[r^2-\sum_{i=1}^{m}\left(f_i(\mathbf{x})-\frac{1}{\sqrt{m}}\right)^2\right]\right\}\leq 0) \tag{36}$$

In this paper, we set $r = 0.2$ for UC4-C3-DTLZ3 with $m = 2$, set $r = 0.5$ for UC4-C3-DTLZ3 with $m \in \{3, 5, 10\}$.

5) Definitions of UC5 Benchmark Suit: The illustrations of UC5-C1-DTLZ1, UC5-C2-DTLZ1, UC5-C2-DTLZ3, UC5-C3-DTLZ1, UC5-C3-DTLZ2 and UC5-C3-DTLZ3 are given in Fig. 5, the definitions of them are given as follows:

- UC5-C1-DTLZ1, UC5-C2-DTLZ1 and UC5-C3-DTLZ1: The UC5-C1-DTLZ1 is defined on the base of UC1-C1-DTLZ1, with modifications to the objective functions as follows:

$$\left.\begin{array}{rl} \min f_1(\mathrm{x}) & = 0.05x_1x_2\cdots x_{m-1}\left(1+g\left(\mathbf{x}_m\right)\right) \\ \min f_2(\mathrm{x}) & = 0.05x_1x_2\cdots\left(1-x_{m-1}\right)\left(1+g\left(\mathbf{x}_m\right)\right) \\ & \vdots \\ \min f_{m-1}(\mathbf{x}) & = 0.05x_1\left(1-x_2\right)\left(1+g\left(\mathbf{x}_m\right)\right) \\ \min f_m(\mathbf{x}) & = 0.05\left(1-x_1\right)\left(1+g\left(\mathbf{x}_m\right)\right) \end{array}\right\}, \tag{37}$$

where $g\left(\mathbf{x}_m\right)$ is defined as follows:

$$g\left(\mathbf{x}_m\right) = 1000\left[\left|\mathbf{x}_m\right|+\sum_{x_i\in\mathbf{x_2}}\left(x_i-0.5\right)^2-\cos\left(20\pi\left(x_i-0.5\right)\right)\right]. \tag{38}$$

The constraint functions of UC5-C2-DTLZ1 and UC5-C3-DTLZ1 are defined to be identical to those of UC1-C2-DTLZ1 and UC1-C3-DTLZ1, respectively. Moreover, the objective functions of UC5-C2-DTLZ1 and UC5-C3-DTLZ1 are defined to be identical to those of UC5-C1-DTLZ1.

- UC5-C2-DTLZ3: The UC5-C2-DTLZ3 is defined on the base of UC5-C2-DTLZ3, with modifications to the objective functions as follows:

$$\left.\begin{aligned} \min f_1(\mathbf{x}) &= 0.05\left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(x_1\pi/2\right)\cdots\cos\left(x_{m-2}\pi/2\right)\\ &\cos\left(x_{m-1}\pi/2\right)\\ \min f_2(\mathbf{x}) &= 0.05\left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(x_1\pi/2\right)\cdots\cos\left(x_{m-2}\pi/2\right)\\ &\sin\left(x_{m-1}\pi/2\right)\\ \min f_3(\mathbf{x}) &= 0.05\left(1+g\left(\mathbf{x}_m\right)\right)\cos\left(x_1\pi/2\right)\cdots\sin\left(x_{m-2}\pi/2\right),\\ &\vdots\\ \min f_m(\mathbf{x}) &= 0.05\left(1+g\left(\mathbf{x}_m\right)\right)\sin\left(x_1\pi/2\right) \end{aligned}\right\}, \tag{39}$$

where $g\left(\mathbf{x}_m\right)$ is defined to be identical to equation (38). The constraint and objective functions of UC5-C3-DTLZ3 are defined to be identical to those of UC1-C3-DTLZ3 and UC5-C2-DTLZ3, respectively.

- UC5-C3-DTLZ2: The constraint and objective functions of UC5-C3-DTLZ2 are defined to be identical to those of UC1-C3-DTLZ2 and UC4-C3-DTLZ2, respectively.
- As discussed in our recent empirical study [2], the unknown constraints of real-world problems often contain noise. Following this nature, we add some noise for the constraints of the proposed synthetic problems as follows:

$$c_{noise}(\mathbf{x}) = [c(\mathbf{x}), c(\mathbf{x}) * \mathbb{1}(p_1 < 0.5), \ldots, c(\mathbf{x}) * \mathbb{1}(p_k < 0.5)], \tag{40}$$

where $c(\mathbf{x})$ is the corresponding constraints of different problems that is defined in equation (4) to equation (33), and equation (36). $p_i \in (0,1), i = (1,\ldots,k)$, is a randomly generated number. k is a parameter used to control the level of noise, which is set to $k = 5$ in this paper.

B. Real-world Test Problems

This section briefly describes the problem formulation related to the design of water distribution systems (WDS) and fine-tuning of hyperparameters in reinforcement learning (RL), including the objective and constraint functions, used in our case study.

1) problem formulation of RL: we consider applying reinforcement learning (RL) functions as a controller to determine the optimal rocket trajectory for the lunar lander task from OpenAI's Gym library [3]. In this task, there are four discrete actions $\mathcal{A}$ available: do nothing, fire left orientation engine, fire main engine, and fire right orientation engine. The state space is represented as an 8-dimensional vector $\mathcal{S} = [s_1, \ldots, s_8]$. Within this vector, s_1 and s_2 represent the lateral and vertical coordinates, and s_3 and s_4 represent the linear velocities in the lateral and vertical direction, respectively. Moreover, s_5 represents the angle, s_6 represents the angular velocity, s_7 and s_8 are two binary values indicating whether right and left leg are in contact with the ground or not, respectively. The pseudo-code of the heuristic controller used in this paper is proved in Algorithm 1.

To achieve the peak performance, we need to consider the fine-tuning 12 hyperparameters of $\mathcal{H}$ in Algorithm 1. Our objective involves a trade-off between maximizing total rewards and minimizing the landing duration. The reward calculation methodology is as follows: 1) Reward for moving from the top of the screen to the landing pad and coming to rest is about 100 to 140 points. If the lander moves away from the landing pad, it loses the reward; 2) If the lander crashes, it receives an additional -100 points. If it comes to rest, it receives an additional $+100$ points; 3) Each leg with ground contact is $+10$ points. Firing the main engine is -0.3 points for each frame. Firing the side engine is -0.03 points for each frame. The maximum steps of RL is set to be 500. Furthermore, we employ wall clock duration as a metric to quantify the landing duration. The unknown constraints considered in this task involve maintaining the lander's awakeness and avoiding crashes, which can be assessed by observing the final state of the lander.

Algorithm 1: Heuristic Controller for RL

Input: $\mathcal{S}$, $\mathcal{H} = [h_1, \ldots, h_{12}]$
Output: $\mathcal{A}$

$\theta_t = s_1 * h_1 + s_3 * h_2$;
if $\theta_t > h_3$ **then**
  $\theta_t = h_3$;
if $\theta_t < -h_3$ **then**
  $\theta_t = -h_3$;
$\delta_t = h_4 * |s_1|$;
$\theta_d = (\theta_t - s_5) * h_5 - s_6 * h_6$;
$\delta_d = (\delta_t - s_2) * h_7 - s_4 * h_8$;
if $s_7 = 1$ *or* $s_8 = 1$ **then**
  $\theta_d = h_9$;
  $\delta_d = -s_4 * h_{10}$;
$\mathcal{A}$ = do nothing;
if $\delta_d > |\theta_d|$ *and* $\delta_d > h_{11}$ **then**
  $\mathcal{A}$ = fire main engine;
else if $\theta_d < -h_{12}$ **then**
  $\mathcal{A}$ = fire right orientation engine;
end
else if $\theta_d > h_{12}$ **then**
  $\mathcal{A}$ = fire left orientation engine;
end
return $\mathcal{A}$;

2) problem formulation of WDS: The planning and management of WDS usually involves addressing multiple conflicting objectives, such as operational cost, system resilience, and profit. In our experiments, we examine the Pescara network (PES) [4], a benchmark case in WDS optimization. The PES consists of 99 pipes, and the task involves optimizing their diameters to enhance overall system performance. Our objectives here are to minimize operational cost and maximize system resilience, while also considering two unknown constraints: preventing backflow and blockage [5]. The operational cost is defined as follows:

$$\underset{\mathbf{D_i}\in\Omega}{\text{minimize}} \quad C = \sum_{i=1}^{np} a \times \mathbf{D_i}^b \times L_i \ , \tag{41}$$

where $\mathbf{D_i}$ is the diameter of pipe i, C is the total cost (monetary units problem dependant), np is the number of pipes, a and b are constants depending on a specific problem, L_i is the length of pipe i.

The system resilience is defined as follows:

$$\begin{aligned} \underset{\mathbf{D_i}\in\Omega}{\text{maximize}} \quad & I = \frac{\sum_{j=1}^{nn} \Phi_j Q_j \left(H_j - H_j^{req}\right)}{\left(\sum_{k=1}^{nr} Q_k H_k + \sum_{i=1}^{npu} \frac{P_i}{\gamma}\right) - \sum_{j=1}^{nn} Q_j H_j^{req}} \\ & \Phi_j = \frac{\sum_{i=1}^{npj} \mathbf{D_i}}{npj \times \max\{\mathbf{D_i}\}} \end{aligned} \ , \tag{42}$$

where $\mathbf{D_i}$ is the diameter of pipe i connected to demand node j, I is the system resilience, nn is the number of demand nodes, nr is the number of reservoirs, npu is the number of pumps, npj is the number of pipes connected to node j, P_i is the power of pump i, γ is the specific weight of water, ϕ_j, Q_j, H_j and H_j^{req} are the demand, actual head and minimum head of node j respectively, Q_k and H_k are the discharge and actual head of reservoir k respectively.

In this paper, we apply the EPANET software to run the water system simulation, in which the variables required for the evaluation of network resilience, states of preventing backflow and blockage can be obtained [6].

APPENDIX B
EXPERIMENTAL SETTINGS

A. Peer Algorithms and Parameter Settings

For a proof-of-concept purpose, we use `NSGA-II`, `IBEA`, and `MOEA/D` as the backbone algorithms under our proposed `EADMM` framework. The corresponding `EADMM` instances are denoted as `EADMM/NSGA-II`, `EADMM/IBEA`, and `EADMM/MOEA/D`, respectively. Five high-performance EMO algorithms for CMOPs, including `C-TAEA` [7], `PPS` [8], `MOEA/D-DAE` [9], `ToP` [10], `CMOCSO` [11], are chosen as the peer algorithms. As discussed in the main paper, these peer algorithms require accessing to the CV information which is yet available in CMOP/UC. To address this issue, we follow the practice in [2] to replace the CV with a crispy value, i.e., the CV value of a feasible solution is 0; otherwise, it is 1 if the solution is infeasible.

The parameter settings are listed as follows.

- Number of function evaluations (FEs): The maximum number of FEs for different problems are listed in Table I and Table II. All synthetic test problems are scalable to any number of objectives while we consider $m \in \{2, 3, 5, 10\}$ in our experiments.
- Reproduction operators: The parameters associated with the simulated binary crossover and polynomial mutation are set as $p_c = 1.0$, $\eta_c = 20$, $p_m = \frac{1}{n}$, $\eta_m = 20$. As for those use differential evolution [12] for offspring reproduction, we set $CR = F = 0.5$.
- Algorithm specific parameters: The parameter settings of peer algorithms considered in our experiments are set identical to their original papers. Note that our proposed `EADMM` framework does not introduce any additional parameters, except the innate ones of the backbone algorithms. All parameter settings are detailed in Table III.
- Number of repeated runs: Each algorithm is independently run on each test problem for 31 times with different random seeds.

TABLE I
THE MAXIMUM NUMBER OF FES FOR DIFFERENT SYNTHETIC TEST PROBLEMS

Problem	m	n	N	FEs	m	n	N	FEs	m	n	N	FEs	m	n	N	FEs
UC1-C1-DTLZ1	2	6	100	40000	3	7	100	45000	5	9	150	180000	10	14	150	270000
UC1-C2-DTLZ1	2	6	100	40000	3	7	100	45000	5	9	150	180000	10	14	150	270000
UC1-C2-DTLZ3	2	11	100	50000	3	12	100	60000	5	14	150	200000	10	19	150	300000
UC1-C3-DTLZ1	2	6	100	40000	3	7	100	50000	5	9	150	200000	10	14	150	300000
UC1-C3-DTLZ2	2	11	100	20000	3	12	100	25000	5	14	150	150000	10	19	150	225000
UC1-C3-DTLZ3	2	11	100	50000	3	12	100	60000	5	14	150	200000	10	19	150	300000
UC2-C1-DTLZ1	2	6	100	45000	3	7	100	50000	5	9	150	150000	10	14	150	225000
UC2-C2-DTLZ1	2	6	100	40000	3	7	100	50000	5	9	150	150000	10	14	150	225000
UC2-C2-DTLZ3	2	11	100	60000	3	12	100	80000	5	14	150	150000	10	19	150	225000
UC2-C3-DTLZ1	2	6	100	40000	3	7	100	50000	5	9	150	150000	10	14	150	225000
UC2-C3-DTLZ2	2	11	100	20000	3	12	100	25000	5	14	150	150000	10	19	150	225000
UC2-C3-DTLZ3	2	11	100	60000	3	12	100	80000	5	14	150	180000	10	19	150	270000
UC3-C1-DTLZ1	2	6	100	40000	3	7	100	50000	5	9	150	150000	10	14	150	225000
UC3-C2-DTLZ1	2	6	100	40000	3	7	100	50000	5	9	150	150000	10	14	150	225000
UC3-C2-DTLZ3	2	11	100	60000	3	12	100	80000	5	14	150	240000	10	19	150	360000
UC3-C3-DTLZ1	2	6	100	40000	3	7	100	45000	5	9	150	150000	10	14	150	225000
UC3-C3-DTLZ2	2	11	100	25000	3	12	100	30000	5	14	150	150000	10	19	150	225000
UC3-C3-DTLZ3	2	11	100	60000	3	12	100	80000	5	14	150	180000	10	19	150	270000
UC4-C1-DTLZ1	2	6	100	70000	3	7	100	80000	5	9	150	180000	10	14	150	270000
UC4-C2-DTLZ1	2	6	100	40000	3	7	100	55000	5	9	150	180000	10	14	150	270000
UC4-C2-DTLZ3	2	11	100	80000	3	12	100	100000	5	14	150	200000	10	19	150	300000
UC4-C3-DTLZ1	2	6	100	60000	3	7	100	80000	5	9	150	180000	10	14	150	270000
UC4-C3-DTLZ2	2	11	100	60000	3	12	100	80000	5	14	150	180000	10	19	150	270000
UC4-C3-DTLZ3	2	11	100	100000	3	12	100	100000	5	14	150	400000	10	19	150	600000
UC5-C1-DTLZ1	2	6	100	80000	3	7	100	100000	5	9	150	200000	10	14	150	300000
UC5-C2-DTLZ1	2	6	100	60000	3	7	100	80000	5	9	150	180000	10	14	150	270000
UC5-C2-DTLZ3	2	11	100	80000	3	12	100	100000	5	14	150	240000	10	19	150	360000
UC5-C3-DTLZ1	2	6	100	80000	3	7	100	100000	5	9	150	200000	10	14	150	300000
UC5-C3-DTLZ2	2	11	100	60000	3	12	100	80000	5	14	150	180000	10	19	150	270000
UC5-C3-DTLZ3	2	11	100	80000	3	12	100	100000	5	14	150	400000	10	19	150	600000

m denotes the number of objective functions, n denotes the dimensions of decision variables, N denotes the size of evolutionary population.

TABLE II
THE MAXIMUM NUMBER OF FES FOR DIFFERENT REAL-WORLD PROBLEMS

Problem	m	n	N	FEs
RL	2	12	50	2500
WDS	2	99	50	1500

TABLE III
THE PARAMETER SETTING FOR DIFFERENT ALGORITHMS

NSGA-II	The number of solutions for tournament selection, $k = 2$.
MOEA/D	The number of the weight vectors in the neighborhood of each weight vector is set as $T = N/10$.
IBEA	The scaling factor for the indicator is set as $\kappa = 0.05$.
C-TAEA	The number of the weight vectors in the neighborhood of each weight vector is set as $T = N/10$.
MOEA/D-DAE	The number of the weight vectors in the neighborhood of each weight vector, the probability of selecting individuals in the neighborhood, and the parameter for controlling ε are set as $T = N/10$, $p = 0.9$ and $\alpha = 0.95$ respectively.
PPS	The parameters for controlling ε are set to $T_c = 0.9 * (FEs/N)$, $\tau = 0.05$, $\alpha = 0.95$.
ToP	The probability of generating offspring by different operators is set as $p = 0.5$.
CMOCSO	The parameters for controlling ε are set to $T_c = 0.9 * (FEs/N)$, $\tau = 0.05$, $\alpha = 0.95$.

B. Performance Metrics and Statistical Tests

We employ inverted generational distance (IGD) [13], IGD$^+$ [14], and hypervolume (HV) [15] in performance assessment. The reference point used in the HV evaluation is constantly set as $(\underbrace{1.1, \ldots, 1.1}_{m})^\top$. Note that all these three performance metrics can assess both convergence and diversity. The smaller the IGD and IGD$^+$, or the larger the HV, the better result is achieved by the corresponding algorithm.

In view of the stochastic nature of EAs, we use the following three statistical tests to conduct a statistical interpretation of the significance of the comparison results.

- Wilcoxon signed-rank test [16]: This is a non-parametric statistical test that makes no assumption about the underlying distribution of the data. It has been recommended in many empirical studies in the EA community [17]. The significance level is set to $p = 0.05$ in our experiments.
- A_{12} effect size [18]: To ensure the resulted differences are not generated from a trivial effect, we apply A_{12} as the effect size measure to evaluate the probability that one algorithm is better than another. Specifically, given a pair of peer algorithms, $A_{12} = 0.5$ means they are *equal*. $A_{12} < 0.5$ denotes that one is worse for more than 50% of the times. $0.36 \leq A_{12} < 0.44$ indicates a *small* effect size while $0.29 \leq A_{12} < 0.36$ and $A_{12} < 0.29$ mean a *medium* and a *large* effect size, respectively.
- Scott-Knott test: Instead of merely comparing the raw metric values, we apply the Scott-Knott test to rank the performance of different peer algorithms over 31 runs on each test problem. In a nutshell, the Scott-Knott test uses a statistical test and effect size to divide the performance of peer algorithms into several clusters. The performance of peer algorithms within the same cluster is statistically equivalent. The clustering process terminates until no split can be made. Finally, each cluster can be assigned a rank according to the mean metric values achieved by the peer algorithms within the cluster. The smaller the rank is, the better performance of the algorithm achieves.

APPENDIX C
EXPERIMENTAL RESULTS

A. Results of Performance Metrics

In Table IV to Table XVI, we provide the comparison results of the IGD, IGD$^+$, and HV values obtained by three proposed algorithm instances and the other five peer algorithms on synthetic test problems. In Table XVII to Table XXVIII, we provide the comparison results of the IGD, IGD$^+$, and HV values of ablation study on synthetic test problems.

B. Results of the Final Solutions

In Fig. 6 to Fig. 17, we provide the plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on the synthetic test problems with the median IGD values and the real-world test problems with the median HV values.

TABLE IV
THE COMPARISON RESULTS OF IGD METRIC ON TWO OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/MOEA/D	EADMM/NSGA-II
UC1-C1-DTLZ1	2	2.1021e-3 (3.18e-4) +	2.2155e-3 (1.95e-4) +	4.1669e+1 (1.44e+2) -	NaN (NaN) -	1.8742e-3 (5.09e-5) +	6.4518e+1 (1.70e+2) -	2.2211e-3 (6.23e-4) +	2.3747e-3 (2.32e-4)
UC1-C2-DTLZ1	2	1.9486e-3 (1.52e-4) +	2.2349e-3 (2.40e-4) +	1.5721e-2 (5.45e-2) -	1.2511e-1 (0.00e+0) =	1.8919e-3 (1.36e-4) +	3.2265e+1 (1.25e+2) =	1.9576e-3 (2.46e-4) +	2.5423e-3 (6.08e-4)
UC1-C2-DTLZ3	2	8.4428e-2 (1.85e-1) -	7.8671e-3 (2.81e-3) =	8.5993e-3 (1.15e-3) =	NaN (NaN) -	2.3039e-2 (3.57e-2) =	4.0326e+2 (2.01e+2) -	1.0357e-1 (2.01e-1) -	7.8267e-3 (6.36e-3)
UC1-C3-DTLZ1	2	4.8165e-2 (3.34e-4) -	5.0796e-2 (9.97e-3) -	7.4945e-2 (7.92e-2) =	NaN (NaN) -	4.8035e-2 (1.99e-4) -	4.8506e+1 (1.50e+2) -	4.8490e-2 (1.04e-3) -	4.7905e-2 (2.10e-4)
UC1-C3-DTLZ2	2	1.4218e-1 (2.44e-4) -	1.4206e-1 (2.11e-4) -	1.4191e-1 (9.87e-5) =	2.6103e-1 (1.45e-1) -	1.4298e-1 (7.92e-4) -	1.6759e-1 (7.56e-6) -	1.4220e-1 (8.80e-5) -	1.4193e-1 (1.54e-4)
UC1-C3-DTLZ3	2	2.5479e-1 (1.78e-1) -	1.4262e-1 (0.00e+0) =	2.6389e-1 (0.00e+0) =	NaN (NaN) -	1.5616e-1 (9.49e-3) +	4.8388e+2 (8.97e+1) -	2.6679e-1 (2.36e-1) -	1.7150e-1 (1.18e-1)
UC2-C1-DTLZ1	2	1.4035e+0 (7.55e+0) -	2.1537e-3 (8.28e-5) +	1.6292e+1 (2.08e+1) -	3.0622e-3 (1.98e-3) -	1.8975e-3 (6.07e-5) +	7.4027e-2 (1.27e-2) -	2.0569e-3 (5.40e-4) +	2.3822e-3 (3.81e-4)
UC2-C2-DTLZ1	2	2.7279e+0 (1.05e+1) =	2.2190e-3 (2.09e-4) +	1.6292e+1 (2.08e+1) -	6.2307e-3 (1.51e-2) -	3.4228e-3 (7.85e-3) -	1.4327e+0 (7.55e+0) -	2.6135e-3 (1.32e-3) =	2.4136e-3 (2.26e-4)
UC2-C2-DTLZ3	2	3.6259e+1 (2.91e+1) -	5.1427e-3 (2.83e-4) +	4.9488e+1 (2.21e+1) -	1.4556e-2 (4.24e-2) =	2.6653e+1 (2.98e+1) -	2.6758e+1 (2.98e+1) -	9.5944e+0 (2.20e+1) -	7.6188e+0 (2.01e+1)
UC2-C3-DTLZ1	2	4.1338e+0 (1.26e+1) -	4.8117e-2 (3.14e-4) -	2.4460e+1 (2.11e+1) -	6.5208e-2 (5.96e-2) -	5.0003e-2 (9.58e-3) -	1.1615e-1 (3.46e-2) -	4.9642e-2 (3.29e-3) -	4.8044e-2 (4.74e-4)
UC2-C3-DTLZ2	2	1.5319e-1 (7.55e-3) -	1.4203e-1 (2.85e-4) =	1.4194e-1 (1.30e-4) =	1.5197e-1 (4.44e-3) -	1.4291e-1 (6.17e-4) -	1.6759e-1 (5.31e-6) -	1.4233e-1 (1.17e-4) -	1.4195e-1 (1.88e-4)
UC2-C3-DTLZ3	2	3.4388e+1 (2.95e+1) -	1.4231e-1 (4.53e-4) +	5.9004e+1 (1.79e-3) -	1.5685e-1 (3.26e-2) +	2.1035e+1 (2.86e+1) -	4.2010e+1 (2.70e+1) -	3.0572e+1 (2.99e+1) -	9.6381e+0 (2.20e+1)
UC3-C1-DTLZ1	2	2.8525e-2 (2.73e-2) -	1.0977e+1 (2.28e+1) =	3.8555e+1 (3.17e+1) -	2.5827e-3 (0.00e+0) =	2.0840e-3 (8.36e-4) +	3.6566e+0 (1.40e+1) -	2.3899e-3 (9.38e-4) +	2.4168e-3 (3.77e-4)
UC3-C2-DTLZ1	2	2.6315e-3 (1.56e-3) -	1.3387e+0 (4.15e+0) =	1.2420e+1 (1.84e+1) -	1.4752e+1 (1.28e+0) -	1.9682e-3 (2.48e-4) +	9.0248e-1 (3.44e+0) -	2.1112e-3 (4.82e-4) +	2.3687e-3 (2.08e-4)
UC3-C2-DTLZ3	2	1.0393e+1 (1.40e+1) -	2.3405e+1 (1.16e+1) -	2.6196e+1 (8.71e+0) -	8.4428e+0 (1.44e+1) =	6.5658e+0 (1.23e+1) =	1.9765e+1 (1.36e+1) -	8.5092e+0 (1.33e+1) -	3.7753e+0 (9.87e+0)
UC3-C3-DTLZ1	2	6.3178e-2 (2.33e-2) -	3.1578e+0 (5.85e+0) -	1.8356e+1 (2.33e+1) -	1.5632e+1 (2.39e+0) -	4.8119e-2 (2.97e-4) -	5.5033e-1 (2.46e+0) -	5.0747e-2 (8.77e-3) -	4.8012e-2 (3.17e-4)
UC3-C3-DTLZ2	2	1.4597e-1 (5.27e-3) -	1.4190e-1 (1.49e-4) =	1.4186e-1 (9.49e-5) =	1.5061e-1 (3.86e-3) -	1.4253e-1 (5.01e-4) -	1.6759e-1 (5.08e-6) -	1.4217e-1 (9.33e-5) -	1.4184e-1 (1.06e-4)
UC3-C3-DTLZ3	2	1.0464e+1 (1.40e+1) -	2.5288e+1 (9.82e+0) -	2.4377e+1 (1.07e+1) -	1.4915e-1 (1.89e-3) +	5.7343e+0 (1.16e+1) -	1.5143e+1 (1.46e+1) -	1.3249e+1 (1.45e+1) -	1.0738e+0 (5.18e+0)
UC4-C1-DTLZ1	2	1.7572e-1 (2.86e-1) -	1.3218e-1 (1.47e-1) -	2.1064e+1 (2.34e+1) -	3.8051e+0 (1.57e+0) -	2.0585e-1 (3.09e-1) =	5.6672e-2 (1.18e-2) +	5.1879e-2 (4.19e-2) +	9.1766e-2 (2.16e-1)
UC4-C2-DTLZ1	2	6.8796e-2 (5.12e-2) =	1.5689e-1 (7.97e-2) -	2.7334e+0 (3.19e+0) -	6.5469e+0 (4.27e+0) -	4.7298e-2 (2.09e-2) -	5.3722e-2 (6.50e-3) -	4.8660e-2 (1.43e-2) =	4.4786e-2 (1.50e-3)
UC4-C2-DTLZ3	2	9.5586e-2 (2.55e-2) -	8.3579e-2 (3.00e-2) -	3.4055e+0 (5.03e+0) -	6.5885e+0 (1.24e+0) -	4.3119e-2 (3.99e-3) +	2.7789e-1 (5.31e-2) -	4.8447e-2 (3.31e-3) +	5.1111e-2 (4.52e-3)
UC4-C3-DTLZ1	2	1.1171e+0 (1.33e-1) -	1.3750e+0 (5.07e-1) -	9.9985e+0 (1.84e+1) -	7.6424e+0 (3.42e+0) -	1.0366e+0 (3.68e-2) -	2.8981e+0 (6.96e-1) -	1.1328e+0 (1.92e-1) -	9.8671e-1 (1.40e-1)
UC4-C3-DTLZ2	2	1.6706e-1 (8.33e-3) -	1.7106e-1 (1.00e-1) -	1.4255e-1 (2.45e-3) =	6.0357e-1 (2.25e-1) -	1.5107e-1 (7.07e-3) -	3.0749e-1 (5.77e-2) -	1.4346e-1 (2.56e-3) +	1.4387e-1 (3.81e-3)
UC4-C3-DTLZ3	2	4.0237e+0 (2.26e+0) -	1.8469e+0 (3.85e-1) -	1.6088e+1 (6.28e+0) -	7.3674e+0 (5.64e-2) -	1.8648e+0 (3.93e-1) -	3.3617e+0 (2.92e-1) -	2.2189e+0 (6.59e-1) -	1.8141e+0 (3.93e-1)
UC5-C1-DTLZ1	2	1.8971e-3 (1.03e-4) +	3.2638e-3 (9.51e-4) -	3.5709e+0 (4.85e+0) -	NaN (NaN) -	1.9485e-3 (2.21e-4) +	2.0963e-3 (3.27e-5) +	1.8082e-3 (1.97e-5) +	2.2467e-3 (1.12e-4)
UC5-C2-DTLZ1	2	1.9004e-3 (1.06e-4) +	1.1669e-2 (7.16e-3) -	2.6701e+0 (4.50e+0) -	NaN (NaN) -	2.6868e-3 (2.33e-3) -	2.1743e-3 (2.61e-4) +	1.9869e-3 (2.18e-4) +	2.3500e-3 (4.62e-4)
UC5-C2-DTLZ3	2	5.3496e-3 (1.32e-3) =	3.4823e-1 (1.79e+0) -	7.0036e+0 (4.66e+0) -	NaN (NaN) -	8.4001e-3 (8.17e-3) =	3.2261e-2 (4.04e-2) -	5.9087e-3 (1.64e-3) -	4.9590e-3 (1.66e-4)
UC5-C3-DTLZ1	2	5.0784e-2 (7.25e-3) -	6.0921e-2 (1.47e-2) -	4.2553e+0 (4.96e+0) -	NaN (NaN) -	5.7404e-2 (5.09e-3) -	1.4739e-1 (3.33e-2) -	5.2909e-2 (8.33e-3) -	4.9245e-2 (7.03e-3)
UC5-C3-DTLZ2	2	1.4343e-1 (2.99e-3) -	1.8139e-1 (1.04e-1) -	1.4201e-1 (2.73e-4) +	9.3832e+0 (2.35e+0) -	1.4889e-1 (5.61e-3) -	2.9521e-1 (2.42e-2) -	1.4268e-1 (8.22e-4) +	1.4287e-1 (3.32e-3)
UC5-C3-DTLZ3	2	2.0915e-1 (1.45e-1) =	2.4244e+0 (4.16e+0) -	9.0457e+0 (2.91e+0) -	NaN (NaN) -	2.8479e-1 (1.78e-1) -	3.2351e-1 (8.02e-2) -	1.8492e-1 (5.73e-2) =	2.1007e-1 (1.19e-1)
+/-/=		4/22/4	6/18/6	1/22/7	2/23/5	8/18/4	3/26/1	11/16/3	

-, + and = denote the performance of the selected algorithm is significantly better and worse than the other compared algorithms according to the Wilcoxon's rank sum test at a 0.05 significance level, respectively. Whereas = denotes the result does not have any statistical significance.

TABLE V
THE COMPARISON RESULTS OF IGD^+ METRIC ON TWO OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/MOEA/D	EADMM/NSGA-II
UC1-C1-DTLZ1	2	1.7434e-3 (4.12e-4) +	1.7898e-3 (2.60e-4) +	1.8647e-3 (1.61e-4) =	NaN (NaN) -	1.4022e-3 (1.17e-4) +	1.6426e-3 (2.09e-4) +	1.9258e-3 (7.22e-4) +	2.0026e-3 (3.37e-4)
UC1-C2-DTLZ1	2	1.5645e-3 (2.28e-4) +	1.7934e-3 (3.40e-4) +	1.1970e-2 (4.19e-2) =	1.0826e-1 (0.00e+0) =	1.4301e-3 (2.21e-4) +	5.9710e-3 (1.47e-2) =	1.6464e-3 (3.64e-4) +	2.1689e-3 (7.44e-4)
UC1-C2-DTLZ3	2	5.8509e-2 (1.24e-1) -	5.2403e-3 (2.47e-3) =	3.6742e-3 (7.51e-4) =	NaN (NaN) -	1.4767e-2 (1.90e-2) -	6.5891e-2 (5.24e-2) -	7.6250e-2 (1.37e-1) -	5.1189e-3 (3.05e-3)
UC1-C3-DTLZ1	2	3.4536e-2 (5.82e-4) -	3.6768e-2 (8.45e-3) -	5.3364e-2 (5.62e-2) =	NaN (NaN) -	3.4231e-2 (3.38e-4) =	9.4937e-2 (6.39e-2) -	3.4949e-2 (1.51e-3) -	3.4129e-2 (3.68e-4)
UC1-C3-DTLZ2	2	4.5255e-2 (4.63e-5) -	4.5191e-2 (2.97e-5) -	4.5215e-2 (2.11e-5) -	1.4919e-1 (1.03e-1) -	4.5406e-2 (7.87e-5) -	4.5989e-2 (2.87e-6) -	4.5371e-2 (3.18e-5) -	4.5163e-2 (1.69e-5)
UC1-C3-DTLZ3	2	1.0578e-1 (1.08e-1) -	4.6190e-2 (0.00e+0) =	1.9383e-1 (0.00e+0) =	NaN (NaN) -	5.0759e-2 (3.39e-3) +	9.2314e-2 (0.00e+0) =	1.2068e-1 (1.42e-1) -	6.1757e-2 (7.00e-2)
UC2-C1-DTLZ1	2	1.3906e+0 (7.55e+0) -	1.6373e-3 (1.18e-4) +	1.6292e+1 (2.08e+1) -	2.6832e-3 (1.73e-3) -	1.4348e-3 (1.53e-4) +	5.2459e-2 (9.02e-3) -	1.7266e-3 (6.24e-4) +	1.9479e-3 (5.02e-4)
UC2-C2-DTLZ1	2	2.7267e+0 (1.05e+1) =	1.7673e-3 (3.25e-4) +	1.6291e+1 (2.08e+1) =	5.7365e-3 (1.38e-2) -	2.6918e-3 (6.21e-3) -	1.4113e+0 (7.56e+0) -	2.3651e-3 (1.35e-3) =	2.0348e-3 (3.52e-4)
UC2-C2-DTLZ3	2	3.6239e+1 (2.91e+1) -	2.4144e-3 (2.72e-4) +	4.9488e+1 (2.21e+1) -	1.2148e-2 (4.21e-2) =	2.6651e+1 (2.98e+1) -	2.6691e+1 (2.98e+1) -	9.5755e+0 (2.20e+1) -	7.6169e+0 (2.01e+1)
UC2-C3-DTLZ1	2	4.1191e+0 (1.26e+1) -	3.4339e-2 (3.94e-4) =	2.4452e+1 (2.11e+1) -	4.8000e-2 (4.39e-2) -	3.6108e-2 (8.09e-3) =	8.2516e-2 (2.49e-2) -	3.6524e-2 (4.24e-3) -	3.4441e-2 (9.08e-4)
UC2-C3-DTLZ2	2	4.7000e-2 (7.57e-4) -	4.5199e-2 (3.50e-5) -	4.5221e-2 (2.97e-5) -	4.7798e-2 (7.03e-4) -	4.5407e-2 (5.86e-5) -	4.5989e-2 (2.04e-6) -	4.5500e-2 (7.07e-5) -	4.5164e-2 (2.05e-5)
UC2-C3-DTLZ3	2	3.4330e+1 (2.95e+1) -	4.5477e-2 (2.18e-4) +	5.9004e+1 (1.79e-3) -	5.4598e-2 (3.64e-2) +	2.0969e+1 (2.87e+1) -	4.1932e+1 (2.71e+1) -	3.0516e+1 (2.99e+1) -	9.5563e+0 (2.20e+1)
UC3-C1-DTLZ1	2	2.0673e-2 (1.91e-2) -	1.0976e+1 (2.28e+1) =	3.8555e+1 (3.17e+1) -	2.2643e-3 (0.00e+0) =	1.6534e-3 (9.09e-4) +	3.6486e+0 (1.40e+1) -	2.1345e-3 (9.53e-4) =	2.0237e-3 (4.78e-4)
UC3-C2-DTLZ1	2	2.2538e-3 (1.43e-3) =	1.3382e+0 (4.15e+0) =	1.2419e+1 (1.84e+1) -	1.4752e+1 (1.28e+0) -	1.5479e-3 (3.87e-4) +	8.9921e-1 (3.44e+0) -	1.8310e-3 (6.18e-4) +	1.9532e-3 (3.48e-4)
UC3-C2-DTLZ3	2	1.0372e+1 (1.41e+1) -	2.3403e+1 (1.16e+1) -	2.6195e+1 (8.72e+0) -	8.4410e+0 (1.44e+1) =	6.5633e+0 (1.23e+1) =	1.9698e+1 (1.37e+1) -	8.4898e+0 (1.33e+1) -	3.7637e+0 (9.88e+0)
UC3-C3-DTLZ1	2	4.6172e-2 (1.67e-2) -	3.1471e+0 (5.86e+0) =	1.8347e+1 (2.34e+1) -	1.5632e+1 (2.39e+0) -	3.4414e-2 (5.69e-4) =	5.1977e-1 (2.46e+0) -	3.6820e-2 (6.65e-3) -	3.4369e-2 (5.54e-4)
UC3-C3-DTLZ2	2	4.5925e-2 (7.32e-4) -	4.5161e-2 (1.47e-5) -	4.5192e-2 (1.64e-5) -	4.7768e-2 (7.97e-4) -	4.5312e-2 (4.97e-5) -	4.5987e-2 (1.89e-6) -	4.5406e-2 (4.54e-5) -	4.5143e-2 (9.03e-6)
UC3-C3-DTLZ3	2	1.0378e+1 (1.40e+1) -	2.5272e+1 (9.87e+0) -	2.4356e+1 (1.08e+1) -	4.7442e-2 (2.81e-4) =	5.6526e+0 (1.16e+1) -	1.5023e+1 (1.47e+1) -	1.3173e+1 (1.46e+1) -	9.8044e-1 (5.20e+0)
UC4-C1-DTLZ1	2	1.2619e-1 (2.04e-1) -	9.8008e-2 (1.06e-1) -	2.0559e+1 (2.38e+1) -	2.7002e+0 (1.10e+0) -	1.5056e-1 (2.22e-1) =	4.0190e-2 (8.38e-3) +	3.8477e-2 (3.04e-2) +	6.6278e-2 (1.56e-1)
UC4-C2-DTLZ1	2	5.3698e-2 (3.87e-2) -	1.1835e-1 (5.71e-2) -	2.4783e+0 (3.07e+0) -	5.8568e+0 (4.45e+0) -	4.0075e-2 (1.75e-2) =	3.8808e-2 (4.88e-3) -	3.9759e-2 (1.22e-2) -	3.3157e-2 (1.37e-3)
UC4-C2-DTLZ3	2	5.0744e-2 (1.44e-2) -	4.8625e-2 (1.73e-2) -	2.6614e+0 (4.89e+0) -	3.7302e+0 (1.84e-1) -	2.1339e-2 (5.03e-3) +	5.5149e-2 (9.59e-3) -	2.6455e-2 (2.81e-3) -	2.2145e-2 (2.10e-3)
UC4-C3-DTLZ1	2	8.1175e-1 (1.00e-1) -	1.0044e+0 (3.80e-1) -	9.6353e+0 (1.86e+1) -	7.1178e+0 (3.71e+0) -	7.7383e-1 (3.89e-2) -	2.0494e+0 (4.92e-1) -	8.0625e-1 (1.35e-1) -	6.9912e-1 (9.93e-2)
UC4-C3-DTLZ2	2	4.8906e-2 (1.78e-3) -	6.4379e-2 (6.38e-2) -	4.5507e-2 (8.64e-4) -	2.9156e-1 (1.72e-1) -	4.7396e-2 (1.61e-3) -	7.8743e-2 (1.28e-2) -	4.5672e-2 (4.67e-4) -	4.5343e-2 (5.20e-4)
UC4-C3-DTLZ3	2	2.1294e+0 (1.27e+0) -	5.4806e-1 (7.88e-2) -	1.5244e+1 (7.57e+0) -	3.8129e+0 (4.91e-2) -	5.4538e-1 (8.22e-2) -	8.2787e-1 (6.03e-2) -	9.2541e-1 (6.57e-1) -	5.2855e-1 (8.31e-2)
UC5-C1-DTLZ1	2	1.3759e-3 (9.86e-5) +	2.5656e-3 (7.02e-4) -	2.7068e-2 (4.92e-2) -	NaN (NaN) -	1.5680e-3 (2.73e-4) +	1.4871e-3 (2.43e-5) +	1.3375e-3 (4.08e-5) +	1.6776e-3 (1.56e-4)
UC5-C2-DTLZ1	2	1.4193e-3 (1.48e-4) +	1.0769e-2 (6.94e-3) -	3.9792e-3 (6.82e-3) -	NaN (NaN) -	2.3691e-3 (2.34e-3) =	1.5574e-3 (2.34e-4) +	1.5919e-3 (2.81e-4) +	1.8192e-3 (5.85e-4)
UC5-C2-DTLZ3	2	2.7364e-3 (6.80e-4) -	1.6446e-2 (8.66e-3) -	7.6314e-3 (1.33e-2) -	NaN (NaN) -	5.1645e-3 (5.99e-3) -	1.2225e-2 (2.76e-2) -	3.4073e-3 (1.33e-3) -	2.2196e-3 (1.02e-4)
UC5-C3-DTLZ1	2	3.7142e-2 (8.68e-3) -	4.5038e-2 (1.10e-2) -	8.4022e-2 (4.61e-2) -	NaN (NaN) -	4.6801e-2 (7.23e-3) -	1.0422e-1 (2.35e-2) -	3.9045e-2 (9.22e-3) -	3.5134e-2 (5.08e-3)
UC5-C3-DTLZ2	2	4.5504e-2 (9.44e-4) -	7.5167e-2 (7.33e-2) -	4.5340e-2 (1.29e-4) -	3.9199e-1 (7.02e-4) -	4.8004e-2 (2.08e-3) -	8.1690e-2 (6.59e-3) -	4.5596e-2 (8.38e-4) -	4.5191e-2 (1.50e-4)
UC5-C3-DTLZ3	2	7.7873e-2 (8.46e-2) =	6.3836e-2 (1.76e-2) =	1.9097e-1 (1.64e-1) =	NaN (NaN) -	1.1741e-1 (1.10e-1) -	9.7012e-2 (6.03e-2) -	8.0492e-2 (5.81e-2) =	9.6936e-2 (9.46e-2)
+/-/=		4/23/3	6/17/7	0/23/7	1/24/5	8/15/7	4/24/2	7/20/3	

TABLE VI
THE COMPARISON RESULTS OF HV METRIC ON TWO OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/MOEA/D	EADMM/NSGA-II
UC1-C1-DTLZ1	2	5.8029e-1 (1.73e-3) +	5.8028e-1 (1.12e-3) +	5.8037e-1 (6.23e-4) +	NaN (NaN) -	5.8195e-1 (5.60e-4) +	5.8114e-1 (9.53e-4) +	5.7946e-1 (2.88e-3) =	5.7931e-1 (1.60e-3)
UC1-C2-DTLZ1	2	5.8162e-1 (7.31e-4) +	5.8088e-1 (1.06e-3) +	5.5919e-1 (8.91e-2) =	2.3022e-1 (0.00e+0) =	5.8206e-1 (6.92e-4) +	5.6704e-1 (4.86e-2) =	5.8136e-1 (1.15e-3) +	5.7972e-1 (2.22e-3)
UC1-C2-DTLZ3	2	2.9921e-1 (8.47e-2) -	3.4193e-1 (4.03e-3) =	3.4459e-1 (1.11e-3) =	NaN (NaN) -	3.2682e-1 (3.40e-2) -	2.1812e-1 (1.05e-1) -	2.8608e-1 (9.00e-2) -	3.4213e-1 (5.58e-3)
UC1-C3-DTLZ1	2	4.7263e-1 (1.89e-3) -	4.6587e-1 (2.70e-2) -	4.3916e-1 (1.01e-1) =	NaN (NaN) -	4.7362e-1 (1.10e-3) -	3.1239e-1 (1.20e-1) -	4.7124e-1 (4.98e-3) -	4.7396e-1 (1.20e-3)
UC1-C3-DTLZ2	2	2.6194e-1 (9.09e-5) -	2.6206e-1 (5.70e-5) -	2.6200e-1 (4.53e-5) -	1.9096e-1 (4.22e-2) -	2.6168e-1 (1.39e-4) -	2.6088e-1 (6.46e-6) -	2.6168e-1 (5.38e-5) -	2.6212e-1 (3.15e-5)
UC1-C3-DTLZ3	2	2.1287e-1 (6.09e-2) -	2.6042e-1 (0.00e+0) =	2.0523e-1 (0.00e+0) =	NaN (NaN) -	2.5271e-1 (5.85e-3) +	1.5955e-1 (0.00e+0) =	2.1465e-1 (7.30e-2) -	2.5114e-1 (3.67e-2)
UC2-C1-DTLZ1	2	4.8183e-1 (9.34e-2) -	5.8104e-1 (5.73e-4) +	5.7999e-1 (5.57e-4) =	5.7653e-1 (5.71e-3) -	5.8182e-1 (7.70e-4) +	4.1308e-1 (2.98e-2) -	5.8037e-1 (2.51e-3) +	5.7969e-1 (2.27e-3)
UC2-C2-DTLZ1	2	5.6435e-1 (4.17e-2) =	5.8096e-1 (1.03e-3) +	5.8087e-1 (3.83e-4) +	5.6834e-1 (4.52e-2) -	5.7793e-1 (2.06e-2) -	4.0756e-1 (3.87e-2) -	5.7900e-1 (4.84e-3) =	5.8010e-1 (1.11e-3)
UC2-C2-DTLZ3	2	2.2843e-1 (1.16e-1) -	3.4654e-1 (4.34e-4) +	3.4455e-1 (6.71e-4) =	3.3709e-1 (3.46e-2) -	3.3922e-1 (1.46e-2) -	2.2269e-1 (7.94e-2) -	2.9708e-1 (9.33e-2) -	3.4528e-1 (1.29e-3)
UC2-C3-DTLZ1	2	4.4096e-1 (4.09e-2) -	4.7326e-1 (1.29e-3) =	4.4757e-1 (6.34e-2) =	4.4151e-1 (7.83e-2) -	4.6741e-1 (2.68e-2) =	3.1396e-1 (8.23e-2) -	4.6598e-1 (1.42e-2) -	4.7295e-1 (2.94e-3)
UC2-C3-DTLZ2	2	2.5867e-1 (1.46e-3) -	2.6205e-1 (6.77e-5) -	2.6198e-1 (6.26e-5) -	2.5680e-1 (1.57e-3) -	2.6168e-1 (1.03e-4) -	2.6087e-1 (4.47e-6) -	2.6146e-1 (1.13e-4) -	2.6212e-1 (3.84e-5)
UC2-C3-DTLZ3	2	2.0648e-1 (6.58e-2) -	2.6160e-1 (3.50e-4) +	NaN (NaN) -	2.5368e-1 (1.83e-2) -	2.5613e-1 (5.48e-3) -	1.3538e-1 (5.11e-2) -	2.1755e-1 (5.90e-2) -	2.6011e-1 (1.65e-3)
UC3-C1-DTLZ1	2	5.1745e-1 (6.26e-2) -	5.7355e-1 (2.50e-2) =	5.8049e-1 (5.66e-4) =	5.7732e-1 (0.00e+0) =	5.8101e-1 (3.14e-3) +	5.1225e-1 (6.52e-2) -	5.7853e-1 (3.76e-3) =	5.7924e-1 (2.11e-3)
UC3-C2-DTLZ1	2	5.7932e-1 (4.80e-3) =	5.7965e-1 (6.70e-3) =	5.8057e-1 (4.84e-4) =	NaN (NaN) -	5.8169e-1 (1.21e-3) +	5.5657e-1 (3.59e-2) -	5.8081e-1 (1.88e-3) +	5.8036e-1 (1.10e-3)
UC3-C2-DTLZ3	2	2.5557e-1 (1.00e-1) -	3.1638e-1 (7.09e-2) =	3.4509e-1 (3.83e-4) =	3.4334e-1 (3.72e-3) =	3.3581e-1 (4.03e-2) =	1.4960e-1 (7.05e-2) -	2.6659e-1 (9.32e-2) -	3.2344e-1 (6.14e-2)
UC3-C3-DTLZ1	2	4.4434e-1 (3.25e-2) -	4.7332e-1 (1.16e-3) =	4.4381e-1 (1.06e-1) -	NaN (NaN) -	4.7302e-1 (1.85e-3) =	3.3077e-1 (8.31e-2) -	4.6675e-1 (1.54e-2) -	4.7318e-1 (1.80e-3)
UC3-C3-DTLZ2	2	2.6064e-1 (1.42e-3) -	2.6212e-1 (2.80e-5) -	2.6205e-1 (3.52e-5) -	2.5678e-1 (1.79e-3) -	2.6185e-1 (9.36e-5) -	2.6088e-1 (4.28e-6) -	2.6162e-1 (7.30e-5) -	2.6215e-1 (1.69e-5)
UC3-C3-DTLZ3	2	2.0905e-1 (5.66e-2) -	2.3620e-1 (4.94e-2) =	1.9400e-1 (7.37e-2) =	2.5760e-1 (4.36e-4) -	2.5694e-1 (4.51e-3) -	1.5999e-1 (2.29e-2) -	2.0979e-1 (7.43e-2) -	2.6010e-1 (2.43e-3)
UC4-C1-DTLZ1	2	5.6711e-1 (2.43e-2) -	5.6987e-1 (1.47e-2) -	3.6554e-1 (1.78e-1) -	2.8559e-1 (9.81e-2) -	5.6313e-1 (2.83e-2) -	5.8002e-1 (1.47e-3) +	5.7883e-1 (5.55e-3) =	5.7658e-1 (1.93e-2)
UC4-C2-DTLZ1	2	5.7770e-1 (6.65e-3) -	5.6729e-1 (9.42e-3) -	3.9022e-1 (2.37e-1) -	2.0892e-1 (1.49e-1) -	5.8017e-1 (2.87e-3) =	5.8036e-1 (8.05e-4) -	5.7979e-1 (2.43e-3) -	5.8130e-1 (2.22e-4)
UC4-C2-DTLZ3	2	3.4140e-1 (2.81e-3) -	3.4120e-1 (3.68e-3) -	2.3350e-1 (1.07e-1) -	9.6554e-2 (1.61e-2) -	3.4693e-1 (8.94e-4) +	3.4224e-1 (1.52e-3) -	3.4581e-1 (5.76e-4) -	3.4678e-1 (3.61e-4)
UC4-C3-DTLZ1	2	4.5433e-1 (1.15e-2) -	4.2495e-1 (4.83e-2) -	3.3046e-1 (1.64e-1) -	1.6948e-1 (1.56e-1) -	4.5898e-1 (6.37e-3) -	2.4801e-1 (8.13e-2) -	4.5989e-1 (1.47e-2) -	4.7121e-1 (1.64e-2)
UC4-C3-DTLZ2	2	2.5472e-1 (3.72e-3) -	2.4666e-1 (3.04e-2) -	2.6144e-1 (1.53e-3) -	1.0454e-1 (4.70e-2) -	2.5737e-1 (3.58e-3) -	1.8523e-1 (2.96e-2) -	2.6104e-1 (9.40e-4) -	2.6176e-1 (1.17e-3)
UC4-C3-DTLZ3	2	1.7095e-1 (5.90e-2) -	2.4091e-1 (1.82e-2) -	1.0249e-1 (3.40e-2) -	8.6447e-2 (4.29e-3) -	2.4162e-1 (1.88e-2) -	1.7606e-1 (1.39e-2) -	2.2373e-1 (3.20e-2) -	2.4515e-1 (1.92e-2)
UC5-C1-DTLZ1	2	5.8215e-1 (3.61e-4) +	5.7833e-1 (2.30e-3) -	5.1967e-1 (1.14e-1) -	NaN (NaN) -	5.8118e-1 (1.38e-3) =	5.8182e-1 (1.13e-4) +	5.8220e-1 (2.88e-4) +	5.8113e-1 (7.54e-4)
UC5-C2-DTLZ1	2	5.8209e-1 (4.78e-4) +	5.5189e-1 (2.23e-2) -	5.7486e-1 (1.80e-2) -	NaN (NaN) -	5.7919e-1 (6.89e-3) =	5.8163e-1 (7.65e-4) +	5.8150e-1 (9.47e-4) +	5.8082e-1 (1.76e-3)
UC5-C2-DTLZ3	2	3.4569e-1 (1.22e-3) -	3.2157e-1 (1.39e-2) -	3.3890e-1 (1.89e-2) -	NaN (NaN) -	3.4208e-1 (9.46e-3) =	3.2956e-1 (5.14e-2) -	3.4467e-1 (1.91e-3) -	3.4676e-1 (1.91e-4)
UC5-C3-DTLZ1	2	4.6488e-1 (2.80e-2) -	4.3800e-1 (3.66e-2) -	3.5623e-1 (8.04e-2) -	NaN (NaN) -	4.3272e-1 (2.37e-2) -	2.4220e-1 (7.78e-2) -	4.5953e-1 (2.92e-2) -	4.7065e-1 (1.68e-2)
UC5-C3-DTLZ2	2	2.6138e-1 (2.14e-3) -	2.4173e-1 (3.36e-2) -	2.6170e-1 (2.94e-4) -	7.7087e-2 (6.38e-4) -	2.5600e-1 (4.63e-3) -	1.7803e-1 (1.53e-2) -	2.6124e-1 (1.54e-3) -	2.6208e-1 (2.26e-4)
UC5-C3-DTLZ3	2	2.3418e-1 (5.03e-2) =	2.1964e-1 (4.04e-2) -	1.3007e-1 (3.66e-2) -	NaN (NaN) -	2.0094e-1 (5.56e-2) -	1.6640e-1 (2.46e-2) -	2.3778e-1 (2.91e-2) =	2.2990e-1 (4.70e-2)
+/-/=		4/23/3	6/16/8	2/16/11	0/16/3	7/16/7	4/24/2	5/20/5	

TABLE VII
THE COMPARISON RESULTS OF IGD METRIC ON THREE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	3	2.2726e-2 (2.88e-4) -	2.1047e-2 (2.41e-4) -	2.6635e-2 (7.99e-4) -	5.0854e+0 (9.83e+0) -	2.0353e-2 (2.46e-3) =	2.1202e-2 (4.98e-4) -	2.6023e-2 (1.35e-3) -	2.0299e-2 (1.73e-4)
UC1-C2-DTLZ1	3	2.3086e-2 (3.73e-4) -	2.1216e-2 (1.88e-4) -	2.7247e-2 (1.56e-3) -	1.3453e-1 (3.47e-2) -	2.1431e-2 (1.57e-3) -	2.1293e-2 (8.08e-4) -	2.6714e-2 (1.71e-3) -	2.0611e-2 (1.25e-4)
UC1-C2-DTLZ3	3	1.0089e-1 (1.82e-1) =	6.3345e-2 (3.92e-2) =	7.2090e-2 (3.18e-3) =	8.4539e-1 (4.41e-1) -	6.9405e-1 (5.02e-1) =	1.8304e-1 (3.52e-1) =	6.7071e-2 (5.67e-3) =	5.7021e-2 (3.37e-1)
UC1-C3-DTLZ1	3	4.9769e-2 (6.17e-4) -	4.5625e-2 (7.21e-4) -	4.9313e-2 (6.63e-2) -	NaN (NaN) -	4.7112e-2 (1.07e-3) -	8.9162e-2 (7.61e-2) -	5.0830e-2 (1.25e-3) -	4.4744e-2 (2.24e-4)
UC1-C3-DTLZ2	3	2.6861e-1 (3.81e-3) -	2.6472e-1 (2.01e-3) -	2.6752e-1 (3.76e-3) -	9.3321e-1 (2.48e-1) -	2.6414e-1 (2.44e-3) -	2.9534e-1 (8.65e-3) -	2.6031e-1 (1.53e-3) -	2.5736e-1 (3.36e-4)
UC1-C3-DTLZ3	3	4.1315e-1 (5.90e-1) =	2.6658e-1 (6.69e-3) +	4.5639e-1 (1.27e-3) -	4.8406e-1 (0.00e+0) =	3.0668e-1 (5.13e-2) =	4.0156e-1 (2.46e-3) =	2.7076e-1 (5.18e-2) =	2.8246e-1 (1.90e-1)
UC2-C1-DTLZ1	3	4.0781e-1 (3.52e+1) -	4.5906e-2 (7.54e-3) -	3.8546e-2 (9.42e-3) -	1.1067e-1 (1.85e-1) -	2.0581e-1 (1.10e-1) -	1.5542e-1 (2.94e-2) -	5.6696e-2 (6.55e-3) -	2.0309e-2 (1.15e-4)
UC2-C2-DTLZ1	3	3.4649e+1 (3.52e+1) -	2.1211e-2 (1.37e-4) -	2.7649e-2 (1.29e-3) -	3.4902e-2 (2.62e-2) -	2.1608e-2 (2.53e-3) -	1.6203e-1 (3.92e-2) -	2.6376e-2 (1.56e-3) -	2.0605e-2 (8.68e-5)
UC2-C2-DTLZ3	3	8.9098e+1 (2.09e-2) -	8.9043e+1 (3.96e-2) -	8.9077e+1 (2.91e-2) -	8.1329e-2 (8.27e-3) -	8.9053e+1 (8.89e+1) -	4.3182e-1 (8.90e+1) -	6.8513e-2 (5.78e-3) -	5.4678e-2 (3.80e-3)
UC2-C3-DTLZ1	3	3.4692e+1 (3.51e+1) -	4.5639e-2 (4.26e-4) -	1.1496e-1 (1.68e-1) -	9.3988e-2 (7.69e-2) -	4.8493e-2 (3.98e-3) -	2.0709e-1 (2.57e-2) -	5.0874e-2 (2.10e-3) -	4.4854e-2 (4.16e-4)
UC2-C3-DTLZ2	3	2.6846e-1 (4.78e-3) -	2.6467e-1 (2.50e-3) -	2.6714e-1 (5.66e-3) -	9.4498e-1 (2.50e-1) -	2.6398e-1 (3.28e-3) -	3.0285e-1 (1.09e-2) -	2.6108e-1 (1.21e-3) -	2.5731e-1 (3.06e-4)
UC2-C3-DTLZ3	3	8.9088e+1 (2.70e-2) -	8.9042e+1 (8.88e+1) =	8.9071e+1 (2.19e-2) -	3.5832e-1 (6.15e-1) =	8.9053e+1 (8.85e+1) -	4.1177e-1 (8.86e+1) =	2.6478e-1 (4.80e-2) =	6.7556e-1 (8.88e+1)
UC3-C1-DTLZ1	3	1.1289e-1 (3.50e-2) -	4.1536e-2 (8.28e-3) -	3.5669e-2 (4.59e+1) -	8.7554e-2 (3.17e-2) -	4.3177e-1 (1.20e-1) -	1.4407e-1 (1.64e-1) -	5.4721e-2 (8.08e-3) -	2.0360e-2 (1.82e-4)
UC3-C2-DTLZ1	3	2.3009e-2 (4.97e-4) -	2.1244e-2 (2.04e-4) -	2.8801e-2 (1.14e+1) -	1.4522e+1 (1.17e+1) -	2.0732e-2 (4.42e-4) -	3.0739e-2 (1.59e-2) -	2.7053e-2 (1.30e-3) -	2.0597e-2 (6.30e-5)
UC3-C2-DTLZ3	3	3.9956e-1 (4.40e+1) =	4.4016e+1 (4.40e+1) =	8.1136e-2 (4.40e+1) =	1.7317e-1 (5.20e-1) =	4.4038e+1 (4.39e+1) -	2.2613e-1 (4.39e+1) =	6.6295e-2 (3.21e-3) =	3.7465e-1 (4.40e+1)
UC3-C3-DTLZ1	3	5.6317e-2 (2.19e-2) -	4.5858e-2 (1.39e-3) -	1.1316e+1 (5.17e+1) -	1.3295e+1 (2.90e+0) -	4.8326e-2 (4.48e-3) -	1.4493e-1 (5.22e-2) -	5.1397e-2 (1.84e-3) -	4.5025e-2 (5.54e-4)
UC3-C3-DTLZ2	3	2.6235e-1 (5.43e-3) +	2.6329e-1 (2.46e-3) +	2.6617e-1 (4.63e-3) +	3.5525e-1 (9.86e-2) -	2.5549e-1 (3.24e-3) +	2.9330e-1 (2.00e-3) -	2.6061e-1 (3.35e-3) +	2.7373e-1 (7.68e-3)
UC3-C3-DTLZ3	3	4.4033e+1 (4.37e+1) -	4.4016e+1 (4.38e+1) =	4.4038e+1 (1.17e-2) -	3.6079e-1 (8.85e-2) =	4.4035e+1 (4.38e+1) -	4.2618e-1 (4.36e+1) =	2.6963e-1 (3.30e+1) =	3.7747e-1 (4.38e+1)
UC4-C1-DTLZ1	3	1.0014e+0 (1.81e-1) -	1.3769e+0 (9.71e-1) -	4.0616e+1 (1.03e-1) -	5.9678e+0 (0.00e+0) =	6.8466e-1 (1.28e+0) -	2.6085e+0 (5.00e+0) -	5.4460e+0 (3.86e+1) -	4.0827e-1 (3.97e-3)
UC4-C2-DTLZ1	3	4.9398e-1 (8.93e-2) -	6.0626e-1 (1.47e-1) -	4.6379e+1 (4.06e+1) -	1.1097e+1 (6.16e+0) -	4.0654e-1 (6.59e-3) +	4.5825e-1 (1.69e-1) -	5.3996e-1 (4.34e-2) -	4.1121e-1 (2.80e-3)
UC4-C2-DTLZ3	3	7.6125e-1 (1.65e-1) -	7.7345e-1 (1.60e-1) -	6.9293e-1 (6.02e+0) -	9.3146e+0 (1.50e-1) -	5.3365e-1 (4.68e-3) +	1.1056e+0 (3.39e-1) -	7.0075e-1 (3.60e-2) -	5.5836e-1 (1.01e-2)
UC4-C3-DTLZ1	3	1.0061e+0 (3.62e-2) -	1.2035e+0 (1.89e-1) -	4.6348e+1 (4.23e+1) -	7.3972e+0 (5.73e+0) -	1.0877e+0 (2.72e-1) -	2.8951e+0 (1.49e+0) -	1.0155e+0 (4.38e-2) -	9.3334e-1 (2.85e-2)
UC4-C3-DTLZ2	3	3.4462e-1 (9.66e-3) -	3.0347e-1 (7.48e-2) -	3.8495e-1 (1.14e-1) -	9.5406e-1 (2.30e-2) -	2.7961e-1 (2.27e-2) -	4.3162e-1 (2.82e-2) -	2.6166e-1 (2.30e-3) -	2.5986e-1 (2.68e-3)
UC4-C3-DTLZ3	3	6.7812e+0 (4.65e+0) -	4.3589e+0 (8.31e-1) +	3.5125e+1 (2.45e-2) -	9.4660e+0 (1.34e-1) -	4.4138e+0 (1.49e-1) +	4.6660e+0 (1.51e-1) =	4.3403e+0 (7.47e-1) +	4.6585e+0 (2.45e+0)
UC5-C1-DTLZ1	3	2.3069e-2 (3.56e-4) -	2.5244e-2 (3.45e-3) -	2.8440e-2 (9.97e+0) -	NaN (NaN) -	2.0753e-2 (8.59e-4) -	2.1008e-2 (4.22e-4) -	2.7163e-2 (2.13e-3) -	2.0508e-2 (5.27e-5)
UC5-C2-DTLZ1	3	2.2975e-2 (3.20e-4) -	2.8370e-2 (1.14e-2) -	4.4100e-2 (2.14e-2) -	NaN (NaN) -	3.4936e-2 (1.65e-2) -	2.1158e-2 (4.32e-4) -	2.8170e-2 (4.51e-3) -	2.0698e-2 (4.16e-4)
UC5-C2-DTLZ3	3	6.3561e-2 (1.73e-3) -	8.3393e-2 (1.19e-2) -	2.8352e-1 (9.93e+0) -	NaN (NaN) -	8.3676e-2 (3.14e-2) -	7.9402e-2 (4.25e-3) -	6.9769e-2 (3.97e-3) -	5.7445e-2 (1.01e-2)
UC5-C3-DTLZ1	3	5.0169e-2 (1.19e-3) -	6.2926e-2 (1.83e-2) -	1.9827e-1 (9.92e+0) -	NaN (NaN) -	5.7868e-2 (9.99e-3) -	1.4467e-1 (7.08e-2) -	5.0645e-2 (2.39e-3) -	4.6125e-2 (1.99e-3)
UC5-C3-DTLZ2	3	2.7182e-1 (5.62e-3) -	3.0314e-1 (9.55e-2) -	3.1121e-1 (1.09e-1) -	NaN (NaN) -	2.8119e-1 (1.76e-2) -	3.9921e-1 (4.08e-3) -	2.6210e-1 (3.16e-3) -	2.5894e-1 (1.84e-3)
UC5-C3-DTLZ3	3	3.9084e-1 (1.17e-1) -	3.5844e-1 (4.40e-2) -	4.5967e-1 (3.20e-2) -	NaN (NaN) -	3.1292e-1 (1.00e-1) =	3.9849e-1 (5.24e-4) -	2.9800e-1 (1.27e-1) =	3.3194e-1 (1.27e-1)
+/-/=		1/26/3	3/23/4	1/27/2	0/25/5	4/22/4	0/24/6	2/22/6	

TABLE VIII
THE COMPARISON RESULTS OF IGD^+ METRIC ON THREE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	3	1.6485e-2 (7.79e-4) -	1.5013e-2 (5.84e-4) -	1.9330e-2 (1.67e-3) -	1.1147e-1 (0.00e+0) =	1.5544e-2 (3.22e-3) -	1.4939e-2 (5.41e-4) -	1.8476e-2 (1.39e-3) -	1.4607e-2 (2.82e-4)
UC1-C2-DTLZ1	3	1.6645e-2 (7.09e-4) -	1.5098e-2 (2.41e-4) =	2.0130e-2 (2.38e-3) -	8.9186e-2 (2.03e-2) -	1.7017e-2 (2.48e-3) -	1.4995e-2 (9.14e-4) =	2.0023e-2 (2.30e-3) -	1.4883e-2 (5.80e-4)
UC1-C2-DTLZ3	3	4.9260e-2 (1.35e-1) =	3.3827e-2 (3.07e-2) =	3.9052e-2 (2.81e-3) =	5.1132e-1 (1.87e-1) =	4.5334e-1 (1.94e-1) =	7.6936e-2 (2.61e-1) =	3.6635e-2 (8.85e-3) =	2.9900e-2 (2.37e-1)
UC1-C3-DTLZ1	3	3.3252e-2 (7.73e-4) -	3.0819e-2 (8.27e-4) -	3.3836e-2 (4.71e-2) -	NaN (NaN) -	3.3585e-2 (1.57e-3) -	5.7511e-2 (4.70e-2) -	3.4268e-2 (1.19e-3) -	3.0349e-2 (4.58e-4)
UC1-C3-DTLZ2	3	1.1094e-1 (1.10e-3) -	1.0923e-1 (6.61e-4) -	1.1114e-1 (1.32e-3) -	5.2737e-1 (1.22e-1) -	1.1030e-1 (6.57e-4) -	1.1056e-1 (1.05e-3) -	1.0818e-1 (1.80e-4) -	1.0790e-1 (1.19e-4)
UC1-C3-DTLZ3	3	1.3942e-1 (4.00e-1) =	1.1043e-1 (1.94e-3) +	3.9663e-1 (1.81e-3) -	3.5518e-1 (0.00e+0) =	1.3068e-1 (3.27e-2) =	1.3604e-1 (2.09e-3) =	1.1419e-1 (1.35e-2) +	1.1832e-1 (1.88e-1)
UC2-C1-DTLZ1	3	3.2782e-1 (3.52e+1) -	3.0889e-2 (4.71e-3) -	2.6916e-2 (7.00e-3) -	8.2495e-2 (1.46e-1) -	1.5731e-1 (8.76e-2) -	1.1259e-1 (2.47e-2) -	3.9554e-2 (5.82e-3) -	1.4628e-2 (2.24e-4)
UC2-C2-DTLZ1	3	3.4649e+1 (3.52e+1) -	1.5052e-2 (2.47e-4) -	2.0986e-2 (1.57e-3) -	3.2045e-2 (2.33e-2) -	1.7252e-2 (4.88e-3) -	1.1701e-1 (3.21e-2) -	1.8850e-2 (1.74e-3) -	1.4842e-2 (4.55e-4)
UC2-C2-DTLZ3	3	8.9098e+1 (2.09e-2) -	8.9043e+1 (3.94e-2) -	8.9077e+1 (2.91e-2) -	5.4197e-2 (1.33e-2) -	8.9053e+1 (8.90e+1) -	1.3846e-1 (8.90e+1) -	3.4579e-2 (4.44e-3) -	2.4114e-2 (7.14e-3)
UC2-C3-DTLZ1	3	3.4692e+1 (3.51e+1) -	3.0874e-2 (4.10e-4) -	7.9786e-2 (1.37e-1) -	7.4396e-2 (6.50e-2) -	3.4908e-2 (4.92e-3) -	1.5658e-1 (2.54e-2) -	3.4393e-2 (2.12e-3) -	3.0639e-2 (8.61e-4)
UC2-C3-DTLZ2	3	1.1107e-1 (1.09e-3) -	1.0933e-1 (4.57e-4) -	1.1109e-1 (1.39e-3) -	5.2791e-1 (1.42e-1) -	1.1031e-1 (7.60e-4) -	1.1137e-1 (1.00e-3) -	1.0827e-1 (1.41e-4) -	1.0789e-1 (1.05e-4)
UC2-C3-DTLZ3	3	8.9088e+1 (2.68e-2) -	8.9041e+1 (8.90e+1) =	8.9071e+1 (2.19e-2) -	1.3984e-1 (4.18e-1) =	8.9053e+1 (8.88e+1) -	1.3607e-1 (8.89e+1) =	1.1169e-1 (1.86e-2) +	3.6924e-1 (8.89e+1)
UC3-C1-DTLZ1	3	7.7194e-2 (1.86e-2) -	2.7778e-2 (5.17e-3) -	2.6361e-2 (4.60e+1) -	5.8128e-2 (2.24e-2) -	3.3515e-1 (9.82e-2) -	1.0310e-1 (1.17e-1) -	3.8689e-2 (7.18e-3) -	1.4585e-2 (4.45e-4)
UC3-C2-DTLZ1	3	1.6705e-2 (8.41e-4) -	1.5053e-2 (2.97e-4) -	2.2234e-2 (1.14e+1) -	1.4521e+1 (1.18e+1) -	1.5424e-2 (1.50e-3) -	2.1336e-2 (9.85e-3) -	1.9552e-2 (2.14e-3) -	1.4806e-2 (3.52e-4)
UC3-C2-DTLZ3	3	3.2542e-1 (4.40e+1) =	4.4016e+1 (4.40e+1) =	5.5726e-2 (4.40e+1) =	1.5534e-1 (4.49e-1) =	4.4038e+1 (4.40e+1) -	6.5748e-2 (4.40e+1) =	3.3369e-2 (5.05e-3) =	3.4197e-1 (4.40e+1)
UC3-C3-DTLZ1	3	4.0190e-2 (2.01e-2) -	3.1417e-2 (1.23e-3) =	1.1316e+1 (5.17e+1) -	1.3294e+1 (2.90e+0) -	3.5205e-2 (6.65e-3) -	9.1393e-2 (2.97e-2) -	3.4974e-2 (2.02e-3) -	3.0809e-2 (1.12e-3)
UC3-C3-DTLZ2	3	1.1365e-1 (1.68e-3) +	1.0911e-1 (3.74e-4) +	1.1076e-1 (1.25e-3) +	1.3340e-1 (1.05e-2) -	1.0975e-1 (5.29e-4) +	1.1167e-1 (1.68e-4) +	1.1097e-1 (7.98e-4) +	1.1608e-1 (2.20e-3)
UC3-C3-DTLZ3	3	4.4033e+1 (4.39e+1) -	4.4016e+1 (4.39e+1) =	4.4038e+1 (1.17e-2) -	1.5150e-1 (2.72e-2) =	4.4035e+1 (4.39e+1) -	1.3805e-1 (4.39e+1) =	1.1337e-1 (3.30e+1) =	2.2801e-1 (4.39e+1)
UC4-C1-DTLZ1	3	7.0868e-1 (1.39e-1) -	9.3618e-1 (6.98e-1) -	4.0616e+1 (1.03e-1) -	4.2731e+0 (0.00e+0) =	4.8208e-1 (8.59e-1) -	2.0083e+0 (3.86e+0) -	3.7281e+0 (3.92e+1) -	2.8966e-1 (3.48e-3)
UC4-C2-DTLZ1	3	3.5715e-1 (6.60e-2) -	4.2209e-1 (9.69e-2) -	4.6379e+1 (4.07e+1) -	1.0429e+1 (6.07e+0) -	2.9917e-1 (1.19e-2) -	3.1708e-1 (1.19e-1) -	3.7423e-1 (3.20e-2) -	2.9619e-1 (3.91e-3)
UC4-C2-DTLZ3	3	3.3831e-1 (6.64e-2) -	2.8072e-1 (4.80e-2) -	3.4190e-1 (4.57e+0) -	5.2364e+0 (9.22e-3) -	2.4196e-1 (7.40e-3) +	2.7710e-1 (4.51e-2) -	3.3151e-1 (1.98e-2) -	2.5359e-1 (1.09e-2)
UC4-C3-DTLZ1	3	6.7710e-1 (5.03e-2) -	8.1277e-1 (1.16e-1) -	4.6348e+1 (4.38e+1) -	7.3253e+0 (6.37e+0) -	7.8621e-1 (1.79e-1) -	1.8227e+0 (9.10e-1) -	6.8543e-1 (2.34e-2) -	6.2098e-1 (1.26e-2)
UC4-C3-DTLZ2	3	1.2313e-1 (1.44e-3) -	1.1956e-1 (1.33e-2) -	1.3380e-1 (1.65e-2) -	5.4020e-1 (8.21e-3) -	1.1357e-1 (5.81e-3) -	1.3561e-1 (1.72e-3) -	1.0834e-1 (3.62e-4) =	1.0853e-1 (8.24e-4)
UC4-C3-DTLZ3	3	2.9288e+0 (2.89e+0) =	1.3722e+0 (1.18e-1) +	3.5124e+1 (2.44e-2) -	5.2163e+0 (4.39e-2) -	1.3800e+0 (8.71e-3) +	1.3806e+0 (4.64e-3) +	1.3723e+0 (1.11e-1) +	2.8717e+0 (1.14e+0)
UC5-C1-DTLZ1	3	1.6196e-2 (3.02e-4) -	1.8353e-2 (2.16e-3) -	2.0683e-2 (1.86e-3) -	NaN (NaN) -	1.6291e-2 (1.47e-3) -	1.4631e-2 (3.52e-4) =	1.9082e-2 (1.24e-3) -	1.4674e-2 (1.18e-4)
UC5-C2-DTLZ1	3	1.6369e-2 (3.23e-4) -	2.1734e-2 (1.35e-2) -	4.2339e-2 (2.20e-2) -	NaN (NaN) -	3.1263e-2 (1.90e-2) -	1.4791e-2 (2.97e-4) +	2.1716e-2 (5.82e-3) -	1.5051e-2 (5.19e-4)
UC5-C2-DTLZ3	3	2.8179e-2 (1.78e-3) =	4.9088e-2 (1.89e-2) -	4.0873e-2 (1.34e-2) -	NaN (NaN) -	6.2532e-2 (3.63e-2) -	2.3586e-2 (1.03e-3) +	3.3686e-2 (1.85e-3) -	2.6264e-2 (1.05e-2)
UC5-C3-DTLZ1	3	3.3203e-2 (1.26e-3) -	4.6336e-2 (2.12e-2) -	7.9244e-2 (6.27e-2) -	NaN (NaN) -	4.4485e-2 (1.27e-2) -	9.1080e-2 (4.35e-2) -	3.3766e-2 (1.29e-3) -	3.0780e-2 (8.80e-4)
UC5-C3-DTLZ2	3	1.1170e-1 (1.65e-3) -	1.2078e-1 (1.52e-2) -	1.3371e-1 (1.79e-2) -	5.3047e-1 (3.35e-2) -	1.1462e-1 (5.01e-3) -	1.3382e-1 (2.55e-4) -	1.0830e-1 (5.29e-4) =	1.0832e-1 (7.18e-4)
UC5-C3-DTLZ3	3	1.3396e-1 (2.18e-2) =	1.3365e-1 (1.02e-2) =	4.0103e-1 (9.61e-3) -	NaN (NaN) -	1.3579e-1 (1.39e-2) =	1.3371e-1 (5.83e-5) =	1.1789e-1 (2.54e-2) =	1.3368e-1 (7.52e-2)
+/-/=		1/23/6	3/20/7	1/27/2	0/23/7	3/24/3	4/18/8	4/20/6	

TABLE IX
THE COMPARISON RESULTS OF HV METRIC ON THREE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	3	8.3057e-1 (1.55e-2) -	8.3689e-1 (1.23e-2) =	8.1747e-1 (9.67e-3) -	4.1713e-1 (0.00e+0) =	8.2779e-1 (1.84e-2) -	8.3403e-1 (6.71e-3) =	8.1791e-1 (1.37e-2) -	8.3579e-1 (6.58e-3)
UC1-C2-DTLZ1	3	8.3732e-1 (1.54e-3) -	8.4048e-1 (8.74e-4) -	8.1328e-1 (7.65e-3) -	4.9333e-1 (3.65e-2) -	8.3596e-1 (5.37e-3) -	8.3827e-1 (2.49e-3) -	8.2078e-1 (6.92e-3) -	8.4100e-1 (1.23e-3)
UC1-C2-DTLZ3	3	4.9581e-1 (2.04e-1) =	5.3940e-1 (6.71e-2) =	5.2412e-1 (8.10e-3) =	9.8422e-2 (1.41e-1) =	1.2588e-1 (1.29e-1) =	4.2278e-1 (2.33e-1) =	5.2743e-1 (1.44e-2) =	5.4676e-1 (3.25e-1)
UC1-C3-DTLZ1	3	8.0041e-1 (1.86e-3) -	8.0523e-1 (1.59e-3) =	7.8642e-1 (1.98e-1) -	NaN (NaN) -	7.9958e-1 (3.41e-3) -	7.3869e-1 (1.31e-1) -	7.8518e-1 (5.97e-3) -	8.0451e-1 (1.08e-3)
UC1-C3-DTLZ2	3	3.3760e-1 (3.33e-3) -	3.4287e-1 (2.04e-3) -	3.3833e-1 (3.81e-3) -	8.1476e-2 (1.75e-2) -	3.4216e-1 (1.61e-3) -	3.4200e-1 (2.62e-3) -	3.4710e-1 (3.73e-4) +	3.4698e-1 (5.15e-4)
UC1-C3-DTLZ3	3	2.4675e-1 (2.26e-1) =	3.3997e-1 (4.31e-3) +	1.5979e-1 (1.27e-3) -	1.7736e-1 (0.00e+0) =	2.8989e-1 (8.38e-2) =	2.5449e-1 (4.72e-3) =	3.3372e-1 (3.36e-2) +	3.1948e-1 (1.43e-1)
UC2-C1-DTLZ1	3	9.2261e-2 (5.41e-1) -	7.8029e-1 (9.65e-3) -	7.7485e-1 (3.25e-2) -	5.9058e-1 (3.76e-1) -	3.6167e-1 (2.53e-1) -	5.0554e-1 (6.84e-2) -	7.3436e-1 (2.58e-2) -	8.3558e-1 (6.23e-3)
UC2-C2-DTLZ1	3	0.0000e+0 (8.01e-1) -	8.4047e-1 (5.18e-4) -	8.1019e-1 (9.03e-3) -	7.9654e-1 (9.22e-2) -	8.3515e-1 (1.13e-2) -	5.0030e-1 (7.61e-2) -	8.2332e-1 (7.11e-3) -	8.4109e-1 (1.01e-3)
UC2-C2-DTLZ3	3	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	4.9534e-1 (1.81e-2) -	0.0000e+0 (4.72e-1) -	2.4950e-1 (5.57e-1) -	5.3138e-1 (1.04e-2) -	5.5681e-1 (1.34e-2)
UC2-C3-DTLZ1	3	0.0000e+0 (4.31e-1) -	8.0505e-1 (8.61e-4) +	5.8555e-1 (3.99e-1) -	6.5312e-1 (2.78e-1) -	7.9552e-1 (1.20e-2) -	3.8541e-1 (8.54e-2) -	7.8707e-1 (7.80e-3) -	8.0404e-1 (2.13e-3)
UC2-C3-DTLZ2	3	3.3685e-1 (3.19e-3) -	3.4256e-1 (2.06e-3) -	3.3898e-1 (3.46e-3) -	8.1191e-2 (1.47e-2) -	3.4246e-1 (1.82e-3) -	3.4051e-1 (2.35e-3) -	3.4704e-1 (2.50e-4) =	3.4697e-1 (4.14e-4)
UC2-C3-DTLZ3	3	0.0000e+0 (0.00e+0) -	0.0000e+0 (3.41e-1) =	0.0000e+0 (0.00e+0) -	2.6487e-1 (2.16e-1) =	0.0000e+0 (1.79e-1) -	2.5433e-1 (2.57e-1) =	3.3953e-1 (4.75e-2) +	1.1188e-1 (3.33e-1)
UC3-C1-DTLZ1	3	6.3005e-1 (4.20e-2) -	7.8594e-1 (1.42e-2) -	7.8439e-1 (7.97e-1) -	6.4483e-1 (6.86e-2) -	8.7607e-2 (1.16e-1) -	5.7705e-1 (3.35e-1) -	7.3268e-1 (2.67e-2) -	8.3570e-1 (1.08e-2)
UC3-C2-DTLZ1	3	8.3727e-1 (1.83e-3) -	8.4043e-1 (8.81e-4) -	8.0137e-1 (8.12e-1) -	0.0000e+0 (1.90e-1) -	8.3961e-1 (3.85e-3) -	8.2330e-1 (2.78e-2) -	8.2376e-1 (6.54e-3) -	8.4118e-1 (7.90e-4)
UC3-C2-DTLZ3	3	2.1055e-1 (5.37e-1) =	0.0000e+0 (5.59e-1) =	4.9208e-1 (5.25e-1) =	3.7075e-1 (4.04e-1) =	0.0000e+0 (4.05e-1) -	4.5892e-1 (4.91e-1) =	5.3352e-1 (1.09e-2) =	1.9380e-1 (5.52e-1)
UC3-C3-DTLZ1	3	7.7537e-1 (7.15e-2) -	8.0393e-1 (2.41e-3) =	0.0000e+0 (7.86e-1) -	0.0000e+0 (0.00e+0) -	7.9526e-1 (1.65e-2) -	6.2955e-1 (7.67e-2) -	7.7967e-1 (1.41e-2) -	8.0343e-1 (2.84e-3)
UC3-C3-DTLZ2	3	3.3461e-1 (5.01e-3) +	3.4337e-1 (1.51e-3) +	3.3992e-1 (3.14e-3) +	2.7819e-1 (3.85e-2) -	3.4509e-1 (1.53e-3) +	3.4386e-1 (9.11e-4) +	3.4457e-1 (1.72e-3) +	3.2454e-1 (7.38e-3)
UC3-C3-DTLZ3	3	0.0000e+0 (2.81e-1) -	0.0000e+0 (3.40e-1) =	0.0000e+0 (0.00e+0) -	2.3152e-1 (6.29e-2) =	0.0000e+0 (3.19e-1) -	2.5005e-1 (2.57e-1) =	3.3507e-1 (3.23e-1) =	2.4451e-1 (3.31e-1)
UC4-C1-DTLZ1	3	7.6763e-1 (3.65e-2) -	7.1097e-1 (1.36e-1) -	0.0000e+0 (0.00e+0) -	2.5625e-1 (0.00e+0) =	7.9382e-1 (1.75e-1) -	5.2895e-1 (5.13e-1) -	2.8941e-1 (5.93e-1) -	8.3913e-1 (4.78e-3)
UC4-C2-DTLZ1	3	8.3477e-1 (9.12e-3) -	8.2905e-1 (1.25e-2) -	0.0000e+0 (1.72e-1) -	0.0000e+0 (1.25e-1) -	8.4070e-1 (1.40e-3) =	8.3410e-1 (1.80e-2) -	8.2335e-1 (6.60e-3) -	8.4022e-1 (1.13e-3)
UC4-C2-DTLZ3	3	5.3525e-1 (1.42e-2) -	5.4625e-1 (1.18e-2) -	5.3124e-1 (4.29e-1) -	8.4901e-2 (1.02e-3) -	5.5824e-1 (1.40e-3) +	5.5075e-1 (9.64e-3) -	5.3284e-1 (4.89e-3) -	5.5375e-1 (2.59e-3)
UC4-C3-DTLZ1	3	7.9826e-1 (6.99e-3) -	7.7647e-1 (2.15e-2) -	0.0000e+0 (5.27e-1) -	4.8585e-2 (2.75e-1) -	7.7834e-1 (3.31e-2) -	6.3159e-1 (1.23e-1) -	7.8663e-1 (9.41e-3) -	8.0026e-1 (3.65e-3)
UC4-C3-DTLZ2	3	3.0239e-1 (4.19e-3) -	3.0940e-1 (4.58e-2) -	2.5958e-1 (6.17e-2) -	0.0000e+0 (0.00e+0) -	3.3198e-1 (1.89e-2) -	2.5558e-1 (4.12e-3) -	3.4632e-1 (1.28e-3) +	3.4509e-1 (2.99e-3)
UC4-C3-DTLZ3	3	1.6426e-1 (1.46e-1) -	2.5146e-1 (4.08e-2) +	0.0000e+0 (0.00e+0) -	8.8990e-2 (6.09e-3) -	2.4971e-1 (2.13e-3) +	2.4955e-1 (1.08e-3) +	2.5147e-1 (3.92e-2) +	1.9714e-1 (7.57e-2)
UC5-C1-DTLZ1	3	8.3818e-1 (7.53e-4) -	8.3435e-1 (4.49e-3) -	8.0889e-1 (6.92e-3) -	NaN (NaN) -	8.3135e-1 (1.27e-2) -	8.3748e-1 (1.68e-3) -	8.2102e-1 (4.96e-3) -	8.4095e-1 (7.14e-4)
UC5-C2-DTLZ1	3	8.3808e-1 (7.98e-4) -	8.2694e-1 (3.56e-2) -	7.5666e-1 (6.25e-2) -	NaN (NaN) -	8.0118e-1 (4.16e-2) -	8.3836e-1 (2.60e-3) -	8.1638e-1 (1.25e-2) -	8.4064e-1 (1.08e-3)
UC5-C2-DTLZ3	3	5.4525e-1 (2.74e-3) =	5.1259e-1 (3.25e-2) -	5.1835e-1 (3.46e-2) -	NaN (NaN) -	4.9366e-1 (6.14e-2) -	5.6169e-1 (1.61e-3) +	5.3308e-1 (6.01e-3) -	5.5284e-1 (2.01e-2)
UC5-C3-DTLZ1	3	7.9998e-1 (3.34e-3) -	7.5938e-1 (5.50e-2) -	5.8472e-1 (2.10e-1) -	NaN (NaN) -	7.6214e-1 (3.12e-2) -	6.3186e-1 (1.25e-1) -	7.8681e-1 (8.96e-3) -	8.0089e-1 (4.80e-3)
UC5-C3-DTLZ2	3	3.3522e-1 (5.49e-3) -	3.0591e-1 (5.26e-2) -	2.8652e-1 (5.53e-2) -	8.0963e-2 (3.05e-2) -	3.2771e-1 (1.53e-2) -	2.5953e-1 (3.67e-4) -	3.4656e-1 (1.44e-3) =	3.4583e-1 (1.80e-3)
UC5-C3-DTLZ3	3	2.5908e-1 (7.37e-2) -	2.5982e-1 (2.58e-2) -	1.5252e-1 (2.33e-2) -	NaN (NaN) -	2.6638e-1 (4.43e-2) -	2.5971e-1 (1.42e-4) -	3.1393e-1 (8.71e-2) =	2.8198e-1 (8.47e-2)
+/-/=		1/25/4	4/19/7	1/27/2	0/23/7	3/24/3	3/21/6	6/18/6	

TABLE X
THE COMPARISON RESULTS OF IGD METRIC ON FIVE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	5	7.2058e-2 (1.15e-3) +	1.3460e-1 (1.13e-2) -	1.2004e-1 (7.45e-3) -	NaN (NaN) -	5.7724e-2 (4.42e-4) +	1.3934e-1 (1.02e-2) -	7.5222e-2 (7.71e-3) +	7.7826e-2 (1.14e-3)
UC1-C2-DTLZ1	5	7.4598e-2 (6.64e-4) -	1.1351e-1 (1.73e-5) -	1.1375e-1 (3.61e-4) -	NaN (NaN) -	6.8788e-2 (1.12e-3) -	1.4950e-1 (1.52e-2) -	1.1056e-1 (8.97e-2) -	6.3336e-2 (2.22e-5)
UC1-C2-DTLZ3	5	2.2570e-1 (4.32e-3) -	3.2085e-1 (2.21e-4) -	3.2549e-1 (5.40e-3) -	1.0530e+0 (0.00e+0) =	NaN (NaN) -	5.7628e-1 (1.34e-2) -	NaN (NaN) -	1.9554e-1 (2.76e-3)
UC1-C3-DTLZ1	5	8.2649e-2 (1.21e-2) -	1.2457e-1 (7.37e-6) -	1.3205e-1 (2.36e-2) -	NaN (NaN) -	7.3056e-2 (1.24e-3) =	1.8492e-1 (1.70e-2) -	8.9035e-2 (4.91e-3) -	7.3128e-2 (3.03e-5)
UC1-C3-DTLZ2	5	5.1810e-1 (2.04e-2) -	5.1549e-1 (3.53e-2) -	8.9356e-1 (1.12e-1) -	1.1163e+0 (2.37e-2) -	4.4404e-1 (3.79e-2) +	4.6008e-1 (2.01e-3) -	4.3402e-1 (2.15e-2) +	4.5624e-1 (2.15e-4)
UC1-C3-DTLZ3	5	6.2083e-1 (2.06e-1) -	5.3117e-1 (4.62e-2) -	1.0347e+0 (3.33e-3) -	1.1022e+0 (0.00e+0) =	NaN (NaN) -	5.8742e-1 (5.68e-3) -	NaN (NaN) -	4.6948e-1 (2.80e-2)
UC2-C1-DTLZ1	5	1.3708e+1 (1.60e+1) -	1.4285e-1 (1.17e-4) -	1.4783e+0 (6.05e+0) -	3.6537e+1 (5.26e+0) -	1.8666e+0 (6.50e+0) -	1.5138e-1 (1.86e-2) -	1.2613e+1 (1.64e+1) -	7.5604e-2 (7.49e-3)
UC2-C2-DTLZ1	5	1.0260e+1 (1.47e+1) -	1.1348e-1 (5.87e-5) -	1.2016e-1 (2.39e-2) -	6.7784e+1 (6.78e+1) -	1.5334e+0 (6.71e+0) -	1.6302e-1 (1.66e-2) -	1.4048e+1 (1.66e+1) -	6.3425e-2 (3.21e-4)
UC2-C2-DTLZ3	5	8.9236e+1 (3.70e-2) -	3.2097e-1 (3.89e-4) -	8.0715e+1 (2.66e+1) -	6.4767e+1 (5.77e+1) -	8.9231e+1 (4.19e-2) -	5.7615e-1 (1.04e-2) -	8.9329e+1 (6.96e-2) -	1.9599e-1 (1.23e-3)
UC2-C3-DTLZ1	5	7.4048e+0 (1.33e+1) -	1.2459e-1 (3.84e-5) -	1.5942e+0 (6.52e+0) -	3.9036e+1 (4.63e+0) -	8.7685e-2 (5.50e-2) -	1.9408e-1 (2.14e-2) -	1.0661e+1 (1.53e+1) -	7.3132e-2 (3.13e-5)
UC2-C3-DTLZ2	5	5.6105e-1 (5.91e-4) -	5.2010e-1 (3.97e-2) -	9.6043e-1 (8.95e-2) -	1.1175e+0 (8.17e-3) -	5.5754e-1 (2.10e-2) -	5.2168e-1 (5.58e-2) -	5.6263e-1 (2.76e-3) -	4.9071e-1 (2.98e-2)
UC2-C3-DTLZ3	5	8.9239e+1 (3.83e-2) -	5.5095e-1 (5.04e-2) -	8.4930e+1 (1.92e+1) -	1.1104e+2 (1.99e+1) -	8.9221e+1 (3.64e-2) -	5.8615e-1 (6.49e-3) -	8.9326e+1 (7.60e-2) -	4.8609e-1 (3.52e-2)
UC3-C1-DTLZ1	5	1.0665e+1 (1.71e+1) -	1.3609e-1 (1.12e-2) -	1.5529e+1 (1.82e+1) -	5.5374e+1 (7.87e+0) -	4.5212e-1 (8.04e-2) -	1.4330e-1 (1.26e-2) -	2.0660e+1 (2.58e+1) -	7.9122e-2 (5.79e-3)
UC3-C2-DTLZ1	5	2.1972e+0 (3.89e+0) -	1.1350e-1 (3.78e-5) -	8.5682e+0 (1.59e+1) -	1.6140e+1 (0.00e+0) =	6.8819e-2 (1.33e-3) -	1.5316e-1 (1.68e-2) -	6.6638e+0 (8.31e+0) -	6.3549e-2 (7.79e-4)
UC3-C2-DTLZ3	5	4.4199e+1 (1.41e+1) -	3.2095e-1 (1.49e-4) -	8.7805e+0 (1.75e+1) -	3.7720e+1 (1.82e+1) -	4.4100e+1 (2.19e-2) -	5.7663e-1 (1.24e-2) -	3.3724e+1 (1.90e+1) -	1.9504e-1 (5.96e-4)
UC3-C3-DTLZ1	5	1.3943e+0 (3.30e+0) -	1.2458e-1 (1.89e-5) -	2.0688e+1 (1.77e+1) -	4.4304e+1 (2.45e+1) -	9.3685e-1 (2.72e+0) -	1.9899e-1 (2.03e-2) -	9.1117e+0 (1.39e+1) -	7.3650e-2 (1.67e-3)
UC3-C3-DTLZ2	5	4.2388e-1 (9.08e-3) +	5.0624e-1 (2.15e-2) -	5.2852e-1 (2.29e-2) -	7.2930e-1 (7.18e-2) -	4.0195e-1 (3.70e-3) +	4.2779e-1 (6.50e-3) +	4.3021e-1 (5.17e-3) +	4.5346e-1 (3.84e-3)
UC3-C3-DTLZ3	5	4.4127e+1 (1.54e-2) -	5.3901e-1 (4.90e-2) -	4.4087e+1 (7.50e-3) -	4.4975e+1 (2.67e-1) -	4.4099e+1 (1.55e-2) -	5.8705e-1 (4.57e-3) -	3.9984e+1 (1.30e+1) -	4.7947e-1 (3.36e-2)
UC4-C1-DTLZ1	5	3.2287e+0 (7.91e-1) -	2.9534e+0 (5.40e-2) -	2.9291e+1 (8.46e+0) -	NaN (NaN) -	5.6620e+0 (4.34e-1) -	4.2119e+0 (2.09e+0) -	3.3845e+1 (2.66e+1) -	1.8571e+0 (1.88e-1)
UC4-C2-DTLZ1	5	1.5790e+0 (1.05e-1) -	NaN (NaN) -	1.7763e+1 (1.64e+1) -	1.8570e+1 (1.56e+1) -	1.2651e+0 (3.17e-1) +	1.9223e+0 (1.46e-1) -	6.8346e+0 (4.53e+0) -	1.3693e+0 (8.96e-2)
UC4-C2-DTLZ3	5	2.4281e+0 (1.40e-1) -	NaN (NaN) -	1.7618e+1 (1.47e+1) -	4.0090e+1 (2.14e+1) -	1.8618e+0 (1.31e-1) +	3.9984e+0 (2.94e-1) -	2.3324e+0 (1.66e-1) -	2.2235e+0 (1.45e-1)
UC4-C3-DTLZ1	5	1.8006e+0 (2.63e-1) =	NaN (NaN) -	1.9568e+1 (1.63e+1) -	8.7458e+0 (4.95e+0) -	1.5678e+0 (1.39e-1) =	2.5348e+0 (3.07e-1) -	1.9260e+0 (6.06e-1) -	1.7086e+0 (2.84e-1)
UC4-C3-DTLZ2	5	6.1183e-1 (2.61e-2) -	NaN (NaN) -	7.9063e-1 (6.89e-2) -	1.1106e+0 (7.13e-3) -	5.2330e-1 (3.37e-3) =	5.9028e-1 (3.73e-3) -	5.2350e-1 (2.79e-3) =	5.0487e-1 (5.23e-2)
UC4-C3-DTLZ3	5	6.2991e+0 (4.24e-1) -	NaN (NaN) -	3.1007e+1 (1.01e+1) -	3.8827e+1 (1.04e+1) -	5.9569e+0 (8.67e-2) -	5.9779e+0 (2.54e-2) -	6.4708e+0 (8.90e-1) -	5.3686e+0 (3.82e-1)
UC5-C1-DTLZ1	5	9.4330e-2 (6.25e-2) =	1.4533e-1 (1.40e-3) -	1.3135e-1 (3.30e-2) -	NaN (NaN) -	6.2839e-2 (8.86e-3) +	1.8023e-1 (7.72e-2) -	1.0601e-1 (6.48e-2) =	6.9732e-2 (5.87e-3)
UC5-C2-DTLZ1	5	8.0109e-2 (6.45e-3) -	NaN (NaN) -	1.2337e-1 (6.23e-3) -	NaN (NaN) -	7.3594e-2 (2.88e-3) -	1.5492e-1 (3.11e-2) -	8.2156e-2 (3.48e-3) -	6.5739e-2 (4.28e-3)
UC5-C2-DTLZ3	5	2.3076e-1 (8.99e-3) -	NaN (NaN) -	3.2351e-1 (3.50e-3) -	NaN (NaN) -	NaN (NaN) -	5.8973e-1 (6.92e-3) -	2.1974e-1 (8.48e-3) -	2.0733e-1 (1.06e-2)
UC5-C3-DTLZ1	5	8.2385e-2 (7.75e-3) -	NaN (NaN) -	1.5443e-1 (2.55e-2) -	NaN (NaN) -	8.8043e-2 (5.80e-3) -	1.8757e-1 (3.51e-2) -	9.5785e-2 (1.31e-2) -	7.5887e-2 (6.24e-3)
UC5-C3-DTLZ2	5	5.3352e-1 (9.26e-3) -	NaN (NaN) -	7.8575e-1 (7.64e-2) -	1.1087e+0 (1.53e-2) -	5.2201e-1 (2.48e-3) =	5.9147e-1 (2.43e-3) -	5.2346e-1 (2.65e-3) =	4.9519e-1 (4.53e-2)
UC5-C3-DTLZ3	5	6.0263e-1 (1.81e-1) -	NaN (NaN) -	1.0300e+0 (1.90e-3) -	NaN (NaN) -	5.9737e-1 (1.71e-1) -	5.9632e-1 (2.63e-3) -	5.2326e-1 (2.38e-3) =	5.0789e-1 (5.04e-2)
+/-/=		2/26/2	0/30/0	0/30/0	0/27/3	6/20/4	1/29/0	3/23/4	

TABLE XI
THE COMPARISON RESULTS OF IGD$^+$ METRIC ON FIVE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	5	5.1111e-2 (8.60e-4) +	9.1464e-2 (5.68e-3) -	8.4822e-2 (5.19e-3) -	NaN (NaN) -	4.0842e-2 (4.59e-4) +	9.7387e-2 (8.52e-3) -	5.1115e-2 (7.36e-3) +	5.7524e-2 (1.09e-3)
UC1-C2-DTLZ1	5	5.3395e-2 (5.79e-4) -	7.9834e-2 (7.97e-5) -	8.1155e-2 (9.87e-4) -	NaN (NaN) -	5.6566e-2 (1.71e-3) -	1.0578e-1 (1.31e-2) -	8.7435e-2 (7.08e-2) -	4.5919e-2 (5.12e-5)
UC1-C2-DTLZ3	5	8.5328e-2 (1.49e-3) -	1.1784e-1 (1.38e-4) -	1.2665e-1 (7.01e-3) -	6.5879e-1 (0.00e+0) =	NaN (NaN) -	1.9723e-1 (2.28e-3) -	NaN (NaN) -	7.1504e-2 (4.63e-4)
UC1-C3-DTLZ1	5	5.6876e-2 (5.17e-3) -	9.0963e-2 (1.41e-5) -	9.1889e-2 (1.02e-2) -	NaN (NaN) -	5.6493e-2 (1.88e-3) -	1.3389e-1 (1.76e-2) -	6.5612e-2 (4.95e-3) -	5.1492e-2 (4.38e-5)
UC1-C3-DTLZ2	5	1.9545e-1 (1.85e-3) -	1.9504e-1 (1.98e-3) -	5.1138e-1 (1.14e-1) -	6.9281e-1 (2.49e-2) -	1.8989e-1 (3.58e-3) -	1.8911e-1 (3.65e-4) +	1.8704e-1 (2.10e-3) +	1.8954e-1 (4.05e-5)
UC1-C3-DTLZ3	5	2.8348e-1 (1.85e-1) -	1.9595e-1 (2.60e-3) -	6.5581e-1 (7.58e-7) -	6.6079e-1 (0.00e+0) =	NaN (NaN) -	1.9917e-1 (4.05e-4) -	NaN (NaN) -	1.9059e-1 (2.14e-3)
UC2-C1-DTLZ1	5	1.3678e+1 (1.60e+1) -	9.4957e-2 (3.28e-4) -	1.4304e+0 (6.06e+0) -	3.6537e+1 (5.26e+0) -	1.7922e+0 (6.52e+0) -	1.0849e-1 (1.56e-2) -	1.2586e+1 (1.64e+1) -	5.5694e-2 (6.10e-3)
UC2-C2-DTLZ1	5	1.0242e+1 (1.47e+1) -	7.9865e-2 (9.05e-5) -	8.5867e-2 (1.65e-2) -	6.7778e+1 (6.78e+1) -	1.5216e+0 (6.71e+0) -	1.1880e-1 (1.55e-2) -	1.4038e+1 (1.66e+1) -	4.5995e-2 (2.13e-4)
UC2-C2-DTLZ3	5	8.9236e+1 (3.69e-2) -	1.1792e-1 (1.09e-4) -	8.0700e+1 (2.66e+1) -	6.4694e+1 (5.78e+1) -	8.9230e+1 (4.19e-2) -	1.9740e-1 (2.25e-3) -	8.9328e+1 (6.92e-2) -	7.1824e-2 (3.13e-4)
UC2-C3-DTLZ1	5	7.3781e+0 (1.33e+1) -	9.0987e-2 (7.33e-5) -	1.5549e+0 (6.53e+0) -	3.9035e+1 (4.63e+0) -	6.9630e-2 (4.68e-2) -	1.4489e-1 (2.05e-2) -	1.0645e+1 (1.54e+1) -	5.1511e-2 (5.64e-5)
UC2-C3-DTLZ2	5	1.9876e-1 (4.08e-5) -	1.9530e-1 (2.22e-3) -	5.4643e-1 (9.09e-2) -	6.8490e-1 (1.23e-2) -	1.9895e-1 (1.53e-3) -	1.9474e-1 (3.63e-3) =	1.9882e-1 (6.01e-5) -	1.9384e-1 (1.95e-3)
UC2-C3-DTLZ3	5	8.9238e+1 (3.82e-2) -	1.9703e-1 (2.86e-3) -	8.4911e+1 (1.93e+1) -	1.1104e+2 (1.99e+1) -	8.9221e+1 (3.63e-2) -	1.9918e-1 (4.46e-4) -	8.9325e+1 (7.54e-2) -	1.9187e-1 (2.70e-3)
UC3-C1-DTLZ1	5	1.0630e+1 (1.71e+1) -	9.2098e-2 (5.69e-3) -	1.5503e+1 (1.82e+1) -	5.5373e+1 (7.87e+0) -	3.7447e-1 (7.83e-2) -	1.0090e-1 (1.08e-2) -	2.0634e+1 (2.58e+1) -	5.8474e-2 (4.52e-3)
UC3-C2-DTLZ1	5	2.1812e+0 (3.90e+0) -	7.9828e-2 (3.57e-5) -	8.5451e+0 (1.59e+1) -	1.6139e+1 (0.00e+0) =	5.6344e-2 (2.01e-3) -	1.0983e-1 (1.51e-2) -	6.6490e+0 (8.32e+0) -	4.6054e-2 (4.87e-4)
UC3-C2-DTLZ3	5	4.4191e+1 (1.42e+1) -	1.1779e-1 (3.49e-5) -	8.6525e+0 (1.76e+1) -	3.7682e+1 (1.82e+1) -	4.4100e+1 (2.18e-2) -	1.9750e-1 (2.17e-3) -	3.3685e+1 (1.91e+1) -	7.1413e-2 (1.48e-4)
UC3-C3-DTLZ1	5	1.3758e+0 (3.31e+0) -	9.0979e-2 (3.67e-5) -	2.0681e+1 (1.78e+1) -	4.4303e+1 (2.45e+1) -	9.2132e-1 (2.73e+0) -	1.4816e-1 (2.11e-2) -	9.0953e+0 (1.39e+1) -	5.1854e-2 (1.14e-3)
UC3-C3-DTLZ2	5	2.0852e-1 (4.93e-2) -	1.9450e-1 (1.21e-3) -	3.7124e-1 (3.61e-2) -	6.6413e-1 (1.02e-1) -	2.0668e-1 (5.92e-3) -	1.9455e-1 (1.23e-2) -	2.4032e-1 (2.88e-2) -	1.8954e-1 (3.79e-5)
UC3-C3-DTLZ3	5	4.4126e+1 (1.53e-2) -	1.9644e-1 (2.71e-3) -	4.4086e+1 (7.44e-3) -	4.4969e+1 (2.66e-1) -	4.4099e+1 (1.55e-2) -	1.9918e-1 (4.02e-4) -	3.9949e+1 (1.31e+1) -	1.9132e-1 (2.54e-3)
UC4-C1-DTLZ1	5	2.2514e+0 (6.21e-1) -	2.0750e+0 (7.56e-2) -	2.9164e+1 (8.86e+0) -	NaN (NaN) -	4.6159e+0 (4.53e-1) -	3.0945e+0 (1.81e+0) -	3.3042e+1 (2.73e+1) -	1.3377e+0 (9.96e-2)
UC4-C2-DTLZ1	5	1.1207e+0 (7.04e-2) -	NaN (NaN) -	1.7476e+1 (1.66e+1) -	1.7902e+1 (1.59e+1) -	8.8831e-1 (2.28e-1) +	1.3055e+0 (1.03e-1) -	5.9860e+0 (4.35e+0) -	9.8882e-1 (6.30e-2)
UC4-C2-DTLZ3	5	9.4916e-1 (4.99e-2) -	NaN (NaN) -	1.6530e+1 (1.55e+1) -	3.8836e+1 (2.23e+1) -	8.5325e-1 (3.72e-2) -	1.4336e+0 (1.32e-1) -	1.1445e+0 (8.55e-2) -	7.8504e-1 (6.32e-2)
UC4-C3-DTLZ1	5	1.3070e+0 (1.85e-1) -	NaN (NaN) -	1.9190e+1 (1.66e+1) -	7.6319e+0 (5.37e+0) -	1.0807e+0 (7.27e-2) +	1.6776e+0 (1.84e-1) -	1.3441e+0 (4.72e-1) =	1.1651e+0 (1.30e-1)
UC4-C3-DTLZ2	5	2.1894e-1 (2.20e-2) -	NaN (NaN) -	3.9978e-1 (5.98e-2) -	6.7927e-1 (1.78e-2) -	1.9655e-1 (4.70e-4) +	1.9982e-1 (1.55e-4) +	1.9597e-1 (2.16e-4) +	2.0489e-1 (2.73e-2)
UC4-C3-DTLZ3	5	2.2580e+0 (3.36e-1) -	NaN (NaN) -	3.0137e+1 (1.17e+1) -	3.7627e+1 (1.16e+1) -	2.0383e+0 (1.76e-2) -	1.9976e+0 (8.69e-4) +	2.4868e+0 (6.83e-1) -	2.0232e+0 (1.72e-1)
UC5-C1-DTLZ1	5	7.2728e-2 (5.80e-2) =	1.0040e-1 (1.94e-3) -	9.7484e-2 (3.43e-2) -	NaN (NaN) -	4.5287e-2 (6.28e-3) +	1.3081e-1 (6.68e-2) -	8.1555e-2 (6.25e-2) =	5.0286e-2 (4.27e-3)
UC5-C2-DTLZ1	5	6.3534e-2 (9.61e-3) -	NaN (NaN) -	9.6607e-2 (9.96e-3) -	NaN (NaN) -	6.4971e-2 (5.25e-3) -	1.1462e-1 (2.64e-2) -	7.0121e-2 (4.40e-3) -	4.7640e-2 (2.93e-3)
UC5-C2-DTLZ3	5	1.0516e-1 (1.64e-2) -	NaN (NaN) -	1.2344e-1 (1.08e-2) -	NaN (NaN) -	NaN (NaN) -	2.0028e-1 (1.33e-3) -	1.4858e-1 (1.40e-2) -	7.4338e-2 (3.16e-3)
UC5-C3-DTLZ1	5	5.9566e-2 (6.19e-3) -	NaN (NaN) -	1.1070e-1 (1.35e-2) -	NaN (NaN) -	7.2946e-2 (5.01e-3) -	1.3989e-1 (3.28e-2) -	7.5139e-2 (9.39e-3) -	5.3211e-2 (3.65e-3)
UC5-C3-DTLZ2	5	1.9731e-1 (1.14e-3) -	NaN (NaN) -	4.0238e-1 (7.37e-2) -	6.7218e-1 (1.45e-2) -	1.9635e-1 (3.77e-4) -	1.9985e-1 (7.92e-5) -	1.9605e-1 (2.54e-4) -	1.9579e-1 (1.60e-2)
UC5-C3-DTLZ3	5	2.6238e-1 (1.65e-1) -	NaN (NaN) -	6.5586e-1 (7.59e-5) -	NaN (NaN) -	2.5164e-1 (1.51e-1) -	2.0023e-1 (3.08e-4) +	1.9592e-1 (1.95e-4) +	2.0521e-1 (2.71e-2)
+/-/=		1/28/1	0/30/0	0/30/0	0/27/3	5/25/0	4/25/1	4/24/2	

TABLE XII
THE COMPARISON RESULTS OF HV METRIC ON FIVE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	5	9.6976e-1 (2.08e-3) +	8.1097e-1 (7.56e-2) -	9.0342e-1 (2.98e-2) -	NaN (NaN) -	9.6202e-1 (6.56e-3) +	8.7775e-1 (1.55e-2) -	9.4276e-1 (4.49e-2) +	9.3883e-1 (1.09e-2)
UC1-C2-DTLZ1	5	9.6946e-1 (4.44e-4) -	9.3663e-1 (3.13e-4) -	9.3533e-1 (9.95e-4) -	NaN (NaN) -	9.6349e-1 (1.56e-3) -	8.6853e-1 (2.22e-2) -	8.7044e-1 (2.28e-1) -	9.7487e-1 (1.35e-4)
UC1-C2-DTLZ3	5	7.6207e-1 (4.58e-3) -	7.1068e-1 (5.63e-4) -	6.9162e-1 (1.55e-2) -	9.3208e-2 (0.00e+0) =	NaN (NaN) -	3.8896e-1 (9.74e-3) -	NaN (NaN) -	7.9448e-1 (1.13e-3)
UC1-C3-DTLZ1	5	9.6408e-1 (6.57e-3) -	9.0684e-1 (3.05e-4) -	8.5049e-1 (9.65e-2) -	NaN (NaN) -	9.6569e-1 (1.57e-3) -	8.0392e-1 (3.61e-2) -	9.4495e-1 (7.95e-3) -	9.7150e-1 (2.01e-4)
UC1-C3-DTLZ2	5	3.9466e-1 (1.03e-2) -	4.0675e-1 (1.15e-2) -	1.6777e-1 (6.00e-2) -	6.1771e-2 (2.26e-2) -	4.3084e-1 (2.11e-2) +	4.3862e-1 (1.60e-3) +	4.4668e-1 (1.22e-2) +	4.2495e-1 (4.80e-4)
UC1-C3-DTLZ3	5	3.3594e-1 (1.20e-1) -	4.0121e-1 (1.51e-2) -	9.5454e-2 (1.25e-6) -	8.9401e-2 (0.00e+0) =	NaN (NaN) -	3.8125e-1 (1.47e-3) -	NaN (NaN) -	4.1909e-1 (1.24e-2)
UC2-C1-DTLZ1	5	3.5041e-1 (3.61e-1) -	7.5538e-1 (2.74e-3) -	6.6410e-1 (1.74e-1) -	0.0000e+0 (0.00e+0) -	1.2362e-1 (7.40e-2) -	8.7420e-1 (3.27e-2) =	4.6843e-1 (3.90e-1) -	9.0170e-1 (7.41e-2)
UC2-C2-DTLZ1	5	5.8721e-1 (4.63e-1) -	9.3665e-1 (2.62e-4) -	9.0975e-1 (9.95e-2) -	8.5168e-3 (3.07e-2) -	9.1803e-1 (2.10e-1) -	8.5299e-1 (2.86e-2) -	5.4261e-1 (4.82e-1) -	9.7488e-1 (2.31e-4)
UC2-C2-DTLZ3	5	0.0000e+0 (0.00e+0) -	7.1053e-1 (4.14e-4) -	7.3904e-3 (2.35e-2) -	4.1372e-2 (5.45e-2) -	0.0000e+0 (0.00e+0) -	3.8843e-1 (9.71e-3) -	0.0000e+0 (0.00e+0) -	7.9378e-1 (4.83e-4)
UC2-C3-DTLZ1	5	6.0948e-1 (4.41e-1) -	9.0677e-1 (3.93e-4) -	7.3322e-1 (3.33e-1) -	0.0000e+0 (0.00e+0) -	9.2878e-1 (1.54e-1) -	7.9317e-1 (4.83e-2) -	6.1968e-1 (4.52e-1) -	9.7163e-1 (1.40e-4)
UC2-C3-DTLZ2	5	3.8241e-1 (4.59e-4) -	4.0497e-1 (1.30e-2) -	1.4375e-1 (4.16e-2) -	6.8841e-2 (1.12e-2) -	3.8317e-1 (9.14e-3) -	4.0772e-1 (2.08e-2) =	3.8263e-1 (5.73e-4) -	4.1006e-1 (1.14e-2)
UC2-C3-DTLZ3	5	0.0000e+0 (0.00e+0) -	3.9485e-1 (1.63e-2) -	4.5452e-3 (2.08e-2) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	3.8112e-1 (1.56e-3) -	0.0000e+0 (0.00e+0) -	4.1165e-1 (1.55e-2)
UC3-C1-DTLZ1	5	6.5456e-1 (4.24e-1) =	7.9927e-1 (7.33e-2) -	4.3068e-1 (3.83e-1) -	0.0000e+0 (0.00e+0) -	1.2907e-1 (1.31e-1) -	8.8032e-1 (2.11e-2) =	4.4017e-1 (3.94e-1) -	8.8431e-1 (6.56e-2)
UC3-C2-DTLZ1	5	7.3882e-1 (4.23e-1) -	9.3670e-1 (2.10e-4) -	6.6778e-1 (4.33e-1) -	0.0000e+0 (0.00e+0) =	9.6359e-1 (1.49e-3) -	8.6274e-1 (2.60e-2) -	4.8042e-1 (4.69e-1) -	9.7487e-1 (6.08e-4)
UC3-C2-DTLZ3	5	3.5790e-2 (1.64e-1) -	7.1073e-1 (5.13e-4) -	3.4635e-1 (2.92e-1) -	2.7500e-2 (6.74e-2) -	0.0000e+0 (0.00e+0) -	3.8758e-1 (8.77e-3) -	1.0395e-1 (2.19e-1) -	7.9466e-1 (6.95e-4)
UC3-C3-DTLZ1	5	8.2293e-1 (3.46e-1) -	9.0686e-1 (2.35e-4) -	1.7410e-1 (3.68e-1) -	0.0000e+0 (0.00e+0) -	8.7145e-1 (2.90e-1) -	7.6740e-1 (5.17e-2) -	5.6040e-1 (4.68e-1) -	9.7110e-1 (1.47e-3)
UC3-C3-DTLZ2	5	4.2476e-1 (5.61e-2) -	4.0956e-1 (6.90e-3) -	2.9284e-1 (2.78e-2) -	4.4070e-2 (2.61e-2) -	4.3900e-1 (1.31e-2) +	4.6824e-1 (8.71e-3) +	3.9258e-1 (2.33e-2) -	4.2684e-1 (2.29e-3)
UC3-C3-DTLZ3	5	0.0000e+0 (0.00e+0) -	3.9876e-1 (1.57e-2) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	3.8101e-1 (1.50e-3) -	1.8159e-2 (8.12e-2) -	4.1485e-1 (1.48e-2)
UC4-C1-DTLZ1	5	7.3390e-1 (8.26e-2) -	7.2203e-1 (1.91e-2) -	5.6803e-2 (1.86e-1) -	NaN (NaN) -	4.6381e-1 (7.27e-2) -	6.3028e-1 (2.43e-1) =	5.4197e-2 (7.84e-2) -	8.0966e-1 (9.56e-3)
UC4-C2-DTLZ1	5	9.6429e-1 (5.03e-3) -	NaN (NaN) -	3.9146e-1 (4.00e-1) -	4.9320e-2 (9.07e-2) -	9.7088e-1 (1.79e-2) +	9.3528e-1 (9.68e-3) -	4.2523e-1 (3.73e-1) -	9.6810e-1 (7.14e-3)
UC4-C2-DTLZ3	5	7.5116e-1 (1.04e-2) -	NaN (NaN) -	1.4263e-1 (1.78e-1) -	1.7445e-2 (3.72e-2) -	7.8240e-1 (7.90e-3) =	6.0403e-1 (4.79e-2) -	7.0735e-1 (2.03e-2) -	7.8000e-1 (1.17e-2)
UC4-C3-DTLZ1	5	9.5629e-1 (1.16e-2) =	NaN (NaN) -	3.4076e-1 (3.92e-1) -	2.0299e-1 (2.01e-1) -	9.6346e-1 (4.49e-3) =	9.1023e-1 (1.67e-2) -	9.2511e-1 (6.76e-2) -	9.6218e-1 (8.87e-3)
UC4-C3-DTLZ2	5	3.3140e-1 (2.92e-2) -	NaN (NaN) -	2.2878e-1 (3.92e-2) -	7.4084e-2 (1.62e-2) -	3.9046e-1 (1.62e-3) -	3.7905e-1 (7.80e-4) -	3.9294e-1 (7.13e-4) -	3.9904e-1 (3.08e-2)
UC4-C3-DTLZ3	5	3.4967e-1 (2.92e-2) -	NaN (NaN) -	1.7532e-2 (3.70e-2) -	9.8187e-3 (2.95e-2) -	3.6509e-1 (6.16e-3) -	3.7916e-1 (6.81e-4) -	3.3539e-1 (5.70e-2) -	3.8921e-1 (1.76e-2)
UC5-C1-DTLZ1	5	8.8734e-1 (1.84e-1) -	7.3260e-1 (6.21e-3) -	8.5995e-1 (1.31e-1) -	NaN (NaN) -	9.4830e-1 (2.53e-2) -	7.5577e-1 (1.64e-1) -	8.3889e-1 (2.02e-1) -	9.6541e-1 (1.24e-2)
UC5-C2-DTLZ1	5	9.6174e-1 (8.23e-3) -	NaN (NaN) -	9.0957e-1 (1.70e-2) -	NaN (NaN) -	9.5636e-1 (4.76e-3) -	8.5420e-1 (5.11e-2) -	9.4166e-1 (4.45e-3) -	9.7206e-1 (6.16e-3)
UC5-C2-DTLZ3	5	7.3181e-1 (2.88e-2) -	NaN (NaN) -	6.9827e-1 (2.03e-2) -	NaN (NaN) -	NaN (NaN) -	3.7787e-1 (5.31e-3) -	6.3841e-1 (2.52e-2) -	7.8891e-1 (6.07e-3)
UC5-C3-DTLZ1	5	9.6235e-1 (5.74e-3) -	NaN (NaN) -	8.4169e-1 (5.47e-2) -	NaN (NaN) -	9.4601e-1 (6.50e-3) -	7.8715e-1 (7.62e-2) -	9.3023e-1 (1.44e-2) -	9.6916e-1 (5.35e-3)
UC5-C3-DTLZ2	5	3.8800e-1 (3.67e-3) -	NaN (NaN) -	2.2863e-1 (4.98e-2) -	8.0513e-2 (1.33e-2) -	3.9123e-1 (1.26e-3) -	3.7902e-1 (6.30e-4) -	3.9282e-1 (6.83e-4) -	4.0660e-1 (2.31e-2)
UC5-C3-DTLZ3	5	3.4756e-1 (1.06e-1) -	NaN (NaN) -	9.5446e-2 (1.22e-5) -	NaN (NaN) -	3.4611e-1 (1.01e-1) -	3.7746e-1 (1.10e-3) -	3.9351e-1 (5.46e-4) -	3.9639e-1 (2.94e-2)
+/-/=		1/27/2	0/30/0	0/30/0	0/27/3	4/24/2	2/24/4	2/28/0	

TABLE XIII
THE COMPARISON RESULTS OF IGD METRIC ON TEN OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	10	1.3654e-1 (2.33e-3) -	1.7771e-1 (2.42e-3) -	1.6124e-1 (2.15e-3) -	NaN (NaN) -	NaN (NaN) -	1.6044e-1 (2.67e-2) -	NaN (NaN) -	1.2231e-1 (4.11e-3)
UC1-C2-DTLZ1	10	1.3657e-1 (1.87e-3) -	1.7843e-1 (2.44e-3) -	1.6778e-1 (9.02e-4) -	NaN (NaN) -	NaN (NaN) -	1.7524e-1 (2.29e-2) -	NaN (NaN) -	1.2126e-1 (5.44e-3)
UC1-C2-DTLZ3	10	4.9528e-1 (1.01e-2) =	7.3185e-1 (1.43e-2) -	6.9470e-1 (1.08e-2) -	NaN (NaN) -	NaN (NaN) -	6.9122e-1 (9.48e-3) -	NaN (NaN) -	4.9084e-1 (3.30e-2)
UC1-C3-DTLZ1	10	1.3749e-1 (4.93e-3) -	1.9438e-1 (4.01e-3) -	1.8025e-1 (8.13e-3) -	NaN (NaN) -	NaN (NaN) -	1.8459e-1 (1.88e-2) -	NaN (NaN) -	1.2203e-1 (3.95e-3)
UC1-C3-DTLZ2	10	8.7245e-1 (2.56e-1) -	1.0352e+0 (8.02e-2) -	1.0905e+0 (0.00e+0) =	1.2837e+0 (1.69e-2) -	NaN (NaN) -	7.0354e-1 (3.37e-3) -	1.1727e+0 (0.00e+0) =	6.7347e-1 (3.52e-2)
UC1-C3-DTLZ3	10	8.9496e-1 (2.59e-1) -	1.0490e+0 (7.94e-2) -	1.1990e+0 (1.26e-2) -	NaN (NaN) -	NaN (NaN) -	7.0918e-1 (3.07e-3) -	NaN (NaN) -	6.7584e-1 (4.38e-2)
UC2-C1-DTLZ1	10	2.0328e+1 (1.30e+1) -	1.7849e-1 (2.01e-3) -	5.9072e+0 (9.30e+0) -	3.1698e+1 (1.08e+1) -	5.7146e+1 (1.05e+1) -	1.7871e-1 (1.51e-2) -	5.2407e+1 (1.23e+1) -	1.2736e-1 (7.90e-3)
UC2-C2-DTLZ1	10	2.2099e+1 (1.26e+1) -	1.7821e-1 (2.33e-3) -	3.9780e+0 (8.05e+0) -	3.2359e+1 (7.71e+0) -	5.8023e+1 (7.72e+0) -	2.0847e-1 (2.28e-2) -	5.8232e+1 (5.82e+0) -	1.2473e-1 (7.45e-3)
UC2-C2-DTLZ3	10	8.9405e+1 (4.89e-2) -	6.6523e+0 (2.29e+1) -	6.8231e+1 (3.87e+1) -	9.0009e+1 (4.51e-1) -	9.3086e+1 (3.20e+0) -	6.9040e-1 (7.03e-3) -	1.3710e+2 (2.37e+1) -	5.3321e-1 (4.15e-2)
UC2-C3-DTLZ1	10	1.8929e+1 (1.36e+1) -	1.9496e-1 (2.28e-3) -	5.8663e+0 (9.22e+0) -	3.2236e+1 (7.91e+0) -	6.0195e+1 (1.03e+1) -	2.3644e-1 (2.71e-2) -	5.1409e+1 (1.25e+1) -	1.2446e-1 (4.79e-3)
UC2-C3-DTLZ2	10	9.4669e-1 (2.63e-1) -	1.0882e+0 (7.39e-2) -	NaN (NaN) -	NaN (NaN) -	NaN (NaN) -	7.1671e-1 (1.91e-3) =	NaN (NaN) -	7.2784e-1 (5.22e-2)
UC2-C3-DTLZ3	10	8.9405e+1 (3.94e-2) -	2.3163e+1 (4.41e+1) -	8.0939e+1 (2.65e+1) -	8.9912e+1 (2.86e-1) -	9.3052e+1 (3.44e+0) -	7.1092e-1 (4.47e-3) -	1.1992e+2 (2.89e+1) -	6.9061e-1 (5.24e-2)
UC3-C1-DTLZ1	10	1.8425e-1 (3.44e-2) -	1.7812e-1 (1.81e-3) -	1.1436e+1 (1.33e+1) -	7.7337e+1 (1.92e+1) -	4.1133e+1 (5.64e+0) -	1.5676e-1 (2.35e-2) -	6.7390e+1 (9.34e+0) -	1.2354e-1 (4.65e-3)
UC3-C2-DTLZ1	10	1.0587e+0 (2.89e+0) -	1.7783e-1 (1.66e-3) -	5.8013e+0 (1.19e+1) -	NaN (NaN) -	3.4794e+1 (1.44e+0) -	1.6438e-1 (1.60e-2) -	1.5030e+1 (6.29e+0) -	1.2474e-1 (7.92e-3)
UC3-C2-DTLZ3	10	4.4258e+1 (1.05e-2) -	7.3216e-1 (1.64e-2) -	1.5238e+1 (2.11e+1) -	8.7441e+1 (1.04e+1) -	4.4236e+1 (1.54e-2) -	6.9513e-1 (7.10e-3) -	8.5032e+1 (1.32e+1) -	4.8734e-1 (3.92e-2)
UC3-C3-DTLZ1	10	1.4315e-1 (4.69e-3) -	1.9329e-1 (5.15e-3) -	1.0659e+1 (1.40e+1) -	NaN (NaN) -	3.5619e+1 (1.33e+0) -	1.8721e-1 (2.33e-2) -	1.5502e+1 (7.36e+0) -	1.2579e-1 (5.41e-3)
UC3-C3-DTLZ2	10	6.3379e-1 (2.22e-3) +	1.0412e+0 (5.42e-2) -	8.7473e-1 (3.05e-2) -	1.7988e+0 (1.69e-2) -	8.2176e-1 (4.15e-2) -	6.3610e-1 (2.33e-2) +	9.3318e-1 (1.69e-2) -	6.6796e-1 (3.58e-2)
UC3-C3-DTLZ3	10	4.4262e+1 (1.07e-2) -	1.9598e+1 (2.19e+1) -	4.0215e+1 (1.30e+1) -	8.5544e+1 (1.34e+1) -	4.4242e+1 (2.01e-2) -	7.0943e-1 (3.12e-3) =	7.6604e+1 (2.05e+1) -	7.2024e-1 (7.58e-2)
UC4-C1-DTLZ1	10	5.1155e+0 (6.24e-1) -	8.3880e+0 (8.80e+0) -	1.3039e+1 (1.04e+1) -	9.9762e+1 (4.86e+1) -	4.0203e+1 (6.24e+0) -	4.9882e+0 (2.12e+0) -	3.5107e+1 (2.98e+1) -	2.6155e+0 (1.31e-1)
UC4-C2-DTLZ1	10	2.8933e+0 (1.96e-1) -	3.5544e+0 (3.60e-2) -	4.6203e+0 (5.12e+0) -	1.9698e+1 (0.00e+0) =	3.3333e+1 (9.93e-1) -	2.7296e+0 (1.72e-1) -	1.1200e+1 (9.01e+0) -	2.5604e+0 (1.38e-1)
UC4-C2-DTLZ3	10	5.0124e+0 (6.14e-2) +	7.4139e+0 (2.55e-1) -	2.1689e+1 (1.61e+1) -	8.1084e+1 (1.32e+1) -	3.5355e+1 (5.87e+0) -	5.7340e+0 (1.84e-1) -	7.4059e+1 (1.56e+1) -	5.4070e+0 (3.45e-1)
UC4-C3-DTLZ1	10	2.7063e+0 (5.01e-2) -	3.6566e+0 (8.32e-2) -	1.0467e+1 (1.07e+1) -	4.6852e+1 (5.99e+1) -	3.3148e+1 (1.51e+0) -	2.9667e+0 (2.88e-1) -	9.3977e+0 (6.03e+0) -	2.5854e+0 (1.39e-1)
UC4-C3-DTLZ2	10	7.2890e-1 (1.54e-3) -	1.4404e+0 (5.01e-1) -	1.2719e+0 (3.28e-1) -	NaN (NaN) -	NaN (NaN) -	7.2694e-1 (3.06e-2) -	NaN (NaN) -	7.2231e-1 (6.87e-2)
UC4-C3-DTLZ3	10	7.3792e+0 (1.58e-1) =	3.3460e+1 (1.07e+1) -	3.6817e+1 (5.63e+0) -	8.1240e+1 (1.33e+1) -	3.6589e+1 (4.76e-2) -	7.2227e+0 (1.94e-2) =	6.8482e+1 (1.88e+1) -	7.4641e+0 (6.49e-1)
UC5-C1-DTLZ1	10	1.4474e-1 (4.14e-2) -	1.7765e-1 (7.04e-3) -	1.6334e-1 (5.10e-3) -	NaN (NaN) -	NaN (NaN) -	2.3146e-1 (7.12e-2) -	NaN (NaN) -	1.3020e-1 (6.56e-3)
UC5-C2-DTLZ1	10	1.4166e-1 (5.53e-3) -	1.7923e-1 (3.89e-3) -	1.6663e-1 (2.30e-3) -	NaN (NaN) -	NaN (NaN) -	1.8822e-1 (3.31e-2) -	NaN (NaN) -	1.3139e-1 (7.22e-3)
UC5-C2-DTLZ3	10	4.9402e-1 (8.88e-3) +	7.4971e-1 (4.04e-2) -	6.9517e-1 (1.81e-2) -	NaN (NaN) -	NaN (NaN) -	7.0075e-1 (9.63e-3) -	NaN (NaN) -	5.2880e-1 (3.12e-2)
UC5-C3-DTLZ1	10	1.4111e-1 (6.42e-3) -	1.8769e-1 (1.09e-2) -	1.7930e-1 (3.42e-3) -	NaN (NaN) -	NaN (NaN) -	2.0675e-1 (3.61e-2) -	NaN (NaN) -	1.2809e-1 (5.02e-3)
UC5-C3-DTLZ2	10	9.1014e-1 (2.49e-1) =	1.0869e+0 (6.74e-2) -	1.1271e+0 (5.30e-2) -	NaN (NaN) -	NaN (NaN) -	7.2283e-1 (2.15e-2) =	NaN (NaN) -	7.3877e-1 (7.16e-2)
UC5-C3-DTLZ3	10	8.5394e-1 (2.42e-1) -	1.0800e+0 (7.06e-2) -	1.1858e+0 (2.80e-2) -	NaN (NaN) -	NaN (NaN) -	7.1288e-1 (4.72e-3) -	NaN (NaN) -	6.9892e-1 (3.92e-2)
+/-/=		0/29/1	1/25/4	3/24/3	0/30/0	0/29/1	0/29/1	0/30/0	

TABLE XIV
THE COMPARISON RESULTS OF IGD^+ METRIC ON TEN OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	10	9.3675e-2 (3.89e-3) -	1.0347e-1 (1.50e-3) -	9.6210e-2 (1.85e-3) -	NaN (NaN) -	NaN (NaN) -	9.9340e-2 (1.55e-2) -	NaN (NaN) -	6.9181e-2 (1.57e-3)
UC1-C2-DTLZ1	10	9.4421e-2 (2.54e-3) -	1.0387e-1 (1.40e-3) -	1.0163e-1 (1.76e-3) -	NaN (NaN) -	NaN (NaN) -	1.1735e-1 (1.96e-2) -	NaN (NaN) -	6.8804e-2 (2.13e-3)
UC1-C2-DTLZ3	10	2.0416e-1 (6.46e-3) +	6.0413e-1 (2.14e-2) -	5.8900e-1 (8.42e-3) -	NaN (NaN) -	NaN (NaN) -	2.7659e-1 (3.40e-3) -	NaN (NaN) -	2.4849e-1 (4.88e-2)
UC1-C3-DTLZ1	10	9.3941e-2 (4.64e-3) -	1.1120e-1 (7.42e-4) -	1.0653e-1 (3.40e-3) -	NaN (NaN) -	NaN (NaN) -	1.2641e-1 (1.92e-2) -	NaN (NaN) -	7.1439e-2 (2.36e-3)
UC1-C3-DTLZ2	10	2.7957e-1 (5.15e-1) =	6.2094e-1 (8.95e-2) -	6.7128e-1 (0.00e+0) =	8.5687e-1 (3.79e-2) -	NaN (NaN) -	2.8058e-1 (4.57e-4) =	7.9257e-1 (0.00e+0) =	2.9610e-1 (3.18e-2)
UC1-C3-DTLZ3	10	2.7868e-1 (5.14e-1) =	6.7097e-1 (8.97e-2) -	7.9277e-1 (6.91e-4) -	NaN (NaN) -	NaN (NaN) -	2.8079e-1 (3.28e-4) +	NaN (NaN) -	3.5306e-1 (3.57e-2)
UC2-C1-DTLZ1	10	2.7470e+1 (2.84e+1) -	1.0403e-1 (1.43e-3) -	9.8617e-2 (2.00e+1) -	2.6928e+1 (1.01e+1) -	6.1971e+1 (7.49e+0) -	1.2542e-1 (2.93e-2) -	5.9918e+1 (1.25e+1) -	6.9786e-2 (3.70e-3)
UC2-C2-DTLZ1	10	2.8961e+1 (1.11e+1) -	1.0388e-1 (1.00e-3) -	1.0110e-1 (3.64e-3) -	3.1732e+1 (1.21e+1) -	6.0292e+1 (1.10e+1) -	1.4903e-1 (1.94e-2) -	5.9939e+1 (4.20e-2) -	6.9157e-2 (2.70e-3)
UC2-C2-DTLZ3	10	8.9398e+1 (5.97e-2) -	5.6689e-1 (5.60e-2) -	8.9325e+1 (2.22e+1) -	8.9888e+1 (4.37e-1) -	9.2130e+1 (4.50e+0) -	2.7627e-1 (2.72e-3) =	1.4390e+2 (2.85e+1) -	2.8491e-1 (6.10e-2)
UC2-C3-DTLZ1	10	2.7198e+1 (2.85e+1) -	1.1156e-1 (1.15e-3) -	1.0726e-1 (1.98e+1) -	3.2318e+1 (1.12e+1) -	6.2917e+1 (7.72e+0) -	1.8429e-1 (4.10e-2) -	5.9914e+1 (1.94e+1) -	7.1139e-2 (1.52e-3)
UC2-C3-DTLZ2	10	2.8150e-1 (5.15e-1) =	6.2766e-1 (9.11e-2) -	NaN (NaN) -	NaN (NaN) -	NaN (NaN) -	2.8174e-1 (1.39e-4) +	NaN (NaN) -	3.3970e-1 (7.58e-2)
UC2-C3-DTLZ3	10	8.9398e+1 (5.10e-2) -	7.3416e-1 (4.44e+1) -	8.9323e+1 (2.93e-2) -	8.9824e+1 (3.94e-1) -	9.1647e+1 (3.45e+0) -	2.8095e-1 (5.06e-4) +	1.0567e+2 (5.32e+1) -	3.5419e-1 (5.14e-2)
UC3-C1-DTLZ1	10	1.1901e-1 (3.19e-2) -	1.0382e-1 (7.74e-4) -	1.0008e-1 (2.63e+1) -	8.0161e+1 (1.66e+1) -	4.1988e+1 (6.15e+0) -	9.9071e-2 (1.69e-2) -	6.9976e+1 (8.57e+0) -	6.9209e-2 (2.34e-3)
UC3-C2-DTLZ1	10	9.5912e-2 (4.31e-3) -	1.0371e-1 (1.40e-3) -	1.0165e-1 (2.52e-3) -	NaN (NaN) -	3.5148e+1 (2.37e+0) -	1.1148e-1 (1.49e-2) -	1.9858e+1 (1.08e+1) -	7.0721e-2 (3.86e-3)
UC3-C2-DTLZ3	10	4.4255e+1 (9.48e-3) -	6.0955e-1 (2.54e-2) -	6.0304e-1 (4.37e+1) -	8.9748e+1 (2.40e-1) -	4.4238e+1 (1.97e-2) -	2.7702e-1 (3.52e-3) -	8.9222e+1 (1.57e-2) -	2.5512e-1 (5.20e-2)
UC3-C3-DTLZ1	10	9.8352e-2 (3.10e-3) -	1.1114e-1 (7.62e-4) -	1.0959e-1 (2.96e+1) -	NaN (NaN) -	3.5562e+1 (2.17e+0) -	1.2942e-1 (1.76e-2) -	1.2197e+1 (9.59e+0) -	7.2599e-2 (1.98e-3)
UC3-C3-DTLZ2	10	2.8181e-1 (1.49e-4) +	5.8147e-1 (9.02e-2) -	8.2092e-1 (1.16e-2) -	1.5311e+0 (2.81e-2) -	7.5168e-1 (6.52e-2) -	2.8030e-1 (8.63e-4) =	8.7139e-1 (6.07e-2) -	2.9607e-1 (6.22e-2)
UC3-C3-DTLZ3	10	4.4262e+1 (1.73e-2) -	6.7158e-1 (4.36e+1) -	4.4305e+1 (4.20e-2) -	8.9686e+1 (2.38e-1) -	4.4238e+1 (2.36e-2) -	2.8081e-1 (4.20e-4) +	8.9263e+1 (4.40e+1) -	3.5594e-1 (3.23e-2)
UC4-C1-DTLZ1	10	3.5869e+0 (6.52e-1) -	2.1350e+0 (5.53e+0) -	2.2784e+0 (2.17e+1) -	9.2560e+1 (3.94e+1) -	4.1756e+1 (1.19e+1) -	2.6786e+0 (2.26e+0) -	9.0492e+0 (5.92e+1) -	1.4126e+0 (7.81e-2)
UC4-C2-DTLZ1	10	1.9946e+0 (1.90e-1) -	2.0974e+0 (2.54e-2) -	1.9814e+0 (2.98e-2) -	1.9073e+1 (0.00e+0) =	3.3478e+1 (1.23e+0) -	1.6997e+0 (1.81e-1) -	7.1723e+0 (6.15e+0) -	1.3991e+0 (7.85e-2)
UC4-C2-DTLZ3	10	2.0465e+0 (4.46e-2) +	5.7867e+0 (4.04e-1) -	5.6746e+0 (3.26e+1) -	8.5131e+1 (1.03e+0) -	3.6529e+1 (4.92e-2) -	2.2688e+0 (9.37e-2) +	8.1414e+1 (4.25e-2) -	3.0185e+0 (2.79e-1)
UC4-C3-DTLZ1	10	1.8824e+0 (5.48e-2) -	2.1782e+0 (2.27e-2) -	2.1328e+0 (2.48e+1) -	4.5922e+1 (8.62e+1) -	3.3048e+1 (1.46e+0) -	1.8853e+0 (1.69e-1) -	7.8819e+0 (3.45e+0) -	1.4593e+0 (5.80e-2)
UC4-C3-DTLZ2	10	2.8891e-1 (3.33e-3) +	6.7258e-1 (1.42e+0) -	7.9291e-1 (1.23e-1) -	NaN (NaN) -	NaN (NaN) -	2.8259e-1 (7.67e-3) +	NaN (NaN) -	3.8739e-1 (2.36e-2)
UC4-C3-DTLZ3	10	2.8407e+0 (2.82e-1) +	3.8366e+1 (1.94e-1) -	3.8001e+1 (1.35e-1) -	8.4934e+1 (1.86e+0) -	3.6493e+1 (6.73e-2) -	2.8188e+0 (1.65e-3) +	8.1397e+1 (3.87e+1) -	3.7466e+0 (3.28e-1)
UC5-C1-DTLZ1	10	9.2750e-2 (3.15e-3) -	1.0375e-1 (2.20e-3) -	9.6867e-2 (3.02e-3) -	NaN (NaN) -	NaN (NaN) -	1.5341e-1 (4.61e-2) -	NaN (NaN) -	7.1313e-2 (3.26e-3)
UC5-C2-DTLZ1	10	9.9337e-2 (1.61e-2) -	1.0611e-1 (3.89e-3) -	1.0053e-1 (3.93e-3) -	NaN (NaN) -	NaN (NaN) -	1.2855e-1 (3.38e-2) -	NaN (NaN) -	7.1644e-2 (3.80e-3)
UC5-C2-DTLZ3	10	2.1386e-1 (1.43e-2) +	5.7429e-1 (3.37e-2) -	5.7263e-1 (1.87e-2) -	NaN (NaN) -	NaN (NaN) -	2.8178e-1 (2.36e-3) =	NaN (NaN) -	2.8154e-1 (3.43e-2)
UC5-C3-DTLZ1	10	1.0005e-1 (2.77e-3) -	1.0919e-1 (4.41e-3) -	1.0603e-1 (5.74e-3) -	NaN (NaN) -	NaN (NaN) -	1.3491e-1 (3.48e-2) -	NaN (NaN) -	7.3151e-2 (2.34e-3)
UC5-C3-DTLZ2	10	3.7240e-1 (5.10e-1) =	6.7103e-1 (2.31e-2) -	6.7119e-1 (1.22e-1) -	NaN (NaN) -	NaN (NaN) -	2.8249e-1 (2.99e-3) +	NaN (NaN) -	3.8927e-1 (2.64e-2)
UC5-C3-DTLZ3	10	2.8277e-1 (5.10e-1) =	6.7121e-1 (1.21e-1) -	7.9286e-1 (5.42e-4) -	NaN (NaN) -	NaN (NaN) -	2.8237e-1 (6.32e-4) +	NaN (NaN) -	3.8550e-1 (3.29e-2)
+/-/=		6/19/5	0/30/0	0/29/1	0/29/1	0/30/0	9/17/4	0/29/1	

TABLE XV
THE COMPARISON RESULTS OF HV METRIC ON TEN OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/NSGA-II	EADMM/MOEA/D
UC1-C1-DTLZ1	10	9.9713e-1 (2.03e-3) =	9.0502e-1 (4.95e-3) -	8.4705e-1 (2.82e-1) -	NaN (NaN) -	NaN (NaN) -	9.3066e-1 (1.71e-2) -	NaN (NaN) -	9.8934e-1 (1.05e-2)
UC1-C2-DTLZ1	10	9.9876e-1 (7.93e-5) =	9.2134e-1 (9.10e-3) -	8.2779e-1 (2.75e-1) -	NaN (NaN) -	NaN (NaN) -	9.8130e-1 (7.61e-3) -	NaN (NaN) -	9.9140e-1 (1.05e-2)
UC1-C2-DTLZ3	10	8.9514e-1 (7.63e-3) +	3.8010e-1 (3.26e-2) -	1.9993e-1 (1.95e-1) -	NaN (NaN) -	NaN (NaN) -	8.6066e-1 (3.30e-2) +	NaN (NaN) -	6.4024e-1 (1.14e-2)
UC1-C3-DTLZ1	10	9.9858e-1 (3.02e-4) +	7.6497e-1 (5.01e-2) -	8.1168e-1 (2.74e-1) -	NaN (NaN) -	NaN (NaN) -	9.8503e-1 (5.33e-3) -	NaN (NaN) -	9.8963e-1 (8.22e-3)
UC1-C3-DTLZ2	10	4.2475e-1 (2.66e-1) =	1.9733e-1 (7.21e-2) -	8.5849e-3 (3.93e-2) -	4.4640e-3 (1.34e-2) -	NaN (NaN) -	5.8788e-1 (3.32e-2) -	4.5395e-3 (2.08e-2) -	6.2141e-1 (1.91e-3)
UC1-C3-DTLZ3	10	4.0109e-1 (2.72e-1) =	1.6426e-1 (8.34e-2) -	2.2663e-2 (4.15e-2) -	0.0000e+0 (0.00e+0) -	NaN (NaN) -	5.3103e-1 (4.40e-2) -	NaN (NaN) -	6.2062e-1 (1.49e-3)
UC2-C1-DTLZ1	10	1.8306e-1 (3.09e-1) -	8.9751e-1 (2.01e-2) -	6.4838e-1 (4.20e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	8.8564e-1 (3.98e-2) -	0.0000e+0 (0.00e+0) -	9.8826e-1 (3.78e-3)
UC2-C2-DTLZ1	10	2.1142e-1 (3.89e-1) -	9.2120e-1 (5.65e-3) -	7.4163e-1 (3.69e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	9.7611e-1 (1.08e-2) -	0.0000e+0 (0.00e+0) -	9.7977e-1 (1.57e-2)
UC2-C2-DTLZ3	10	0.0000e+0 (0.00e+0) -	2.9180e-1 (2.16e-1) -	9.1993e-2 (1.69e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	8.1154e-1 (5.11e-2) +	0.0000e+0 (0.00e+0) -	6.4399e-1 (1.01e-2)
UC2-C3-DTLZ1	10	3.0342e-1 (4.42e-1) -	7.5253e-1 (3.30e-2) -	6.4875e-1 (4.20e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	9.7795e-1 (6.71e-3) +	0.0000e+0 (0.00e+0) -	9.5519e-1 (3.16e-2)
UC2-C3-DTLZ2	10	3.6727e-1 (2.69e-1) =	1.4898e-1 (1.00e-1) -	NaN (NaN) -	NaN (NaN) -	NaN (NaN) -	5.5499e-1 (5.30e-2) -	NaN (NaN) -	6.1536e-1 (6.45e-4)
UC2-C3-DTLZ3	10	0.0000e+0 (0.00e+0) -	2.4665e-2 (6.67e-2) -	1.3185e-2 (4.38e-2) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	5.1411e-1 (4.88e-2) -	0.0000e+0 (0.00e+0) -	6.1958e-1 (1.92e-3)
UC3-C1-DTLZ1	10	9.5163e-1 (7.37e-2) -	8.9741e-1 (1.72e-2) -	5.2521e-1 (4.66e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	9.1407e-1 (2.94e-2) -	0.0000e+0 (0.00e+0) -	9.9098e-1 (7.57e-3)
UC3-C2-DTLZ1	10	8.9278e-1 (3.01e-1) -	9.2186e-1 (6.95e-3) -	7.4203e-1 (3.69e-1) -	NaN (NaN) -	0.0000e+0 (0.00e+0) -	9.7487e-1 (1.17e-2) -	2.1840e-3 (1.00e-2) -	9.9453e-1 (4.78e-3)
UC3-C2-DTLZ3	10	0.0000e+0 (0.00e+0) -	3.7660e-1 (3.74e-2) -	2.4606e-1 (1.79e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	8.6714e-1 (3.60e-2) +	0.0000e+0 (0.00e+0) -	6.3797e-1 (1.08e-2)
UC3-C3-DTLZ1	10	9.5078e-1 (2.18e-1) -	7.7189e-1 (6.67e-2) -	5.1099e-1 (4.56e-1) -	NaN (NaN) -	0.0000e+0 (0.00e+0) -	9.7833e-1 (6.64e-3) -	0.0000e+0 (0.00e+0) -	9.8631e-1 (1.71e-2)
UC3-C3-DTLZ2	10	6.6357e-1 (5.20e-3) =	2.1867e-1 (5.00e-2) -	1.7308e-1 (8.00e-3) -	0.0000e+0 (0.00e+0) -	1.1381e-1 (4.26e-2) -	5.7613e-1 (5.01e-2) -	1.9754e-2 (6.33e-3) -	6.5912e-1 (1.64e-2)
UC3-C3-DTLZ3	10	0.0000e+0 (0.00e+0) -	1.1248e-1 (1.02e-1) -	9.0857e-3 (2.87e-2) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	5.0051e-1 (4.53e-2) -	0.0000e+0 (0.00e+0) -	6.1978e-1 (1.55e-3)
UC4-C1-DTLZ1	10	6.2835e-1 (1.57e-1) =	6.1033e-1 (3.52e-1) =	4.7584e-1 (4.65e-1) =	4.1453e-3 (1.90e-2) -	0.0000e+0 (0.00e+0) -	8.8724e-1 (3.23e-2) =	5.0858e-2 (4.52e-2) -	6.7773e-1 (2.71e-1)
UC4-C2-DTLZ1	10	9.9712e-1 (1.59e-3) +	9.0734e-1 (8.59e-3) -	8.5216e-1 (2.13e-1) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	9.4137e-1 (2.82e-2) -	4.1085e-1 (3.53e-1) -	9.9541e-1 (1.98e-3)
UC4-C2-DTLZ3	10	8.4402e-1 (2.64e-2) -	4.0795e-1 (4.73e-2) -	2.2365e-1 (2.19e-1) -	0.0000e+0 (0.00e+0) -	2.5363e-3 (1.16e-2) -	7.4988e-1 (4.07e-2) -	0.0000e+0 (0.00e+0) -	9.1454e-1 (7.57e-3)
UC4-C3-DTLZ1	10	9.9856e-1 (8.86e-5) +	8.9790e-1 (2.26e-2) -	6.0204e-1 (4.04e-1) -	1.7211e-2 (7.89e-2) -	0.0000e+0 (0.00e+0) -	9.6026e-1 (1.21e-2) -	3.4767e-1 (3.16e-1) -	9.9461e-1 (4.28e-3)
UC4-C3-DTLZ2	10	5.7781e-1 (1.79e-2) -	1.1788e-1 (9.53e-2) -	1.2200e-1 (6.97e-2) -	NaN (NaN) -	NaN (NaN) -	4.6520e-1 (4.18e-2) -	NaN (NaN) -	5.9602e-1 (3.60e-2)
UC4-C3-DTLZ3	10	5.9324e-1 (1.89e-2) -	2.1497e-2 (4.82e-2) -	4.3828e-3 (2.01e-2) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	4.8238e-1 (3.65e-2) -	0.0000e+0 (0.00e+0) -	6.1465e-1 (8.95e-4)
UC5-C1-DTLZ1	10	9.6343e-1 (1.21e-1) +	8.8966e-1 (2.64e-2) -	8.0123e-1 (3.35e-1) =	NaN (NaN) -	NaN (NaN) -	9.0759e-1 (1.87e-2) +	NaN (NaN) -	8.9267e-1 (1.87e-1)
UC5-C2-DTLZ1	10	9.9805e-1 (6.99e-4) +	3.0195e-1 (4.38e-1) -	9.1451e-1 (9.42e-3) -	NaN (NaN) -	NaN (NaN) -	9.4962e-1 (1.50e-2) -	NaN (NaN) -	9.8007e-1 (2.47e-2)
UC5-C2-DTLZ3	10	8.7065e-1 (3.12e-2) +	1.7654e-1 (2.10e-1) -	3.7429e-1 (9.16e-2) -	NaN (NaN) -	NaN (NaN) -	7.8059e-1 (3.78e-2) +	NaN (NaN) -	6.1751e-1 (1.23e-2)
UC5-C3-DTLZ1	10	9.9809e-1 (7.61e-4) +	6.7339e-1 (3.87e-1) -	6.2836e-1 (4.11e-1) -	NaN (NaN) -	NaN (NaN) -	9.5950e-1 (1.02e-2) =	NaN (NaN) -	9.6125e-1 (3.74e-2)
UC5-C3-DTLZ2	10	3.8168e-1 (2.57e-1) -	1.5062e-1 (9.14e-2) -	1.4844e-1 (4.26e-2) -	NaN (NaN) -	NaN (NaN) -	4.4975e-1 (2.85e-2) -	NaN (NaN) -	6.0073e-1 (2.61e-2)
UC5-C3-DTLZ3	10	4.4246e-1 (2.52e-1) =	8.2848e-2 (1.06e-1) -	6.7652e-2 (5.23e-2) -	NaN (NaN) -	NaN (NaN) -	4.8043e-1 (3.75e-2) -	NaN (NaN) -	6.1282e-1 (2.62e-3)
+/-/=		8/14/8	0/29/1	0/28/2	0/30/0	0/30/0	6/22/2	0/30/0	

TABLE XVI
THE COMPARISON RESULTS OF HV METRIC ON TWO REAL-WORLD PROBLEMS

Problem	C-TAEA	MOEA/D-DAE	PPS	ToP	CMOCSO	EADMM/IBEA	EADMM/MOEA/D	EADMM/NSGA-II
RL	1.004e-1 (3.15e-1) -	7.678e-1 (4.63e-1) -	0.0000e+0 (0.00e+0) -	8.489e-1 (1.68e-1) =	9.264e-1 (9.76e-2) =	7.640e-1 (3.90e-1) -	7.694e-1 (2.12e-1) -	9.487e-1 (5.41e-2)
WDS	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	0.0000e+0 (0.00e+0) -	3.9632e-1 (0.58e-1) -	2.808e-1 (1.25e-1) -	0.0000e+0 (0.00e+0) -	4.0831e-1 (0.82e-1)
+/-/=	0/2/0	0/2/0	0/2/0	0/1/1	0/1/1	0/2/0	0/2/0	

TABLE XVII
THE COMPARISON RESULTS OF IGD METRIC OF ABLATION STUDY ON TWO OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	2	2.3747e-3 (2.32e-4) +	NaN (NaN)	2.1599e-3 (2.07e-4) +	NaN (NaN)	2.2211e-3 (6.23e-4) +	NaN (NaN)
UC1-C2-DTLZ1	2	2.5423e-3 (6.08e-4) +	NaN (NaN)	2.2763e-3 (6.30e-4) +	NaN (NaN)	1.9576e-3 (2.46e-4) +	NaN (NaN)
UC1-C2-DTLZ3	2	7.8267e-3 (6.36e-3) +	NaN (NaN)	5.0000e+2 (0.00e+0) +	NaN (NaN)	1.0357e-1 (2.01e-1) +	NaN (NaN)
UC1-C3-DTLZ1	2	4.7905e-2 (2.10e-4) +	NaN (NaN)	8.8179e-2 (8.02e-2) +	NaN (NaN)	4.8490e-2 (1.04e-3) +	NaN (NaN)
UC1-C3-DTLZ2	2	1.4193e-1 (1.54e-4) +	NaN (NaN)	1.6759e-1 (1.22e-5) +	NaN (NaN)	1.4220e-1 (8.80e-5) +	NaN (NaN)
UC1-C3-DTLZ3	2	1.7150e-1 (1.18e-1) +	NaN (NaN)	5.0000e+2 (0.00e+0) +	NaN (NaN)	2.6679e-1 (2.36e-1) +	NaN (NaN)
UC2-C1-DTLZ1	2	2.3822e-3 (3.81e-4) +	4.2081e+1 (8.68e-3)	7.2430e-2 (2.33e-2) +	4.2074e+1 (1.52e-3)	2.0569e-3 (5.40e-4) +	4.2085e+1 (1.29e-2)
UC2-C2-DTLZ1	2	2.4136e-3 (2.26e-4) +	4.2080e+1 (7.83e-3)	7.6530e-2 (1.47e-2) +	4.2074e+1 (8.94e-4)	2.6135e-3 (1.32e-3) +	4.2085e+1 (9.47e-3)
UC2-C2-DTLZ3	2	7.6188e+0 (2.01e+1) +	5.9005e+1 (2.42e-3)	3.4460e-1 (5.89e+1) +	5.9001e+1 (2.05e-3)	9.5944e+0 (2.20e+1) +	5.9006e+1 (1.56e-3)
UC2-C3-DTLZ1	2	4.8044e-2 (4.74e-4) +	4.2081e+1 (1.05e-2)	9.5362e-2 (7.19e-2) +	4.2074e+1 (1.42e-3)	4.9642e-2 (3.29e-3) +	4.2084e+1 (1.01e-2)
UC2-C3-DTLZ2	2	1.4195e-1 (1.88e-4) +	8.0069e-1 (7.11e-5)	1.6759e-1 (9.45e-6) -	9.5862e-1 (4.73e-2)	1.4233e-1 (1.17e-4) +	8.0070e-1 (9.90e-5)
UC2-C3-DTLZ3	2	9.6381e+0 (2.20e+1) +	5.9006e+1 (2.43e-3)	5.9006e+1 (5.83e+1) =	5.9001e+1 (1.82e-3)	3.0572e+1 (2.99e+1) =	5.9006e+1 (1.64e-3)
UC3-C1-DTLZ1	2	2.4168e-3 (3.77e-4) +	7.0365e+1 (2.88e+1)	3.0928e-2 (4.42e-2) -	5.6216e+1 (1.20e-3)	2.3899e-3 (9.38e-4) +	5.6228e+1 (2.11e-2)
UC3-C2-DTLZ1	2	2.3687e-3 (2.08e-4) +	5.3402e+1 (2.21e+1)	6.6289e-3 (1.88e-2) -	6.3287e+1 (6.28e-3)	2.1112e-3 (4.82e-4) +	4.3809e+1 (2.43e+1)
UC3-C2-DTLZ3	2	3.7753e+0 (9.87e+0) +	3.0001e+1 (5.48e+0)	2.9003e+1 (2.86e+1) -	2.9001e+1 (1.68e-4)	8.5092e+0 (1.33e+1) +	2.9002e+1 (8.97e-4)
UC3-C3-DTLZ1	2	4.8012e-2 (3.17e-4) +	6.3294e+1 (1.14e-2)	8.7852e-2 (7.86e-2) -	6.3287e+1 (3.41e-2)	5.0747e-2 (8.77e-3) +	4.6922e+1 (2.36e+1)
UC3-C3-DTLZ2	2	1.4184e-1 (1.06e-4) +	3.5059e-1 (5.79e-5)	1.6759e-1 (7.47e-6) -	3.5187e-1 (7.94e-4)	1.4217e-1 (9.33e-5) +	3.5048e-1 (6.59e-5)
UC3-C3-DTLZ3	2	1.0738e+0 (5.18e+0) +	3.5001e+1 (1.22e+1)	2.9003e+1 (2.87e+1) =	2.9001e+1 (1.72e-4)	1.3249e+1 (1.45e+1) =	2.9001e+1 (9.82e-4)
UC4-C1-DTLZ1	2	9.1766e-2 (2.16e-1) +	5.6576e+1 (2.16e+1)	5.3904e-2 (1.81e-2) -	4.9499e+1 (1.88e-3)	5.1879e-2 (4.19e-2) +	4.9503e+1 (5.74e-3)
UC4-C2-DTLZ1	2	4.4786e-2 (1.50e-3) +	5.0390e+1 (1.75e+1)	5.3299e-2 (1.07e-2) -	5.6571e+1 (3.22e-2)	4.8660e-2 (1.43e-2) +	3.7504e+1 (2.38e+1)
UC4-C2-DTLZ3	2	5.1111e-2 (4.52e-3) +	2.1003e+1 (5.48e+0)	2.6373e-1 (7.33e-2) -	2.0005e+1 (2.17e-3)	4.8447e-2 (3.31e-3) +	1.9337e+1 (3.64e+0)
UC4-C3-DTLZ1	2	9.8671e-1 (1.40e-1) +	5.6579e+1 (1.02e-2)	3.3014e+0 (1.17e+0) -	5.6571e+1 (7.09e-3)	1.1328e+0 (1.92e-1) +	4.1271e+1 (2.38e+1)
UC4-C3-DTLZ2	2	1.4387e-1 (3.81e-3) +	NaN (NaN)	3.2433e-1 (3.62e-2) -	NaN (NaN)	1.4346e-1 (2.56e-3) +	6.0221e+0 (2.53e+0)
UC4-C3-DTLZ3	2	1.8141e+0 (3.93e-1) +	1.9392e+1 (3.34e+0)	3.4242e+0 (7.23e-7) -	2.0006e+1 (1.37e-3)	2.2189e+0 (6.59e-1) +	2.0001e+1 (7.51e-4)
UC5-C1-DTLZ1	2	2.2467e-3 (1.12e-4) +	NaN (NaN)	2.0870e-3 (4.99e-5) -	NaN (NaN)	1.8082e-3 (1.97e-5) +	NaN (NaN)
UC5-C2-DTLZ1	2	2.3500e-3 (4.62e-4) +	NaN (NaN)	2.1286e-3 (6.70e-5) -	NaN (NaN)	1.9869e-3 (2.18e-4) +	NaN (NaN)
UC5-C2-DTLZ3	2	4.9590e-3 (1.66e-4) +	NaN (NaN)	1.8144e-2 (6.72e-3) -	NaN (NaN)	5.9087e-3 (1.64e-3) +	NaN (NaN)
UC5-C3-DTLZ1	2	4.9245e-2 (7.03e-3) +	NaN (NaN)	1.6507e-1 (9.57e-6) -	NaN (NaN)	5.2909e-2 (8.33e-3) +	NaN (NaN)
UC5-C3-DTLZ2	2	1.4287e-1 (3.32e-3) +	NaN (NaN)	2.9875e-1 (3.42e-3) -	NaN (NaN)	1.4268e-1 (8.22e-4) +	NaN (NaN)
UC5-C3-DTLZ3	2	2.1007e-1 (1.19e-1) +	NaN (NaN)	2.9890e-1 (2.65e-2) -	NaN (NaN)	1.8492e-1 (5.73e-2) +	NaN (NaN)
+/-/=		30/0/0		30/0/0		28/0/2	

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TABLE XVIII
THE COMPARISON RESULTS OF IGD^+ METRIC OF ABLATION STUDY ON TWO OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	2	2.0026e-3 (3.37e-4) +	NaN (NaN)	1.6426e-3 (2.09e-4) +	NaN (NaN)	1.9258e-3 (7.22e-4) +	NaN (NaN)
UC1-C2-DTLZ1	2	2.1689e-3 (7.44e-4) +	NaN (NaN)	5.9710e-3 (1.47e-2) +	NaN (NaN)	1.6464e-3 (3.64e-4) +	NaN (NaN)
UC1-C2-DTLZ3	2	5.1189e-3 (3.05e-3) +	NaN (NaN)	6.5891e-2 (5.24e-2) +	NaN (NaN)	7.6250e-2 (1.37e-1) +	NaN (NaN)
UC1-C3-DTLZ1	2	3.4129e-2 (3.68e-4) +	NaN (NaN)	9.4937e-2 (6.39e-2) +	NaN (NaN)	3.4949e-2 (1.51e-3) +	NaN (NaN)
UC1-C3-DTLZ2	2	4.5163e-2 (1.69e-5) +	NaN (NaN)	4.5989e-2 (2.87e-6) =	4.9835e-2 (0.00e+0)	4.5371e-2 (3.18e-5) +	NaN (NaN)
UC1-C3-DTLZ3	2	6.1757e-2 (7.00e-2) +	NaN (NaN)	9.2314e-2 (0.00e+0) +	NaN (NaN)	1.2068e-1 (1.42e-1) +	NaN (NaN)
UC2-C1-DTLZ1	2	1.9479e-3 (5.02e-4) +	4.2080e+1 (8.61e-3)	5.2459e-2 (9.02e-3) +	4.2074e+1 (1.16e-3)	1.7266e-3 (6.24e-4) +	4.2086e+1 (1.44e-2)
UC2-C2-DTLZ1	2	2.0348e-3 (3.52e-4) +	4.2080e+1 (7.76e-3)	1.4113e+0 (7.56e+0) +	4.2074e+1 (1.13e-3)	2.3651e-3 (1.35e-3) +	4.2085e+1 (9.36e-3)
UC2-C2-DTLZ3	2	7.6169e+0 (2.01e+1) +	5.9005e+1 (2.38e-3)	2.6691e+1 (2.98e+1) +	5.9002e+1 (2.01e-3)	9.5755e+0 (2.20e+1) +	5.9006e+1 (1.54e-3)
UC2-C3-DTLZ1	2	3.4441e-2 (9.08e-4) +	4.2080e+1 (1.04e-2)	8.2516e-2 (2.49e-2) +	4.2075e+1 (4.09e-3)	3.6524e-2 (4.24e-3) +	4.2085e+1 (1.06e-2)
UC2-C3-DTLZ2	2	4.5164e-2 (2.05e-5) +	8.0067e-1 (7.43e-5)	4.5989e-2 (2.04e-6) +	8.7374e-1 (1.80e-2)	4.5500e-2 (7.07e-5) +	8.0069e-1 (9.71e-5)
UC2-C3-DTLZ3	2	9.5563e+0 (2.20e+1) +	5.9006e+1 (2.43e-3)	4.1932e+1 (2.71e+1) +	5.9002e+1 (2.62e-3)	3.0516e+1 (2.99e+1) =	5.9006e+1 (1.62e-3)
UC3-C1-DTLZ1	2	2.0237e-3 (4.78e-4) +	6.9908e+1 (2.84e+1)	3.6486e+0 (1.40e+1) +	5.6485e+1 (1.36e+0)	2.1345e-3 (9.53e-4) +	5.6228e+1 (2.08e-2)
UC3-C2-DTLZ1	2	1.9532e-3 (3.48e-4) +	5.3402e+1 (2.21e+1)	8.9921e-1 (3.44e+0) +	5.7307e+1 (1.76e+1)	1.8310e-3 (6.18e-4) +	4.4438e+1 (2.41e+1)
UC3-C2-DTLZ3	2	3.7637e+0 (9.88e+0) +	2.9969e+1 (5.39e+0)	1.9698e+1 (1.37e+1) +	2.9001e+1 (1.40e-4)	8.4898e+0 (1.33e+1) +	2.9002e+1 (8.91e-4)
UC3-C3-DTLZ1	2	3.4369e-2 (5.54e-4) +	6.3294e+1 (1.14e-2)	5.1977e-1 (2.46e+0) +	6.1268e+1 (1.38e+1)	3.6820e-2 (6.65e-3) +	4.5853e+1 (2.39e+1)
UC3-C3-DTLZ2	2	4.5143e-2 (9.03e-6) +	3.5058e-1 (5.70e-5)	4.5987e-2 (1.89e-6) +	3.3159e-1 (7.62e-2)	4.5406e-2 (4.54e-5) +	3.5047e-1 (6.36e-5)
UC3-C3-DTLZ3	2	9.8044e-1 (5.20e+0) +	3.4808e+1 (1.20e+1)	1.5023e+1 (1.47e+1) +	2.9001e+1 (2.19e-4)	1.3173e+1 (1.46e+1) +	2.9001e+1 (9.67e-4)
UC4-C1-DTLZ1	2	6.6278e-2 (1.56e-1) +	5.6348e+1 (2.12e+1)	4.0190e-2 (8.38e-3) +	4.9619e+1 (4.33e-1)	3.8477e-2 (3.04e-2) +	4.9503e+1 (5.69e-3)
UC4-C2-DTLZ1	2	3.3157e-2 (1.37e-3) +	5.0390e+1 (1.75e+1)	3.8808e-2 (4.88e-3) +	5.5335e+1 (9.36e+0)	3.9759e-2 (1.22e-2) +	3.8073e+1 (2.37e+1)
UC4-C2-DTLZ3	2	2.2145e-2 (2.10e-3) +	2.0970e+1 (5.39e+0)	5.5149e-2 (9.59e-3) +	1.8073e+1 (6.00e+0)	2.6455e-2 (2.81e-3) +	1.9357e+1 (3.59e+0)
UC4-C3-DTLZ1	2	6.9912e-1 (9.93e-2) +	5.6579e+1 (1.02e-2)	2.0494e+0 (4.92e-1) +	5.3597e+1 (1.24e+1)	8.0625e-1 (1.35e-1) +	4.1710e+1 (2.37e+1)
UC4-C3-DTLZ2	2	4.5343e-2 (5.20e-4) +	NaN (NaN)	7.8743e-2 (1.28e-2) +	NaN (NaN)	4.5672e-2 (4.67e-4) +	6.0178e+0 (2.54e+0)
UC4-C3-DTLZ3	2	5.2855e-1 (8.31e-2) +	1.9373e+1 (3.50e+0)	8.2787e-1 (6.03e-2) +	2.0005e+1 (1.22e-3)	9.2541e-1 (6.57e-1) +	2.0001e+1 (7.55e-4)
UC5-C1-DTLZ1	2	1.6776e-3 (1.56e-4) +	NaN (NaN)	1.4871e-3 (2.43e-5) +	NaN (NaN)	1.3375e-3 (4.08e-5) +	NaN (NaN)
UC5-C2-DTLZ1	2	1.8192e-3 (5.85e-4) +	NaN (NaN)	1.5574e-3 (2.34e-4) +	NaN (NaN)	1.5919e-3 (2.81e-4) +	NaN (NaN)
UC5-C2-DTLZ3	2	2.2196e-3 (1.02e-4) +	NaN (NaN)	1.2225e-2 (2.76e-2) +	NaN (NaN)	3.4073e-3 (1.33e-3) +	NaN (NaN)
UC5-C3-DTLZ1	2	3.5134e-2 (5.08e-3) +	NaN (NaN)	1.0422e-1 (2.35e-2) +	NaN (NaN)	3.9045e-2 (9.22e-3) +	NaN (NaN)
UC5-C3-DTLZ2	2	4.5191e-2 (1.50e-4) +	NaN (NaN)	8.1690e-2 (6.59e-3) +	NaN (NaN)	4.5596e-2 (8.38e-4) +	NaN (NaN)
UC5-C3-DTLZ3	2	9.6936e-2 (9.46e-2) +	NaN (NaN)	9.7012e-2 (6.03e-2) +	NaN (NaN)	8.0492e-2 (5.81e-2) +	NaN (NaN)
+/-/=		30/0/0		29/0/1		29/0/1	

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TABLE XIX
THE COMPARISON RESULTS OF HV METRIC OF ABLATION STUDY ON TWO OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	2	5.7931e-1 (1.60e-3) +	0.0000e+0 (0.00e+0)	5.8114e-1 (9.53e-4) +	NaN (NaN)	5.7946e-1 (2.88e-3) +	0.0000e+0 (0.00e+0)
UC1-C2-DTLZ1	2	5.7972e-1 (2.22e-3) +	0.0000e+0 (0.00e+0)	5.6704e-1 (4.86e-2) +	NaN (NaN)	5.8136e-1 (1.15e-3) +	NaN (NaN)
UC1-C2-DTLZ3	2	3.4213e-1 (5.58e-3) +	0.0000e+0 (0.00e+0)	2.1812e-1 (1.05e-1) +	NaN (NaN)	2.8608e-1 (9.00e-2) +	NaN (NaN)
UC1-C3-DTLZ1	2	4.7396e-1 (1.20e-3) +	0.0000e+0 (0.00e+0)	3.1239e-1 (1.20e-1) +	NaN (NaN)	4.7124e-1 (4.98e-3) +	NaN (NaN)
UC1-C3-DTLZ2	2	2.6212e-1 (3.15e-5) +	0.0000e+0 (0.00e+0)	2.6088e-1 (6.46e-6) +	NaN (NaN)	2.6168e-1 (5.38e-5) +	NaN (NaN)
UC1-C3-DTLZ3	2	2.5114e-1 (3.67e-2) +	0.0000e+0 (0.00e+0)	1.5955e-1 (0.00e+0) +	NaN (NaN)	2.1465e-1 (7.30e-2) +	NaN (NaN)
UC2-C1-DTLZ1	2	5.7969e-1 (2.27e-3) +	0.0000e+0 (0.00e+0)	4.1308e-1 (2.98e-2) +	0.0000e+0 (0.00e+0)	5.8037e-1 (2.51e-3) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ1	2	5.8010e-1 (1.11e-3) +	0.0000e+0 (0.00e+0)	4.0756e-1 (3.87e-2) +	0.0000e+0 (0.00e+0)	5.7900e-1 (4.84e-3) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ3	2	3.4528e-1 (1.29e-3) +	0.0000e+0 (0.00e+0)	2.2269e-1 (7.94e-2) +	0.0000e+0 (0.00e+0)	2.9708e-1 (9.33e-2) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ1	2	4.7295e-1 (2.94e-3) +	0.0000e+0 (0.00e+0)	3.1396e-1 (8.23e-2) +	0.0000e+0 (0.00e+0)	4.6598e-1 (1.42e-2) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ2	2	2.6212e-1 (3.84e-5) +	0.0000e+0 (0.00e+0)	2.6087e-1 (4.47e-6) +	0.0000e+0 (0.00e+0)	2.6146e-1 (1.13e-4) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ3	2	2.6011e-1 (1.65e-3) +	0.0000e+0 (0.00e+0)	1.3538e-1 (5.11e-2) +	0.0000e+0 (0.00e+0)	2.1755e-1 (5.90e-2) +	0.0000e+0 (0.00e+0)
UC3-C1-DTLZ1	2	5.7924e-1 (2.11e-3) +	0.0000e+0 (0.00e+0)	5.1225e-1 (6.52e-2) +	0.0000e+0 (0.00e+0)	5.7853e-1 (3.76e-3) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ1	2	5.8036e-1 (1.10e-3) +	0.0000e+0 (0.00e+0)	5.5657e-1 (3.59e-2) +	0.0000e+0 (0.00e+0)	5.8081e-1 (1.88e-3) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ3	2	3.2344e-1 (6.14e-2) +	0.0000e+0 (0.00e+0)	1.4960e-1 (7.05e-2) +	0.0000e+0 (0.00e+0)	2.6659e-1 (9.32e-2) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ1	2	4.7318e-1 (1.80e-3) +	0.0000e+0 (0.00e+0)	3.3077e-1 (8.31e-2) +	0.0000e+0 (0.00e+0)	4.6675e-1 (1.54e-2) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ2	2	2.6215e-1 (1.69e-5) +	3.4399e-2 (1.84e-4)	2.6088e-1 (4.28e-6) +	4.9889e-2 (5.63e-2)	2.6162e-1 (7.30e-5) +	3.4216e-2 (1.61e-4)
UC3-C3-DTLZ3	2	2.6010e-1 (2.43e-3) +	0.0000e+0 (0.00e+0)	1.5999e-1 (2.29e-2) +	0.0000e+0 (0.00e+0)	2.0979e-1 (7.43e-2) +	0.0000e+0 (0.00e+0)
UC4-C1-DTLZ1	2	5.7658e-1 (1.93e-2) +	0.0000e+0 (0.00e+0)	5.8002e-1 (1.47e-3) +	0.0000e+0 (0.00e+0)	5.7883e-1 (5.55e-3) +	0.0000e+0 (0.00e+0)
UC4-C2-DTLZ1	2	5.8130e-1 (2.22e-4) +	4.8009e-4 (2.67e-3)	5.8036e-1 (8.05e-4) +	5.2658e-4 (2.84e-3)	5.7979e-1 (2.43e-3) +	2.8468e-3 (5.60e-3)
UC4-C2-DTLZ3	2	3.4678e-1 (3.61e-4) +	0.0000e+0 (0.00e+0)	3.4224e-1 (1.52e-3) =	3.3308e-2 (1.03e-1)	3.4581e-1 (5.76e-4) +	1.1199e-2 (6.24e-2)
UC4-C3-DTLZ1	2	4.7121e-1 (1.64e-2) +	0.0000e+0 (0.00e+0)	2.4801e-1 (8.13e-2) +	9.7096e-4 (3.76e-3)	4.5989e-1 (1.47e-2) +	4.2382e-2 (1.25e-1)
UC4-C3-DTLZ2	2	2.6176e-1 (1.17e-3) +	0.0000e+0 (0.00e+0)	1.8523e-1 (2.96e-2) +	NaN (NaN)	2.6104e-1 (9.40e-4) +	0.0000e+0 (0.00e+0)
UC4-C3-DTLZ3	2	2.4515e-1 (1.92e-2) +	8.1097e-3 (4.52e-2)	1.7606e-1 (1.39e-2) +	0.0000e+0 (0.00e+0)	2.2373e-1 (3.20e-2) +	0.0000e+0 (0.00e+0)
UC5-C1-DTLZ1	2	5.8113e-1 (7.54e-4) +	0.0000e+0 (0.00e+0)	5.8182e-1 (1.13e-4) +	NaN (NaN)	5.8220e-1 (2.88e-4) +	NaN (NaN)
UC5-C2-DTLZ1	2	5.8082e-1 (1.76e-3) +	0.0000e+0 (0.00e+0)	5.8163e-1 (7.65e-4) +	NaN (NaN)	5.8150e-1 (9.47e-4) +	NaN (NaN)
UC5-C2-DTLZ3	2	3.4676e-1 (1.91e-4) +	0.0000e+0 (0.00e+0)	3.2956e-1 (5.14e-2) +	NaN (NaN)	3.4467e-1 (1.91e-3) +	NaN (NaN)
UC5-C3-DTLZ1	2	4.7065e-1 (1.68e-2) +	0.0000e+0 (0.00e+0)	2.4220e-1 (7.78e-2) +	NaN (NaN)	4.5953e-1 (2.92e-2) +	NaN (NaN)
UC5-C3-DTLZ2	2	2.6208e-1 (2.26e-4) +	0.0000e+0 (0.00e+0)	1.7803e-1 (1.53e-2) +	NaN (NaN)	2.6124e-1 (1.54e-3) +	NaN (NaN)
UC5-C3-DTLZ3	2	2.2990e-1 (4.70e-2) +	0.0000e+0 (0.00e+0)	1.6640e-1 (2.46e-2) +	NaN (NaN)	2.3778e-1 (2.91e-2) +	NaN (NaN)
+/-/=		30/0/0		29/0/1		30/0/0	

TABLE XX
THE COMPARISON RESULTS OF IGD METRIC OF ABLATION STUDY ON THREE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	3	2.6023e-2 (1.35e-3) +	NaN (NaN)	2.1202e-2 (4.98e-4) +	NaN (NaN)	2.0299e-2 (1.73e-4) +	NaN (NaN)
UC1-C2-DTLZ1	3	2.6714e-2 (1.71e-3) +	NaN (NaN)	2.1293e-2 (8.08e-4) +	NaN (NaN)	2.0611e-2 (1.25e-4) +	NaN (NaN)
UC1-C2-DTLZ3	3	6.7071e-2 (5.67e-3) +	NaN (NaN)	1.8304e-1 (3.52e-1) +	NaN (NaN)	5.7021e-2 (3.37e-1) +	NaN (NaN)
UC1-C3-DTLZ1	3	5.0830e-2 (1.25e-3) +	NaN (NaN)	8.9162e-2 (7.61e-2) +	NaN (NaN)	4.4744e-2 (2.24e-4) +	NaN (NaN)
UC1-C3-DTLZ2	3	2.6031e-1 (1.53e-3) +	NaN (NaN)	2.9534e-1 (8.65e-3) +	4.5452e-1 (0.00e+0)	2.5736e-1 (3.36e-4) +	6.3812e-1 (2.36e-1)
UC1-C3-DTLZ3	3	2.7076e-1 (5.18e-2) +	NaN (NaN)	4.0156e-1 (2.46e-3) +	NaN (NaN)	2.8246e-1 (1.90e-1) +	NaN (NaN)
UC2-C1-DTLZ1	3	5.6696e-2 (6.55e-3) +	3.5115e+1 (4.53e-1)	1.5542e-1 (2.94e-2) +	3.4465e+1 (1.56e-1)	2.0309e-2 (1.15e-4) +	3.4551e+1 (1.98e-1)
UC2-C2-DTLZ1	3	2.6376e-2 (1.56e-3) +	3.5211e+1 (5.05e-1)	1.6203e-1 (3.92e-2) +	3.4458e+1 (1.11e-1)	2.0605e-2 (8.68e-5) +	3.4542e+1 (1.93e-1)
UC2-C2-DTLZ3	3	6.8513e-2 (5.78e-3) +	8.9073e+1 (1.90e-2)	4.3182e-1 (8.90e+1) +	8.9033e+1 (6.23e-3)	5.4678e-2 (3.80e-3) +	8.9035e+1 (5.66e-3)
UC2-C3-DTLZ1	3	5.0874e-2 (2.10e-3) +	3.5129e+1 (3.54e-1)	2.0709e-1 (2.57e-2) +	3.4440e+1 (2.10e-1)	4.4854e-2 (4.16e-4) +	3.4559e+1 (2.27e-1)
UC2-C3-DTLZ2	3	2.6108e-1 (1.21e-3) +	NaN (NaN)	3.0285e-1 (1.09e-2) +	4.0078e-1 (0.00e+0)	2.5731e-1 (3.06e-4) +	6.6757e-1 (2.35e-1)
UC2-C3-DTLZ3	3	2.6478e-1 (4.80e-2) +	8.9075e+1 (1.41e-2)	4.1177e-1 (8.86e+1) +	8.9037e+1 (8.96e-3)	6.7556e-1 (8.88e+1) +	8.9034e+1 (4.82e-3)
UC3-C1-DTLZ1	3	5.4721e-2 (8.08e-3) +	8.1043e+1 (2.90e+1)	1.4407e-1 (1.64e-1) +	4.5950e+1 (8.79e-2)	2.0360e-2 (1.82e-4) +	4.5915e+1 (2.50e-2)
UC3-C2-DTLZ1	3	2.7053e-2 (1.30e-3) +	5.1138e+1 (2.28e+1)	3.0739e-2 (1.59e-2) +	5.1733e+1 (9.03e-2)	2.0597e-2 (6.30e-5) +	3.9558e+1 (1.88e+1)
UC3-C2-DTLZ3	3	6.6295e-2 (3.21e-3) +	4.4039e+1 (7.86e-3)	2.2613e-1 (4.39e+1) +	4.4013e+1 (1.17e-2)	3.7465e-1 (4.40e+1) +	4.4022e+1 (6.91e-3)
UC3-C3-DTLZ1	3	5.1397e-2 (1.84e-3) +	5.2112e+1 (1.53e-1)	1.4493e-1 (5.22e-2) +	5.1697e+1 (5.42e-2)	4.5025e-2 (5.54e-4) +	4.2273e+1 (1.74e+1)
UC3-C3-DTLZ2	3	2.6061e-1 (3.35e-3) +	3.4602e-1 (3.80e-2)	2.9330e-1 (2.00e-3) +	2.9551e-1 (6.96e-2)	2.7373e-1 (7.68e-3) =	3.5798e-1 (5.12e-3)
UC3-C3-DTLZ3	3	2.6963e-1 (3.30e+1) +	4.4037e+1 (7.34e-3)	4.2618e-1 (4.36e+1) +	4.4014e+1 (7.96e-3)	3.7747e-1 (4.38e+1) +	4.4019e+1 (8.75e-3)
UC4-C1-DTLZ1	3	5.4460e+0 (3.86e+1) +	7.5623e+1 (2.89e+1)	2.6085e+0 (5.00e+0) +	4.0523e+1 (5.25e-2)	4.0827e-1 (3.97e-3) +	4.0584e+1 (5.14e-3)
UC4-C2-DTLZ1	3	5.3996e-1 (4.34e-2) +	4.6454e+1 (2.03e-1)	4.5825e-1 (1.69e-1) +	4.6276e+1 (2.59e-2)	4.1121e-1 (2.80e-3) +	3.8125e+1 (1.68e+1)
UC4-C2-DTLZ3	3	7.0075e-1 (3.60e-2) +	3.5144e+1 (1.29e-2)	1.1056e+0 (3.39e-1) +	3.5068e+1 (2.79e-2)	5.5836e-1 (1.01e-2) +	3.5066e+1 (2.22e-2)
UC4-C3-DTLZ1	3	1.0155e+0 (4.38e-2) +	4.6683e+1 (2.63e-1)	2.8951e+0 (1.49e+0) +	4.6267e+1 (4.44e-2)	9.3334e-1 (2.85e-2) +	3.8090e+1 (1.68e+1)
UC4-C3-DTLZ2	3	2.6166e-1 (2.30e-3) +	NaN (NaN)	4.3162e-1 (2.82e-2) +	NaN (NaN)	2.5986e-1 (2.68e-3) +	3.6586e+0 (2.92e+0)
UC4-C3-DTLZ3	3	4.3403e+0 (7.47e-1) +	3.5148e+1 (1.62e-2)	4.6660e+0 (1.51e-1) +	3.5069e+1 (3.01e-2)	4.6585e+0 (2.45e+0) +	3.5068e+1 (1.58e-2)
UC5-C1-DTLZ1	3	2.7163e-2 (2.13e-3) +	NaN (NaN)	2.1008e-2 (4.22e-4) +	NaN (NaN)	2.0508e-2 (5.27e-5) +	NaN (NaN)
UC5-C2-DTLZ1	3	2.8170e-2 (4.51e-3) +	NaN (NaN)	2.1158e-2 (4.32e-4) +	NaN (NaN)	2.0698e-2 (4.16e-4) +	NaN (NaN)
UC5-C2-DTLZ3	3	6.9769e-2 (3.97e-3) +	NaN (NaN)	7.9402e-2 (4.25e-3) +	NaN (NaN)	5.7445e-2 (1.01e-2) +	NaN (NaN)
UC5-C3-DTLZ1	3	5.0645e-2 (2.39e-3) +	NaN (NaN)	1.4467e-1 (7.08e-2) +	NaN (NaN)	4.6125e-2 (1.99e-3) +	NaN (NaN)
UC5-C3-DTLZ2	3	2.6210e-1 (3.16e-3) +	NaN (NaN)	3.9921e-1 (4.08e-3) +	NaN (NaN)	2.5894e-1 (1.84e-3) +	8.1530e+0 (3.76e+0)
UC5-C3-DTLZ3	3	2.9800e-1 (1.27e-1) +	NaN (NaN)	3.9849e-1 (5.24e-4) +	NaN (NaN)	3.3194e-1 (1.27e-1) +	NaN (NaN)
+/-/=		30/0/0		30/0/0		29/0/1	

TABLE XXI
THE COMPARISON RESULTS OF IGD^+ METRIC OF ABLATION STUDY ON THREE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	3	1.8476e-2 (1.39e-3) +	NaN (NaN)	1.4939e-2 (5.41e-4) +	NaN (NaN)	1.4607e-2 (2.82e-4) +	NaN (NaN)
UC1-C2-DTLZ1	3	2.0023e-2 (2.30e-3) +	NaN (NaN)	1.4995e-2 (9.14e-4) +	NaN (NaN)	1.4883e-2 (5.80e-4) +	NaN (NaN)
UC1-C2-DTLZ3	3	3.6635e-2 (8.85e-3) +	NaN (NaN)	7.6936e-2 (2.61e-1) +	NaN (NaN)	2.9900e-2 (2.37e-1) +	NaN (NaN)
UC1-C3-DTLZ1	3	3.4268e-2 (1.19e-3) +	NaN (NaN)	5.7511e-2 (4.70e-2) +	NaN (NaN)	3.0349e-2 (4.58e-4) +	NaN (NaN)
UC1-C3-DTLZ2	3	1.0818e-1 (1.80e-4) +	NaN (NaN)	1.1056e-1 (1.05e-3) +	1.4106e-1 (0.00e+0)	1.0790e-1 (1.19e-4) +	4.1146e-1 (1.39e-1)
UC1-C3-DTLZ3	3	1.1419e-1 (1.35e-2) +	NaN (NaN)	1.3604e-1 (2.09e-3) +	NaN (NaN)	1.1832e-1 (1.88e-1) +	NaN (NaN)
UC2-C1-DTLZ1	3	3.9554e-2 (5.82e-3) +	3.5112e+1 (4.18e-1)	1.1259e-1 (2.47e-2) +	3.4508e+1 (1.67e-1)	1.4628e-2 (2.24e-4) +	3.4564e+1 (2.09e-1)
UC2-C2-DTLZ1	3	1.8850e-2 (1.74e-3) +	3.5084e+1 (4.21e-1)	1.1701e-1 (3.21e-2) +	3.4474e+1 (8.21e-2)	1.4842e-2 (4.55e-4) +	3.4555e+1 (2.02e-1)
UC2-C2-DTLZ3	3	3.4579e-2 (4.44e-3) +	8.9070e+1 (1.29e-2)	1.3846e-1 (8.90e+1) +	8.9033e+1 (4.75e-3)	2.4114e-2 (7.14e-3) +	8.9035e+1 (5.57e-3)
UC2-C3-DTLZ1	3	3.4393e-2 (2.12e-3) +	3.5050e+1 (3.82e-1)	1.5658e-1 (2.54e-2) +	3.4511e+1 (1.44e-1)	3.0639e-2 (8.61e-4) +	3.4552e+1 (2.26e-1)
UC2-C3-DTLZ2	3	1.0827e-1 (1.41e-4) +	NaN (NaN)	1.1137e-1 (1.00e-3) +	1.3405e-1 (0.00e+0)	1.0789e-1 (1.05e-4) +	4.2985e-1 (1.30e-1)
UC2-C3-DTLZ3	3	1.1169e-1 (1.86e-2) +	8.9068e+1 (1.38e-2)	1.3607e-1 (8.89e+1) +	8.9036e+1 (5.88e-3)	3.6924e-1 (8.89e+1) +	8.9034e+1 (4.78e-3)
UC3-C1-DTLZ1	3	3.8689e-2 (7.18e-3) +	8.7620e+1 (2.70e+1)	1.0310e-1 (1.17e-1) +	4.6059e+1 (4.19e-1)	1.4585e-2 (4.45e-4) +	4.5915e+1 (2.47e-2)
UC3-C2-DTLZ1	3	1.9552e-2 (2.14e-3) +	5.2139e+1 (4.54e-1)	2.1336e-2 (9.85e-3) +	5.0968e+1 (7.85e+0)	1.4806e-2 (3.52e-4) +	3.9950e+1 (1.86e+1)
UC3-C2-DTLZ3	3	3.3369e-2 (5.05e-3) +	4.4039e+1 (6.55e-3)	6.5748e-2 (4.40e+1) +	4.4014e+1 (6.63e-3)	3.4197e-1 (4.40e+1) +	4.4022e+1 (6.79e-3)
UC3-C3-DTLZ1	3	3.4974e-2 (2.02e-3) +	5.2108e+1 (3.33e-1)	9.1393e-2 (2.97e-2) +	4.7556e+1 (1.25e+1)	3.0809e-2 (1.12e-3) +	4.2577e+1 (1.71e+1)
UC3-C3-DTLZ2	3	1.1097e-1 (7.98e-4) +	2.7880e-1 (1.16e-1)	1.1167e-1 (1.68e-4) +	1.9292e-1 (1.10e-1)	1.1608e-1 (2.20e-3) +	3.5019e-1 (2.80e-2)
UC3-C3-DTLZ3	3	1.1337e-1 (3.30e+1) +	4.4038e+1 (8.66e-3)	1.3805e-1 (4.39e+1) +	4.4014e+1 (5.99e-3)	2.2801e-1 (4.39e+1) +	4.4019e+1 (8.60e-3)
UC4-C1-DTLZ1	3	3.7281e+0 (3.92e+1) +	7.2674e+1 (2.94e+1)	2.0083e+0 (3.86e+0) +	3.9339e+1 (7.26e+0)	2.8966e-1 (3.48e-3) +	4.0584e+1 (5.05e-3)
UC4-C2-DTLZ1	3	3.7423e-1 (3.20e-2) +	4.6547e+1 (2.54e-1)	3.1708e-1 (1.19e-1) +	4.0514e+1 (1.47e+1)	2.9619e-1 (3.91e-3) +	3.8360e+1 (1.66e+1)
UC4-C2-DTLZ3	3	3.3151e-1 (1.98e-2) +	3.4020e+1 (6.25e+0)	2.7710e-1 (4.51e-2) +	3.3987e+1 (6.00e+0)	2.5359e-1 (1.09e-2) +	3.5065e+1 (2.17e-2)
UC4-C3-DTLZ1	3	6.8543e-1 (2.34e-2) +	4.6911e+1 (7.43e-1)	1.8227e+0 (9.10e-1) +	4.3500e+1 (1.08e+1)	6.2098e-1 (1.26e-2) +	3.8346e+1 (1.66e+1)
UC4-C3-DTLZ2	3	1.0834e-1 (3.62e-4) +	NaN (NaN)	1.3561e-1 (1.72e-3) +	NaN (NaN)	1.0853e-1 (8.24e-4) +	3.6385e+0 (2.94e+0)
UC4-C3-DTLZ3	3	1.3723e+0 (1.11e-1) +	3.5143e+1 (1.60e-2)	1.3806e+0 (4.64e-3) +	3.5067e+1 (1.76e-2)	2.8717e+0 (1.14e+0) +	3.5067e+1 (1.56e-2)
UC5-C1-DTLZ1	3	1.9082e-2 (1.24e-3) +	NaN (NaN)	1.4631e-2 (3.52e-4) +	NaN (NaN)	1.4674e-2 (1.18e-4) +	NaN (NaN)
UC5-C2-DTLZ1	3	2.1716e-2 (5.82e-3) +	NaN (NaN)	1.4791e-2 (2.97e-4) +	NaN (NaN)	1.5051e-2 (5.19e-4) +	NaN (NaN)
UC5-C2-DTLZ3	3	3.3686e-2 (1.85e-3) +	NaN (NaN)	2.3586e-2 (1.03e-3) +	NaN (NaN)	2.6264e-2 (1.05e-2) +	NaN (NaN)
UC5-C3-DTLZ1	3	3.3766e-2 (1.29e-3) +	NaN (NaN)	9.1080e-2 (4.35e-2) +	NaN (NaN)	3.0780e-2 (8.80e-4) +	NaN (NaN)
UC5-C3-DTLZ2	3	1.0830e-1 (5.29e-4) +	NaN (NaN)	1.3382e-1 (2.55e-4) +	NaN (NaN)	1.0832e-1 (7.18e-4) +	4.6692e-1 (1.54e-1)
UC5-C3-DTLZ3	3	1.1789e-1 (2.54e-2) +	NaN (NaN)	1.3371e-1 (5.83e-5) +	NaN (NaN)	1.3368e-1 (7.52e-2) +	NaN (NaN)
+/-/=		30/0/0		30/0/0		30/0/0	

TABLE XXII
THE COMPARISON RESULTS OF HV METRIC OF ABLATION STUDY ON THREE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	3	8.1791e-1 (1.37e-2) +	NaN (NaN)	8.3403e-1 (6.71e-3) +	NaN (NaN)	8.3579e-1 (6.58e-3) +	NaN (NaN)
UC1-C2-DTLZ1	3	8.2078e-1 (6.92e-3) +	NaN (NaN)	8.3827e-1 (2.49e-3) +	NaN (NaN)	8.4100e-1 (1.23e-3) +	NaN (NaN)
UC1-C2-DTLZ3	3	5.2743e-1 (1.44e-2) +	NaN (NaN)	4.2278e-1 (2.33e-1) +	NaN (NaN)	5.4676e-1 (3.25e-1) +	NaN (NaN)
UC1-C3-DTLZ1	3	7.8518e-1 (5.97e-3) +	NaN (NaN)	7.3869e-1 (1.31e-1) +	NaN (NaN)	8.0451e-1 (1.08e-3) +	NaN (NaN)
UC1-C3-DTLZ2	3	3.4710e-1 (3.73e-4) +	NaN (NaN)	3.4200e-1 (2.62e-3) +	2.4302e-1 (0.00e+0)	3.4698e-1 (5.15e-4) +	1.4396e-1 (6.77e-2)
UC1-C3-DTLZ3	3	3.3372e-1 (3.36e-2) +	NaN (NaN)	2.5449e-1 (4.72e-3) +	NaN (NaN)	3.1948e-1 (1.43e-1) +	NaN (NaN)
UC2-C1-DTLZ1	3	7.3436e-1 (2.58e-2) +	0.0000e+0 (0.00e+0)	5.0554e-1 (6.84e-2) +	0.0000e+0 (0.00e+0)	8.3558e-1 (6.23e-3) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ1	3	8.2332e-1 (7.11e-3) +	0.0000e+0 (0.00e+0)	5.0030e-1 (7.61e-2) +	0.0000e+0 (0.00e+0)	8.4109e-1 (1.01e-3) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ3	3	5.3138e-1 (1.04e-2) +	0.0000e+0 (0.00e+0)	2.4950e-1 (5.57e-1) +	0.0000e+0 (0.00e+0)	5.5681e-1 (1.34e-2) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ1	3	7.8707e-1 (7.80e-3) +	0.0000e+0 (0.00e+0)	3.8541e-1 (8.54e-2) +	0.0000e+0 (0.00e+0)	8.0404e-1 (2.13e-3) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ2	3	3.4704e-1 (2.50e-4) +	NaN (NaN)	3.4051e-1 (2.35e-3) +	2.5893e-1 (0.00e+0)	3.4697e-1 (4.14e-4) +	1.2968e-1 (6.63e-2)
UC2-C3-DTLZ3	3	3.3953e-1 (4.75e-2) +	0.0000e+0 (0.00e+0)	2.5433e-1 (2.57e-1) +	0.0000e+0 (0.00e+0)	1.1188e-1 (3.33e-1) +	0.0000e+0 (0.00e+0)
UC3-C1-DTLZ1	3	7.3268e-1 (2.67e-2) +	0.0000e+0 (0.00e+0)	5.7705e-1 (3.35e-1) +	0.0000e+0 (0.00e+0)	8.3570e-1 (1.08e-2) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ1	3	8.2376e-1 (6.54e-3) +	0.0000e+0 (0.00e+0)	8.2330e-1 (2.78e-2) +	0.0000e+0 (0.00e+0)	8.4118e-1 (7.90e-4) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ3	3	5.3352e-1 (1.09e-2) +	0.0000e+0 (0.00e+0)	4.5892e-1 (4.91e-1) +	0.0000e+0 (0.00e+0)	1.9380e-1 (5.52e-1) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ1	3	7.7967e-1 (1.41e-2) +	0.0000e+0 (0.00e+0)	6.2955e-1 (7.67e-2) +	0.0000e+0 (0.00e+0)	8.0343e-1 (2.84e-3) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ2	3	3.4457e-1 (1.72e-3) +	1.7699e-1 (1.07e-1)	3.4386e-1 (9.11e-4) +	2.6692e-1 (1.00e-1)	3.2454e-1 (7.38e-3) +	1.0878e-1 (1.73e-2)
UC3-C3-DTLZ3	3	3.3507e-1 (3.23e-1) +	0.0000e+0 (0.00e+0)	2.5005e-1 (2.57e-1) +	0.0000e+0 (0.00e+0)	2.4451e-1 (3.31e-1) +	0.0000e+0 (0.00e+0)
UC4-C1-DTLZ1	3	2.8941e-1 (5.93e-1) +	0.0000e+0 (0.00e+0)	5.2895e-1 (5.13e-1) +	2.6868e-2 (1.50e-1)	8.3913e-1 (4.78e-3) +	0.0000e+0 (0.00e+0)
UC4-C2-DTLZ1	3	8.2335e-1 (6.60e-3) +	0.0000e+0 (0.00e+0)	8.3410e-1 (1.80e-2) +	4.8087e-2 (1.62e-1)	8.4022e-1 (1.13e-3) +	5.7020e-2 (1.67e-1)
UC4-C2-DTLZ3	3	5.3284e-1 (4.89e-3) +	1.7006e-2 (9.47e-2)	5.5075e-1 (9.64e-3) +	1.2402e-2 (6.90e-2)	5.5375e-1 (2.59e-3) +	0.0000e+0 (0.00e+0)
UC4-C3-DTLZ1	3	7.8663e-1 (9.41e-3) +	0.0000e+0 (0.00e+0)	6.3159e-1 (1.23e-1) +	3.1799e-2 (1.47e-1)	8.0026e-1 (3.65e-3) +	5.5910e-2 (1.55e-1)
UC4-C3-DTLZ2	3	3.4632e-1 (1.28e-3) +	NaN (NaN)	2.5558e-1 (4.12e-3) +	NaN (NaN)	3.4509e-1 (2.99e-3) +	1.4839e-2 (6.21e-2)
UC4-C3-DTLZ3	3	2.5147e-1 (3.92e-2) +	0.0000e+0 (0.00e+0)	2.4955e-1 (1.08e-3) +	0.0000e+0 (0.00e+0)	1.9714e-1 (7.57e-2) +	0.0000e+0 (0.00e+0)
UC5-C1-DTLZ1	3	8.2102e-1 (4.96e-3) +	NaN (NaN)	8.3748e-1 (1.68e-3) +	NaN (NaN)	8.4095e-1 (7.14e-4) +	NaN (NaN)
UC5-C2-DTLZ1	3	8.1638e-1 (1.25e-2) +	NaN (NaN)	8.3836e-1 (2.60e-3) +	NaN (NaN)	8.4064e-1 (1.08e-3) +	NaN (NaN)
UC5-C2-DTLZ3	3	5.3308e-1 (6.01e-3) +	NaN (NaN)	5.6169e-1 (1.61e-3) +	NaN (NaN)	5.5284e-1 (2.01e-2) +	NaN (NaN)
UC5-C3-DTLZ1	3	7.8681e-1 (8.96e-3) +	NaN (NaN)	6.3186e-1 (1.25e-1) +	NaN (NaN)	8.0089e-1 (4.80e-3) +	NaN (NaN)
UC5-C3-DTLZ2	3	3.4656e-1 (1.44e-3) +	NaN (NaN)	2.5953e-1 (3.67e-4) +	NaN (NaN)	3.4583e-1 (1.80e-3) +	1.0151e-1 (7.30e-2)
UC5-C3-DTLZ3	3	3.1393e-1 (8.71e-2) +	NaN (NaN)	2.5971e-1 (1.42e-4) +	NaN (NaN)	2.8198e-1 (8.47e-2) +	NaN (NaN)
+/-/=		30/0/0		30/0/0		30/0/0	

TABLE XXIII
THE COMPARISON RESULTS OF IGD METRIC OF ABLATION STUDY ON FIVE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	5	7.5222e-2 (7.71e-3) +	NaN (NaN)	1.3934e-1 (1.02e-2) +	NaN (NaN)	7.7826e-2 (1.14e-3) +	2.8120e-1 (1.35e-1)
UC1-C2-DTLZ1	5	1.1056e-1 (8.97e-2) +	NaN (NaN)	1.4950e-1 (1.52e-2) +	NaN (NaN)	6.3336e-2 (2.22e-5) +	8.8735e-2 (8.06e-2)
UC1-C2-DTLZ3	5	NaN (NaN) =	NaN (NaN)	5.7628e-1 (1.34e-2) +	NaN (NaN)	1.9554e-1 (2.76e-3) +	NaN (NaN)
UC1-C3-DTLZ1	5	8.9035e-2 (4.91e-3) +	NaN (NaN)	1.8492e-1 (1.70e-2) +	NaN (NaN)	7.3128e-2 (3.03e-5) =	8.9118e-2 (0.00e+0)
UC1-C3-DTLZ2	5	4.3402e-1 (2.15e-2) +	NaN (NaN)	4.6008e-1 (2.01e-3) +	5.2672e-1 (3.86e-1)	4.5624e-1 (2.15e-4) +	8.9179e-1 (1.73e-1)
UC1-C3-DTLZ3	5	NaN (NaN) =	NaN (NaN)	5.8742e-1 (5.68e-3) +	NaN (NaN)	4.6948e-1 (2.80e-2) +	NaN (NaN)
UC2-C1-DTLZ1	5	1.2613e+1 (1.64e+1) +	3.0579e+1 (2.17e+0)	1.5138e-1 (1.86e-2) +	2.7034e+1 (4.48e-1)	7.5604e-2 (7.49e-3) +	2.6669e+1 (8.16e-2)
UC2-C2-DTLZ1	5	1.4048e+1 (1.66e+1) +	3.1088e+1 (1.51e+0)	1.6302e-1 (1.66e-2) +	2.7095e+1 (3.34e-1)	6.3425e-2 (3.21e-4) +	2.6632e+1 (4.15e-2)
UC2-C2-DTLZ3	5	8.9329e+1 (6.96e-2) =	8.9315e+1 (1.04e-1)	5.7615e-1 (1.04e-2) +	8.9095e+1 (1.04e-2)	1.9599e-1 (1.23e-3) +	8.9071e+1 (8.99e-3)
UC2-C3-DTLZ1	5	1.0661e+1 (1.53e+1) +	3.0149e+1 (1.72e+0)	1.9408e-1 (2.14e-2) +	2.6988e+1 (2.77e-1)	7.3132e-2 (3.13e-5) +	2.6649e+1 (6.73e-2)
UC2-C3-DTLZ2	5	5.6263e-1 (2.76e-3) +	NaN (NaN)	5.2168e-1 (5.58e-2) +	NaN (NaN)	4.9071e-1 (2.98e-2) +	9.0621e-1 (1.80e-1)
UC2-C3-DTLZ3	5	8.9326e+1 (7.60e-2) -	8.9269e+1 (6.58e-2)	5.8615e-1 (6.49e-3) +	8.9093e+1 (1.11e-2)	4.8609e-1 (3.52e-2) +	8.9064e+1 (7.93e-3)
UC3-C1-DTLZ1	5	2.0660e+1 (2.58e+1) +	8.4000e+1 (6.24e+0)	1.4330e-1 (1.26e-2) +	3.5913e+1 (3.50e-1)	7.9122e-2 (5.79e-3) +	3.5555e+1 (4.77e-3)
UC3-C2-DTLZ1	5	6.6638e+0 (8.31e+0) +	4.4910e+1 (1.40e+0)	1.5316e-1 (1.68e-2) +	4.0460e+1 (3.27e-1)	6.3549e-2 (7.79e-4) +	4.0026e+1 (1.78e-4)
UC3-C2-DTLZ3	5	3.3724e+1 (1.90e+1) +	4.4160e+1 (6.16e-2)	5.7663e-1 (1.24e-2) +	4.4064e+1 (1.15e-2)	1.9504e-1 (5.96e-4) +	4.4030e+1 (2.05e-2)
UC3-C3-DTLZ1	5	9.1117e+0 (1.39e+1) +	4.2534e+1 (1.63e+0)	1.9899e-1 (2.03e-2) +	4.0348e+1 (6.74e-1)	7.3650e-2 (1.67e-3) +	4.0026e+1 (1.58e-4)
UC3-C3-DTLZ2	5	4.3021e-1 (5.17e-3) +	4.5157e-1 (8.16e-3)	4.2779e-1 (6.50e-3) -	4.2334e-1 (1.73e-2)	4.5346e-1 (3.84e-3) -	4.2789e-1 (9.58e-3)
UC3-C3-DTLZ3	5	3.9984e+1 (1.30e+1) +	4.4218e+1 (9.06e-2)	5.8705e-1 (4.57e-3) +	4.4068e+1 (8.94e-3)	4.7947e-1 (3.36e-2) +	4.4033e+1 (2.10e-2)
UC4-C1-DTLZ1	5	3.3845e+1 (2.66e+1) +	8.2124e+1 (2.80e+0)	4.2119e+0 (2.09e+0) +	3.1859e+1 (3.72e-1)	1.8571e+0 (1.88e-1) +	3.1573e+1 (2.37e-3)
UC4-C2-DTLZ1	5	6.8346e+0 (4.53e+0) +	3.9014e+1 (4.60e+0)	1.9223e+0 (1.46e-1) +	3.6241e+1 (2.68e+1)	1.3693e+0 (8.96e-2) +	3.6011e+1 (7.19e-5)
UC4-C2-DTLZ3	5	2.3324e+0 (1.66e-1) +	3.6183e+1 (7.93e-1)	3.9984e+0 (2.94e-1) +	3.5425e+1 (1.61e-2)	2.2235e+0 (1.45e-1) +	3.5372e+1 (1.27e-1)
UC4-C3-DTLZ1	5	1.9260e+0 (6.06e-1) +	4.0085e+1 (2.08e-1)	2.5348e+0 (3.07e-1) +	3.6402e+1 (5.10e-1)	1.7086e+0 (2.84e-1) +	3.6011e+1 (1.19e-3)
UC4-C3-DTLZ2	5	5.2350e-1 (2.79e-3) +	NaN (NaN)	5.9028e-1 (3.73e-3) +	NaN (NaN)	5.0487e-1 (5.23e-2) +	7.5254e+0 (5.80e+0)
UC4-C3-DTLZ3	5	6.4708e+0 (8.90e-1) +	3.5922e+1 (4.58e-1)	5.9779e+0 (2.54e-2) +	3.5396e+1 (9.06e-2)	5.3686e+0 (3.82e-1) +	3.5276e+1 (1.80e-2)
UC5-C1-DTLZ1	5	1.0601e-1 (6.48e-2) +	NaN (NaN)	1.8023e-1 (7.72e-2) +	NaN (NaN)	6.9732e-2 (5.87e-3) +	9.3687e-2 (2.70e-2)
UC5-C2-DTLZ1	5	8.2156e-2 (3.48e-3) +	NaN (NaN)	1.5492e-1 (3.11e-2) +	NaN (NaN)	6.5739e-2 (4.28e-3) +	8.0576e-2 (1.84e-2)
UC5-C2-DTLZ3	5	2.1974e-1 (8.48e-3) +	NaN (NaN)	5.8973e-1 (6.92e-3) +	NaN (NaN)	2.0733e-1 (1.06e-2) +	NaN (NaN)
UC5-C3-DTLZ1	5	9.5785e-2 (1.31e-2) +	NaN (NaN)	1.8757e-1 (3.51e-2) +	NaN (NaN)	7.5887e-2 (6.24e-3) +	1.3751e-1 (1.48e-2)
UC5-C3-DTLZ2	5	5.2346e-1 (2.65e-3) +	NaN (NaN)	5.9147e-1 (2.43e-3) +	NaN (NaN)	4.9519e-1 (4.53e-2) +	8.8605e-1 (8.77e-2)
UC5-C3-DTLZ3	5	5.2326e-1 (2.38e-3) +	NaN (NaN)	5.9632e-1 (2.63e-3) +	NaN (NaN)	5.0789e-1 (5.04e-2) +	8.8640e-1 (8.64e-4)
+/-/=		26/1/3		29/1/0		29/1/1	

TABLE XXIV
THE COMPARISON RESULTS OF IGD^+ METRIC OF ABLATION STUDY ON FIVE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	5	5.1115e-2 (7.36e-3) +	NaN (NaN)	9.7387e-2 (8.52e-3) +	NaN (NaN)	5.7524e-2 (1.09e-3) +	2.2018e-1 (9.90e-2)
UC1-C2-DTLZ1	5	8.7435e-2 (7.08e-2) +	NaN (NaN)	1.0578e-1 (1.31e-2) +	NaN (NaN)	4.5919e-2 (5.12e-5) +	9.2943e-2 (5.76e-2)
UC1-C2-DTLZ3	5	NaN (NaN) =	NaN (NaN)	1.9723e-1 (2.28e-3) +	NaN (NaN)	7.1504e-2 (4.63e-4) +	NaN (NaN)
UC1-C3-DTLZ1	5	6.5612e-2 (4.95e-3) +	NaN (NaN)	1.3389e-1 (1.76e-2) +	NaN (NaN)	5.1492e-2 (4.38e-5) +	6.3035e-2 (0.00e+0)
UC1-C3-DTLZ2	5	1.8704e-1 (2.10e-3) +	NaN (NaN)	1.8911e-1 (3.65e-4) +	3.4903e-1 (2.67e-1)	1.8954e-1 (4.05e-5) +	5.4364e-1 (1.17e-1)
UC1-C3-DTLZ3	5	NaN (NaN) =	NaN (NaN)	1.9917e-1 (4.05e-4) +	NaN (NaN)	1.9059e-1 (2.14e-3) +	NaN (NaN)
UC2-C1-DTLZ1	5	1.2586e+1 (1.64e+1) +	3.0672e+1 (1.34e+0)	1.0849e-1 (1.56e-2) +	2.7073e+1 (3.23e-1)	5.5694e-2 (6.10e-3) +	2.6702e+1 (1.21e-1)
UC2-C2-DTLZ1	5	1.4038e+1 (1.66e+1) +	3.1143e+1 (1.36e+0)	1.1880e-1 (1.55e-2) +	2.7122e+1 (3.44e-1)	4.5995e-2 (2.13e-4) +	2.6721e+1 (1.95e-1)
UC2-C2-DTLZ3	5	8.9328e+1 (6.92e-2) =	8.9303e+1 (6.52e-2)	1.9740e-1 (2.25e-3) +	8.9096e+1 (8.23e-3)	7.1824e-2 (3.13e-4) +	8.9071e+1 (7.16e-3)
UC2-C3-DTLZ1	5	1.0645e+1 (1.54e+1) +	3.0876e+1 (1.62e+0)	1.4489e-1 (2.05e-2) +	2.7059e+1 (3.09e-1)	5.1511e-2 (5.64e-5) +	2.6675e+1 (8.36e-2)
UC2-C3-DTLZ2	5	1.9882e-1 (6.01e-5) +	NaN (NaN)	1.9474e-1 (3.63e-3) +	NaN (NaN)	1.9384e-1 (1.95e-3) +	5.4386e-1 (1.09e-1)
UC2-C3-DTLZ3	5	8.9325e+1 (7.54e-2) -	8.9268e+1 (4.72e-2)	1.9918e-1 (4.46e-4) +	8.9093e+1 (8.30e-3)	1.9187e-1 (2.70e-3) +	8.9065e+1 (5.32e-3)
UC3-C1-DTLZ1	5	2.0634e+1 (2.58e+1) +	7.8531e+1 (1.72e+1)	1.0090e-1 (1.08e-2) +	3.5992e+1 (2.79e-1)	5.8474e-2 (4.52e-3) +	4.2163e+1 (1.60e+1)
UC3-C2-DTLZ1	5	6.6490e+0 (8.32e+0) +	4.4434e+1 (8.66e-1)	1.0983e-1 (1.51e-2) +	3.9094e+1 (6.96e+0)	4.6054e-2 (4.87e-4) +	3.5555e+1 (1.12e+1)
UC3-C2-DTLZ3	5	3.3685e+1 (1.91e+1) +	4.6328e+1 (9.80e+0)	1.9750e-1 (2.17e-3) +	4.4061e+1 (9.46e-3)	7.1413e-2 (1.48e-4) +	4.6179e+1 (9.82e+0)
UC3-C3-DTLZ1	5	9.0953e+0 (1.39e+1) +	4.2534e+1 (1.15e+0)	1.4816e-1 (2.11e-2) +	3.6029e+1 (1.14e+1)	5.1854e-2 (1.14e-3) +	3.5556e+1 (1.12e+1)
UC3-C3-DTLZ2	5	2.4032e-1 (2.88e-2) +	4.1855e-1 (4.72e-2)	1.9455e-1 (1.23e-2) =	2.4420e-1 (8.71e-2)	1.8954e-1 (3.79e-5) +	3.2845e-1 (9.85e-2)
UC3-C3-DTLZ3	5	3.9949e+1 (1.31e+1) +	4.4239e+1 (1.02e-1)	1.9918e-1 (4.02e-4) +	4.4065e+1 (1.13e-2)	1.9132e-1 (2.54e-3) +	4.6181e+1 (9.82e+0)
UC4-C1-DTLZ1	5	3.3042e+1 (2.73e+1) +	7.9935e+1 (1.05e+1)	3.0945e+0 (1.81e+0) +	3.1905e+1 (2.29e-1)	1.3377e+0 (9.96e-2) +	3.5818e+1 (1.34e+1)
UC4-C2-DTLZ1	5	5.9860e+0 (4.35e+0) +	4.0990e+1 (5.98e+0)	1.3055e+0 (1.03e-1) +	2.7480e+1 (1.45e+1)	9.8882e-1 (6.30e-2) +	2.9963e+1 (1.28e+1)
UC4-C2-DTLZ3	5	1.1445e+0 (8.55e-2) +	3.8478e+1 (9.66e+0)	1.4336e+0 (1.32e-1) +	3.3997e+1 (6.36e+0)	7.8504e-1 (6.32e-2) +	3.5342e+1 (6.34e-2)
UC4-C3-DTLZ1	5	1.3441e+0 (4.72e-1) +	4.0085e+1 (1.47e-1)	1.6776e+0 (1.84e-1) +	3.1794e+1 (1.18e+1)	1.1651e+0 (1.30e-1) +	3.4553e+1 (6.69e+0)
UC4-C3-DTLZ2	5	1.9597e-1 (2.16e-4) +	NaN (NaN)	1.9982e-1 (1.55e-4) +	NaN (NaN)	2.0489e-1 (2.73e-2) +	4.4973e+0 (3.30e+0)
UC4-C3-DTLZ3	5	2.4868e+0 (6.83e-1) +	3.5917e+1 (2.50e-1)	1.9976e+0 (8.69e-4) +	3.3762e+1 (7.28e+0)	2.0232e+0 (1.72e-1) +	3.5258e+1 (2.16e-2)
UC5-C1-DTLZ1	5	8.1555e-2 (6.25e-2) +	NaN (NaN)	1.3081e-1 (6.68e-2) +	NaN (NaN)	5.0286e-2 (4.27e-3) +	6.7288e-2 (1.35e-2)
UC5-C2-DTLZ1	5	7.0121e-2 (4.40e-3) +	NaN (NaN)	1.1462e-1 (2.64e-2) +	NaN (NaN)	4.7640e-2 (2.93e-3) +	8.6510e-2 (7.07e-2)
UC5-C2-DTLZ3	5	1.4858e-1 (1.40e-2) +	NaN (NaN)	2.0028e-1 (1.33e-3) +	NaN (NaN)	7.4338e-2 (3.16e-3) +	NaN (NaN)
UC5-C3-DTLZ1	5	7.5139e-2 (9.39e-3) +	NaN (NaN)	1.3989e-1 (3.28e-2) +	NaN (NaN)	5.3211e-2 (3.65e-3) +	8.8715e-2 (1.40e-2)
UC5-C3-DTLZ2	5	1.9605e-1 (2.54e-4) +	NaN (NaN)	1.9985e-1 (7.92e-5) +	NaN (NaN)	1.9579e-1 (1.60e-2) +	4.8869e-1 (1.08e-1)
UC5-C3-DTLZ3	5	1.9592e-1 (1.95e-4) +	NaN (NaN)	2.0023e-1 (3.08e-4) +	NaN (NaN)	2.0521e-1 (2.71e-2) +	4.7746e-1 (4.87e-3)
+/-/=		26/1/3		29/0/1		30/0/0	

TABLE XXV
THE COMPARISON RESULTS OF HV METRIC OF ABLATION STUDY ON FIVE OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	5	9.4276e-1 (4.49e-2) +	NaN (NaN)	8.7775e-1 (1.55e-2) +	NaN (NaN)	9.3883e-1 (1.09e-2) +	4.3154e-1 (2.03e-1)
UC1-C2-DTLZ1	5	8.7044e-1 (2.28e-1) +	NaN (NaN)	8.6853e-1 (2.22e-2) +	NaN (NaN)	9.7487e-1 (1.35e-4) +	8.5796e-1 (1.69e-1)
UC1-C2-DTLZ3	5	NaN (NaN) =	NaN (NaN)	3.8896e-1 (9.74e-3) +	NaN (NaN)	7.9448e-1 (1.13e-3) +	NaN (NaN)
UC1-C3-DTLZ1	5	9.4495e-1 (7.95e-3) +	NaN (NaN)	8.0392e-1 (3.61e-2) +	NaN (NaN)	9.7150e-1 (2.01e-4) +	9.3738e-1 (0.00e+0)
UC1-C3-DTLZ2	5	4.4668e-1 (1.22e-2) +	NaN (NaN)	4.3862e-1 (1.60e-3) +	2.9439e-1 (1.73e-1)	4.2495e-1 (4.80e-4) +	1.5151e-1 (6.08e-2)
UC1-C3-DTLZ3	5	NaN (NaN) =	NaN (NaN)	3.8125e-1 (1.47e-3) +	NaN (NaN)	4.1909e-1 (1.24e-2) +	NaN (NaN)
UC2-C1-DTLZ1	5	4.6843e-1 (3.90e-1) +	0.0000e+0 (0.00e+0)	8.7420e-1 (3.27e-2) +	0.0000e+0 (0.00e+0)	9.0170e-1 (7.41e-2) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ1	5	5.4261e-1 (4.82e-1) +	0.0000e+0 (0.00e+0)	8.5299e-1 (2.86e-2) +	0.0000e+0 (0.00e+0)	9.7488e-1 (2.31e-4) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ3	5	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	3.8843e-1 (9.71e-3) +	0.0000e+0 (0.00e+0)	7.9378e-1 (4.83e-4) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ1	5	6.1968e-1 (4.52e-1) +	0.0000e+0 (0.00e+0)	7.9317e-1 (4.83e-2) +	0.0000e+0 (0.00e+0)	9.7163e-1 (1.40e-4) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ2	5	3.8263e-1 (5.73e-4) +	NaN (NaN)	4.0772e-1 (2.08e-2) +	NaN (NaN)	4.1006e-1 (1.14e-2) +	1.4698e-1 (5.35e-2)
UC2-C3-DTLZ3	5	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	3.8112e-1 (1.56e-3) +	0.0000e+0 (0.00e+0)	4.1165e-1 (1.55e-2) +	0.0000e+0 (0.00e+0)
UC3-C1-DTLZ1	5	4.4017e-1 (3.94e-1) +	0.0000e+0 (0.00e+0)	8.8032e-1 (2.11e-2) +	0.0000e+0 (0.00e+0)	8.8431e-1 (6.56e-2) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ1	5	4.8042e-1 (4.69e-1) +	0.0000e+0 (0.00e+0)	8.6274e-1 (2.60e-2) +	0.0000e+0 (0.00e+0)	9.7487e-1 (6.08e-4) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ3	5	1.0395e-1 (2.19e-1) +	0.0000e+0 (0.00e+0)	3.8758e-1 (8.77e-3) +	0.0000e+0 (0.00e+0)	7.9466e-1 (6.95e-4) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ1	5	5.6040e-1 (4.68e-1) +	0.0000e+0 (0.00e+0)	7.6740e-1 (5.17e-2) +	0.0000e+0 (0.00e+0)	9.7110e-1 (1.47e-3) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ2	5	3.9258e-1 (2.33e-2) +	1.9727e-1 (4.78e-2)	4.6824e-1 (8.71e-3) =	4.3295e-1 (8.51e-2)	4.2684e-1 (2.29e-3) +	2.9587e-1 (9.41e-2)
UC3-C3-DTLZ3	5	1.8159e-2 (8.12e-2) +	0.0000e+0 (0.00e+0)	3.8101e-1 (1.50e-3) +	0.0000e+0 (0.00e+0)	4.1485e-1 (1.48e-2) +	0.0000e+0 (0.00e+0)
UC4-C1-DTLZ1	5	5.4197e-2 (7.84e-2) +	0.0000e+0 (0.00e+0)	6.3028e-1 (2.43e-1) +	0.0000e+0 (0.00e+0)	8.0966e-1 (9.56e-3) +	0.0000e+0 (0.00e+0)
UC4-C2-DTLZ1	5	4.2523e-1 (3.73e-1) +	0.0000e+0 (0.00e+0)	9.3528e-1 (9.68e-3) +	1.3925e-1 (2.73e-1)	9.6810e-1 (7.14e-3) +	1.1856e-1 (2.66e-1)
UC4-C2-DTLZ3	5	7.0735e-1 (2.03e-2) +	0.0000e+0 (0.00e+0)	6.0403e-1 (4.79e-2) +	6.0674e-3 (2.78e-2)	7.8000e-1 (1.17e-2) +	0.0000e+0 (0.00e+0)
UC4-C3-DTLZ1	5	9.2511e-1 (6.76e-2) +	0.0000e+0 (0.00e+0)	9.1023e-1 (1.67e-2) +	9.1950e-2 (2.47e-1)	9.6218e-1 (8.87e-3) +	2.3719e-2 (1.09e-1)
UC4-C3-DTLZ2	5	3.9294e-1 (7.13e-4) +	NaN (NaN)	3.7905e-1 (7.80e-4) +	NaN (NaN)	3.9904e-1 (3.08e-2) +	5.6641e-2 (1.22e-1)
UC4-C3-DTLZ3	5	3.3539e-1 (5.70e-2) +	0.0000e+0 (0.00e+0)	3.7916e-1 (6.81e-4) +	1.8189e-2 (8.34e-2)	3.8921e-1 (1.76e-2) +	0.0000e+0 (0.00e+0)
UC5-C1-DTLZ1	5	8.3889e-1 (2.02e-1) +	NaN (NaN)	7.5577e-1 (1.64e-1) +	NaN (NaN)	9.6541e-1 (1.24e-2) =	9.0137e-1 (6.12e-2)
UC5-C2-DTLZ1	5	9.4166e-1 (4.45e-3) +	NaN (NaN)	8.5420e-1 (5.11e-2) +	NaN (NaN)	9.7206e-1 (6.16e-3) +	8.5365e-1 (2.51e-1)
UC5-C2-DTLZ3	5	6.3841e-1 (2.52e-2) +	NaN (NaN)	3.7787e-1 (5.31e-3) +	NaN (NaN)	7.8891e-1 (6.07e-3) +	NaN (NaN)
UC5-C3-DTLZ1	5	9.3023e-1 (1.44e-2) +	NaN (NaN)	7.8715e-1 (7.62e-2) +	NaN (NaN)	9.6916e-1 (5.35e-3) +	8.9569e-1 (3.47e-2)
UC5-C3-DTLZ2	5	3.9282e-1 (6.83e-4) +	NaN (NaN)	3.7902e-1 (6.30e-4) +	NaN (NaN)	4.0660e-1 (2.31e-2) +	1.7967e-1 (5.82e-2)
UC5-C3-DTLZ3	5	3.9351e-1 (5.46e-4) +	NaN (NaN)	3.7746e-1 (1.10e-3) +	NaN (NaN)	3.9639e-1 (2.94e-2) +	1.7550e-1 (8.18e-3)
+/-/=		26/0/4		29/1/0		29/0/1	

TABLE XXVI
THE COMPARISON RESULTS OF IGD METRIC OF ABLATION STUDY ON TEN OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.6044e-1 (2.67e-2) +	NaN (NaN)	1.2231e-1 (4.11e-3) +	1.7705e-1 (1.89e-2)
UC1-C2-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.7524e-1 (2.29e-2) +	NaN (NaN)	1.2126e-1 (5.44e-3) +	1.5535e-1 (2.17e-2)
UC1-C2-DTLZ3	10	NaN (NaN) =	NaN (NaN)	6.9122e-1 (9.48e-3) +	NaN (NaN)	4.9084e-1 (3.30e-2) +	NaN (NaN)
UC1-C3-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.8459e-1 (1.88e-2) +	NaN (NaN)	1.2203e-1 (3.95e-3) +	1.7973e-1 (1.75e-2)
UC1-C3-DTLZ2	10	1.1727e+0 (0.00e+0) +	NaN (NaN)	7.0354e-1 (3.37e-3) +	9.1394e-1 (1.32e-1)	6.7347e-1 (3.52e-2) +	1.1926e+0 (8.95e-2)
UC1-C3-DTLZ3	10	NaN (NaN) +	NaN (NaN)	7.0918e-1 (3.07e-3) +	NaN (NaN)	6.7584e-1 (4.38e-2) +	NaN (NaN)
UC2-C1-DTLZ1	10	5.2407e+1 (1.23e+1) +	5.8029e+1 (5.91e+0)	1.7871e-1 (1.51e-2) +	2.1836e+1 (1.19e+0)	1.2736e-1 (7.90e-3) +	2.2524e+1 (8.56e+0)
UC2-C2-DTLZ1	10	5.8232e+1 (5.82e+0) =	5.6646e+1 (6.79e+0)	2.0847e-1 (2.28e-2) +	2.1296e+1 (6.41e-1)	1.2473e-1 (7.45e-3) +	2.0824e+1 (8.04e+0)
UC2-C2-DTLZ3	10	1.3710e+2 (2.37e+1) +	1.4560e+2 (2.38e+1)	6.9040e-1 (7.03e-3) +	8.9230e+1 (1.09e-2)	5.3321e-1 (4.15e-2) +	8.9183e+1 (1.84e-2)
UC2-C3-DTLZ1	10	5.1409e+1 (1.25e+1) +	5.8024e+1 (5.91e+0)	2.3644e-1 (2.71e-2) +	2.1572e+1 (9.58e-1)	1.2446e-1 (4.79e-3) +	2.0487e+1 (1.08e+1)
UC2-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	7.1671e-1 (1.91e-3) +	NaN (NaN)	7.2784e-1 (5.22e-2) +	1.1223e+0 (1.01e-1)
UC2-C3-DTLZ3	10	1.1992e+2 (2.89e+1) +	1.2375e+2 (2.32e+1)	7.1092e-1 (4.47e-3) +	8.9228e+1 (1.26e-2)	6.9061e-1 (5.24e-2) +	8.9178e+1 (1.62e-2)
UC3-C1-DTLZ1	10	6.7390e+1 (9.34e+0) +	6.9992e+1 (1.16e+1)	1.5676e-1 (2.35e-2) +	2.8615e+1 (1.42e+0)	1.2354e-1 (4.65e-3) +	2.6799e+1 (1.01e+1)
UC3-C2-DTLZ1	10	1.5030e+1 (6.29e+0) +	3.7735e+1 (3.80e+0)	1.6438e-1 (1.60e-2) +	2.9596e+1 (7.73e+0)	1.2474e-1 (7.92e-3) +	3.0467e+1 (3.94e+0)
UC3-C2-DTLZ3	10	8.5032e+1 (1.32e+1) -	8.0816e+1 (1.78e+1)	6.9513e-1 (7.10e-3) +	4.4178e+1 (2.07e-2)	4.8734e-1 (3.92e-2) +	4.4163e+1 (8.73e-2)
UC3-C3-DTLZ1	10	1.5502e+1 (7.36e+0) +	3.8213e+1 (1.85e+0)	1.8721e-1 (2.33e-2) +	2.9798e+1 (5.34e+0)	1.2579e-1 (5.41e-3) +	3.0037e+1 (2.19e+0)
UC3-C3-DTLZ2	10	9.3318e-1 (1.69e-2) =	9.4354e-1 (1.06e-2)	6.3610e-1 (2.33e-2) +	6.1397e-1 (2.54e-2)	6.6796e-1 (3.58e-2) +	6.9457e-1 (4.67e-2)
UC3-C3-DTLZ3	10	7.6604e+1 (2.05e+1) -	7.4530e+1 (2.14e+1)	7.0943e-1 (3.12e-3) +	4.4190e+1 (1.92e-2)	7.2024e-1 (7.58e-2) +	4.4177e+1 (4.32e-2)
UC4-C1-DTLZ1	10	3.5107e+1 (2.98e+1) +	6.8191e+1 (9.75e+0)	4.9882e+0 (2.12e+0) +	2.5727e+1 (1.36e+0)	2.6155e+0 (1.31e-1) +	2.3822e+1 (1.95e+0)
UC4-C2-DTLZ1	10	1.1200e+1 (9.01e+0) +	3.6556e+1 (1.53e+0)	2.7296e+0 (1.72e-1) +	2.2159e+1 (1.14e+1)	2.5604e+0 (1.38e-1) +	2.7876e+1 (5.35e+0)
UC4-C2-DTLZ3	10	7.4059e+1 (1.56e+1) -	7.5807e+1 (1.41e+1)	5.7340e+0 (1.84e-1) +	3.6586e+1 (4.71e-2)	5.4070e+0 (3.45e-1) +	3.7170e+1 (8.46e-1)
UC4-C3-DTLZ1	10	9.3977e+0 (6.03e+0) +	3.4107e+1 (2.66e+0)	2.9667e+0 (2.88e-1) +	2.4661e+1 (1.01e+1)	2.5854e+0 (1.39e-1) +	2.7321e+1 (4.03e+0)
UC4-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	7.2694e-1 (3.06e-2) +	NaN (NaN)	7.2231e-1 (6.87e-2) +	7.6779e+0 (6.44e-2)
UC4-C3-DTLZ3	10	6.8482e+1 (1.88e+1) -	5.9430e+1 (1.95e+1)	7.2227e+0 (1.94e-2) +	3.6564e+1 (6.19e-2)	7.4641e+0 (6.49e-1) +	3.6650e+1 (4.04e-1)
UC5-C1-DTLZ1	10	NaN (NaN) =	NaN (NaN)	2.3146e-1 (7.12e-2) +	NaN (NaN)	1.3020e-1 (6.56e-3) +	1.8450e-1 (5.22e-2)
UC5-C2-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.8822e-1 (3.31e-2) +	NaN (NaN)	1.3139e-1 (7.22e-3) +	1.6517e-1 (2.59e-2)
UC5-C2-DTLZ3	10	NaN (NaN) =	NaN (NaN)	7.0075e-1 (9.63e-3) +	NaN (NaN)	5.2880e-1 (3.12e-2) +	NaN (NaN)
UC5-C3-DTLZ1	10	NaN (NaN) =	NaN (NaN)	2.0675e-1 (3.61e-2) +	NaN (NaN)	1.2809e-1 (5.02e-3) +	1.7241e-1 (2.63e-2)
UC5-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	7.2283e-1 (2.15e-2) +	NaN (NaN)	7.3877e-1 (7.16e-2) +	1.1138e+0 (7.92e-2)
UC5-C3-DTLZ3	10	NaN (NaN) =	NaN (NaN)	7.1288e-1 (4.72e-3) +	NaN (NaN)	6.9892e-1 (3.92e-2) +	1.0241e+0 (1.33e-1)
+/-/=		11/4/15		30/0/0		30/0/0	

TABLE XXVII
THE COMPARISON RESULTS OF IGD^+ METRIC OF ABLATION STUDY ON TEN OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.9340e-2 (1.55e-2) +	NaN (NaN)	6.9181e-2 (1.57e-3) +	1.1590e-1 (3.00e-2)
UC1-C2-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.1735e-1 (1.96e-2) +	NaN (NaN)	6.8804e-2 (2.13e-3) +	9.8451e-2 (9.58e-3)
UC1-C2-DTLZ3	10	NaN (NaN) =	NaN (NaN)	2.7659e-1 (3.40e-3) +	NaN (NaN)	2.4849e-1 (4.88e-2) +	NaN (NaN)
UC1-C3-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.2641e-1 (1.92e-2) +	NaN (NaN)	7.1439e-2 (2.36e-3) +	1.1388e-1 (1.11e-2)
UC1-C3-DTLZ2	10	7.9257e-1 (0.00e+0) +	NaN (NaN)	2.8058e-1 (4.57e-4) +	4.9415e-1 (1.21e-1)	2.9610e-1 (3.18e-2) +	7.5263e-1 (5.90e-2)
UC1-C3-DTLZ3	10	NaN (NaN) =	NaN (NaN)	2.8079e-1 (3.28e-4) +	NaN (NaN)	3.5306e-1 (3.57e-2) +	NaN (NaN)
UC2-C1-DTLZ1	10	5.9918e+1 (1.25e+1) =	5.8029e+1 (5.91e+0)	1.2542e-1 (2.93e-2) +	2.1836e+1 (1.19e+0)	6.9786e-2 (3.70e-3) +	2.4872e+1 (5.84e+0)
UC2-C2-DTLZ1	10	5.9939e+1 (4.20e-2) -	5.6645e+1 (6.79e+0)	1.4903e-1 (1.94e-2) +	2.1296e+1 (6.41e-1)	6.9157e-2 (2.70e-3) +	2.3979e+1 (5.60e+0)
UC2-C2-DTLZ3	10	1.4390e+2 (2.85e+1) +	1.4560e+2 (2.38e+1)	2.7627e-1 (2.72e-3) +	8.9229e+1 (1.09e-2)	2.8491e-1 (6.10e-2) +	8.9185e+1 (1.25e-2)
UC2-C3-DTLZ1	10	5.9914e+1 (1.94e+1) =	5.8024e+1 (5.91e+0)	1.8429e-1 (4.10e-2) +	2.1572e+1 (9.58e-1)	7.1139e-2 (1.52e-3) +	2.4299e+1 (6.23e+0)
UC2-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	2.8174e-1 (1.39e-4) +	NaN (NaN)	3.3970e-1 (7.58e-2) +	7.2285e-1 (7.60e-2)
UC2-C3-DTLZ3	10	1.0567e+2 (5.32e+1) +	1.2374e+2 (2.32e+1)	2.8095e-1 (5.06e-4) +	8.9227e+1 (1.26e-2)	3.5419e-1 (5.14e-2) +	8.9189e+1 (2.70e-2)
UC3-C1-DTLZ1	10	6.9976e+1 (8.57e+0) =	6.9991e+1 (1.16e+1)	9.9071e-2 (1.69e-2) +	2.8615e+1 (1.42e+0)	6.9209e-2 (2.34e-3) +	3.4677e+1 (1.50e+1)
UC3-C2-DTLZ1	10	1.9858e+1 (1.08e+1) +	3.7735e+1 (3.80e+0)	1.1148e-1 (1.49e-2) +	2.9596e+1 (7.73e+0)	7.0721e-2 (3.86e-3) +	3.0257e+1 (9.52e+0)
UC3-C2-DTLZ3	10	8.9222e+1 (1.57e-2) -	8.0815e+1 (1.78e+1)	2.7702e-1 (3.52e-3) +	4.4176e+1 (2.06e-2)	2.5512e-1 (5.20e-2) +	4.4189e+1 (5.52e-2)
UC3-C3-DTLZ1	10	1.2197e+1 (9.59e+0) +	3.8213e+1 (1.85e+0)	1.2942e-1 (1.76e-2) +	2.9798e+1 (5.34e+0)	7.2599e-2 (1.98e-3) +	2.7193e+1 (8.50e+0)
UC3-C3-DTLZ2	10	8.7139e-1 (6.07e-2) +	8.8204e-1 (2.30e-2)	2.8030e-1 (8.63e-4) +	3.5023e-1 (1.03e-1)	2.9607e-1 (6.22e-2) +	4.2920e-1 (1.10e-1)
UC3-C3-DTLZ3	10	8.9263e+1 (4.40e+1) -	7.4528e+1 (2.14e+1)	2.8081e-1 (4.20e-4) +	4.4188e+1 (1.93e-2)	3.5594e-1 (3.23e-2) +	4.8461e+1 (1.35e+1)
UC4-C1-DTLZ1	10	9.0492e+0 (5.92e+1) +	6.8161e+1 (9.78e+0)	2.6786e+0 (2.26e+0) +	2.5724e+1 (1.36e+0)	1.4126e+0 (7.81e-2) +	3.0462e+1 (1.80e+1)
UC4-C2-DTLZ1	10	7.1723e+0 (6.15e+0) +	3.6511e+1 (1.54e+0)	1.6997e+0 (1.81e-1) +	2.2124e+1 (1.14e+1)	1.3991e+0 (7.85e-2) +	2.6824e+1 (1.09e+1)
UC4-C2-DTLZ3	10	8.1414e+1 (4.25e-2) -	7.5725e+1 (1.43e+1)	2.2688e+0 (9.37e-2) +	3.6358e+1 (5.01e-2)	3.0185e+0 (2.79e-1) +	3.6946e+1 (5.44e-1)
UC4-C3-DTLZ1	10	7.8819e+0 (3.45e+0) +	3.4062e+1 (2.67e+0)	1.8853e+0 (1.69e-1) +	2.4594e+1 (1.03e+1)	1.4593e+0 (5.80e-2) +	2.5750e+1 (1.20e+1)
UC4-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	2.8259e-1 (7.67e-3) +	NaN (NaN)	3.8739e-1 (2.36e-2) +	6.5208e+0 (2.51e+0)
UC4-C3-DTLZ3	10	8.1397e+1 (3.87e+1) -	5.9064e+1 (1.98e+1)	2.8188e+0 (1.65e-3) +	3.6324e+1 (5.41e-2)	3.7466e+0 (3.28e-1) +	3.6569e+1 (3.95e-1)
UC5-C1-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.5341e-1 (4.61e-2) +	NaN (NaN)	7.1313e-2 (3.26e-3) +	1.3576e-1 (6.58e-2)
UC5-C2-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.2855e-1 (3.38e-2) +	NaN (NaN)	7.1644e-2 (3.80e-3) +	1.1307e-1 (1.57e-2)
UC5-C2-DTLZ3	10	NaN (NaN) =	NaN (NaN)	2.8178e-1 (2.36e-3) +	NaN (NaN)	2.8154e-1 (3.43e-2) +	NaN (NaN)
UC5-C3-DTLZ1	10	NaN (NaN) =	NaN (NaN)	1.3491e-1 (3.48e-2) +	NaN (NaN)	7.3151e-2 (2.34e-3) +	1.4752e-1 (9.23e-2)
UC5-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	2.8249e-1 (2.99e-3) +	NaN (NaN)	3.8927e-1 (2.64e-2) +	6.8949e-1 (7.91e-2)
UC5-C3-DTLZ3	10	NaN (NaN) =	NaN (NaN)	2.8237e-1 (6.32e-4) +	NaN (NaN)	3.8550e-1 (3.29e-2) +	5.8022e-1 (8.27e-2)
+/-/=		9/5/17		1/25/4		30/0/0	

TABLE XXVIII
THE COMPARISON RESULTS OF HV METRIC OF ABLATION STUDY ON TEN OBJECTIVE SYNTHETIC TEST PROBLEMS

Problem	m	EADMM/NSGA-II	EADMM/NSGA-II†	EADMM/IBEA	EADMM/IBEA†	EADMM/MOEA/D	EADMM/MOEA/D†
UC1-C1-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.3066e-1 (1.71e-2) +	NaN (NaN)	9.8934e-1 (1.05e-2) +	2.2082e-1 (4.05e-1)
UC1-C2-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.8130e-1 (7.61e-3) +	NaN (NaN)	9.9140e-1 (1.05e-2) +	3.7382e-1 (4.89e-1)
UC1-C2-DTLZ3	10	NaN (NaN) =	NaN (NaN)	8.6066e-1 (3.30e-2) +	NaN (NaN)	6.4024e-1 (1.14e-2) +	NaN (NaN)
UC1-C3-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.8503e-1 (5.33e-3) +	NaN (NaN)	9.8963e-1 (8.22e-3) +	3.6736e-1 (4.80e-1)
UC1-C3-DTLZ2	10	4.5395e-3 (2.08e-2) +	NaN (NaN)	5.8788e-1 (3.32e-2) +	3.3722e-2 (1.11e-1)	6.2141e-1 (1.91e-3) +	1.2387e-1 (4.15e-2)
UC1-C3-DTLZ3	10	NaN (NaN) =	NaN (NaN)	5.3103e-1 (4.40e-2) +	NaN (NaN)	6.2062e-1 (1.49e-3) +	NaN (NaN)
UC2-C1-DTLZ1	10	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	8.8564e-1 (3.98e-2) +	0.0000e+0 (0.00e+0)	9.8826e-1 (3.78e-3) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ1	10	0.0000e+0 (0.00e+1) =	0.0000e+0 (0.00e+0)	9.7611e-1 (1.08e-2) +	0.0000e+0 (0.00e+0)	9.7977e-1 (1.57e-2) +	0.0000e+0 (0.00e+0)
UC2-C2-DTLZ3	10	0.0000e+0 (0.00e+2) =	0.0000e+0 (0.00e+0)	8.1154e-1 (5.11e-2) +	0.0000e+0 (0.00e+0)	6.4399e-1 (1.01e-2) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ1	10	0.0000e+0 (0.00e+3) =	0.0000e+0 (0.00e+0)	9.7795e-1 (6.71e-3) +	0.0000e+0 (0.00e+0)	9.5519e-1 (3.16e-2) +	0.0000e+0 (0.00e+0)
UC2-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	5.5499e-1 (5.30e-2) +	NaN (NaN)	6.1536e-1 (6.45e-4) +	1.4288e-1 (5.42e-2)
UC2-C3-DTLZ3	10	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	5.1411e-1 (4.88e-2) +	0.0000e+0 (0.00e+0)	6.1958e-1 (1.92e-3) +	0.0000e+0 (0.00e+0)
UC3-C1-DTLZ1	10	0.0000e+0 (0.00e+1) =	0.0000e+0 (0.00e+0)	9.1407e-1 (2.94e-2) +	0.0000e+0 (0.00e+0)	9.9098e-1 (7.57e-3) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ1	10	2.1840e-3 (1.00e-2) +	0.0000e+0 (0.00e+0)	9.7487e-1 (1.17e-2) +	0.0000e+0 (0.00e+0)	9.9453e-1 (4.78e-3) +	0.0000e+0 (0.00e+0)
UC3-C2-DTLZ3	10	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	8.6714e-1 (3.60e-2) +	0.0000e+0 (0.00e+0)	6.3797e-1 (1.08e-2) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ1	10	0.0000e+0 (0.00e+1) =	0.0000e+0 (0.00e+0)	9.7833e-1 (6.64e-3) +	0.0000e+0 (0.00e+0)	9.8631e-1 (1.71e-2) +	0.0000e+0 (0.00e+0)
UC3-C3-DTLZ2	10	1.9754e-2 (6.33e-3) +	1.6953e-2 (3.07e-3)	5.7613e-1 (5.01e-2) -	6.7836e-1 (1.22e-1)	6.5912e-1 (1.64e-2) +	5.3664e-1 (6.45e-2)
UC3-C3-DTLZ3	10	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	5.0051e-1 (4.53e-2) +	0.0000e+0 (0.00e+0)	6.1978e-1 (1.55e-3) +	0.0000e+0 (0.00e+0)
UC4-C1-DTLZ1	10	5.0858e-2 (4.52e-2) +	0.0000e+0 (0.00e+0)	8.8724e-1 (3.23e-2) +	7.2303e-10 (3.31e-9)	6.7773e-1 (2.71e-1) +	3.4983e-7 (6.24e-7)
UC4-C2-DTLZ1	10	4.1085e-1 (3.53e-1) +	0.0000e+0 (0.00e+0)	9.4137e-1 (2.82e-2) +	2.2863e-1 (3.71e-1)	9.9541e-1 (1.98e-3) +	1.1089e-1 (2.85e-1)
UC4-C2-DTLZ3	10	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	7.4988e-1 (4.07e-2) +	0.0000e+0 (0.00e+0)	9.1454e-1 (7.57e-3) +	0.0000e+0 (0.00e+0)
UC4-C3-DTLZ1	10	3.4767e-1 (3.16e-1) +	0.0000e+0 (0.00e+0)	9.6026e-1 (1.21e-2) +	1.4981e-1 (3.17e-1)	9.9461e-1 (4.28e-3) +	1.3800e-1 (2.92e-1)
UC4-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	4.6520e-1 (4.18e-2) +	NaN (NaN)	5.9602e-1 (3.60e-2) +	2.4002e-2 (1.10e-1)
UC4-C3-DTLZ3	10	0.0000e+0 (0.00e+0) =	0.0000e+0 (0.00e+0)	4.8238e-1 (3.65e-2) +	0.0000e+0 (0.00e+0)	6.1465e-1 (8.95e-4) +	0.0000e+0 (0.00e+0)
UC5-C1-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.0759e-1 (1.87e-2) +	NaN (NaN)	8.9267e-1 (1.87e-1) +	4.2113e-1 (4.37e-1)
UC5-C2-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.4962e-1 (1.50e-2) +	NaN (NaN)	9.8007e-1 (2.47e-2) +	5.9826e-1 (4.84e-1)
UC5-C2-DTLZ3	10	NaN (NaN) =	NaN (NaN)	7.8059e-1 (3.78e-2) +	NaN (NaN)	6.1751e-1 (1.23e-2) +	NaN (NaN)
UC5-C3-DTLZ1	10	NaN (NaN) =	NaN (NaN)	9.5950e-1 (1.02e-2) +	NaN (NaN)	9.6125e-1 (3.74e-2) +	6.3120e-1 (4.64e-1)
UC5-C3-DTLZ2	10	NaN (NaN) =	NaN (NaN)	4.4975e-1 (2.85e-2) +	NaN (NaN)	6.0073e-1 (2.61e-2) +	1.7128e-1 (6.20e-2)
UC5-C3-DTLZ3	10	NaN (NaN) =	NaN (NaN)	4.8043e-1 (3.75e-2) +	NaN (NaN)	6.1282e-1 (2.62e-3) +	8.7449e-2 (1.35e-1)
+/-/=		6/0/24		29/1/0		30/0/0	

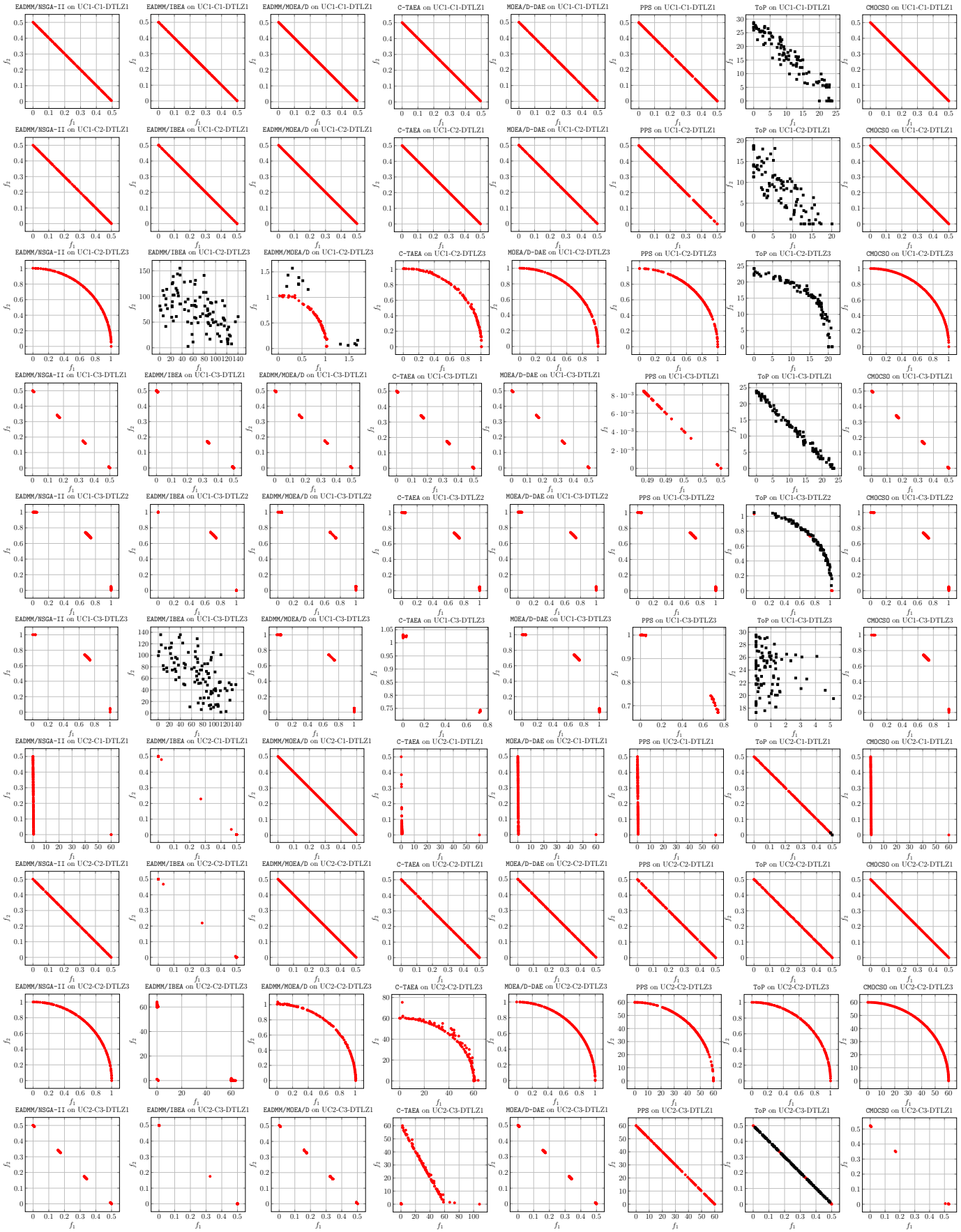

Fig. 6. Scatter plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten bi-objective synthetic test problems (UC1-C1-DTLZ1 to UC2-C3-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red circles and black squares, respectively.

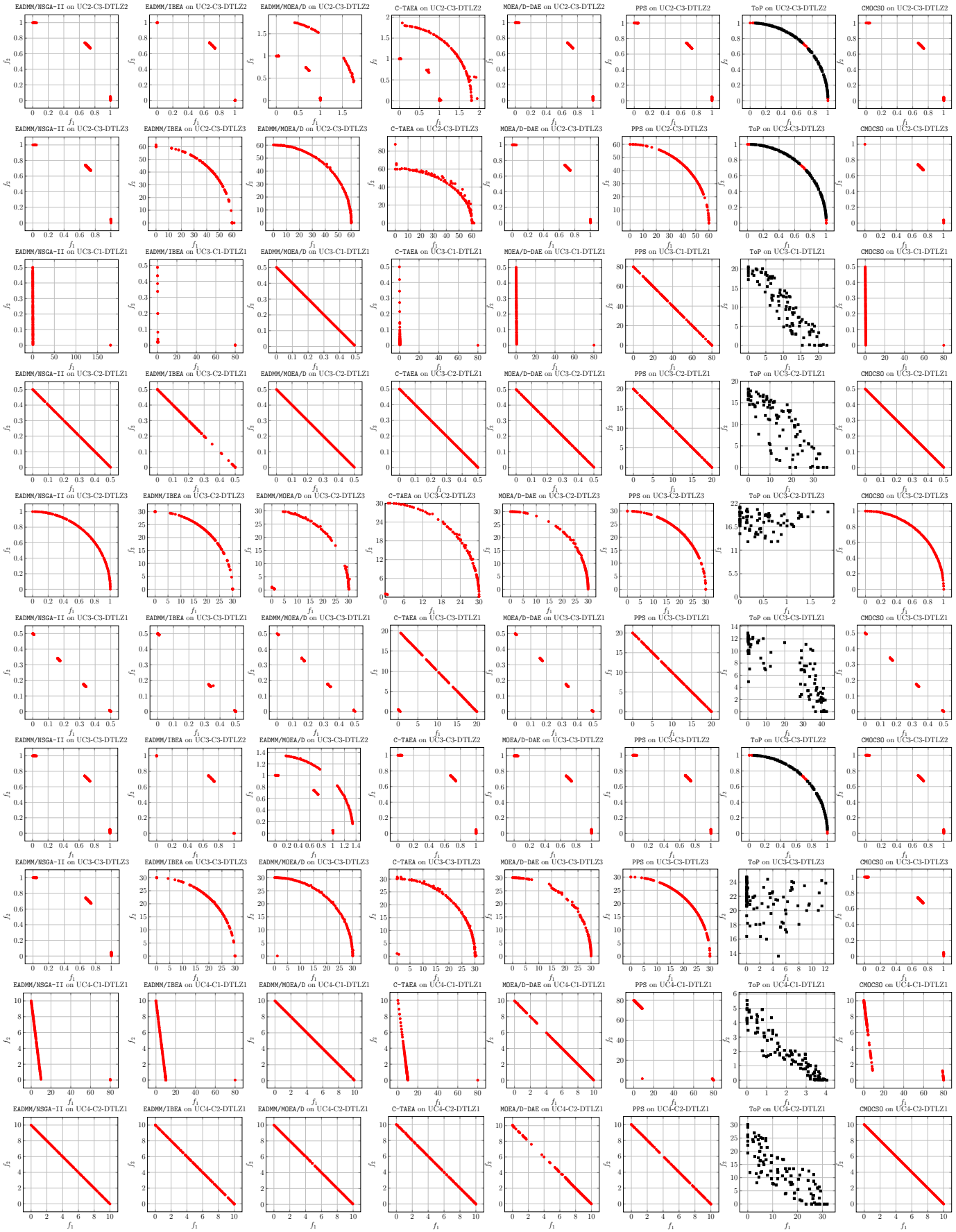

Fig. 7. Scatter plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten bi-objective synthetic test problems (UC2-C3-DTLZ2 to UC4-C2-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red circles and black squares, respectively.

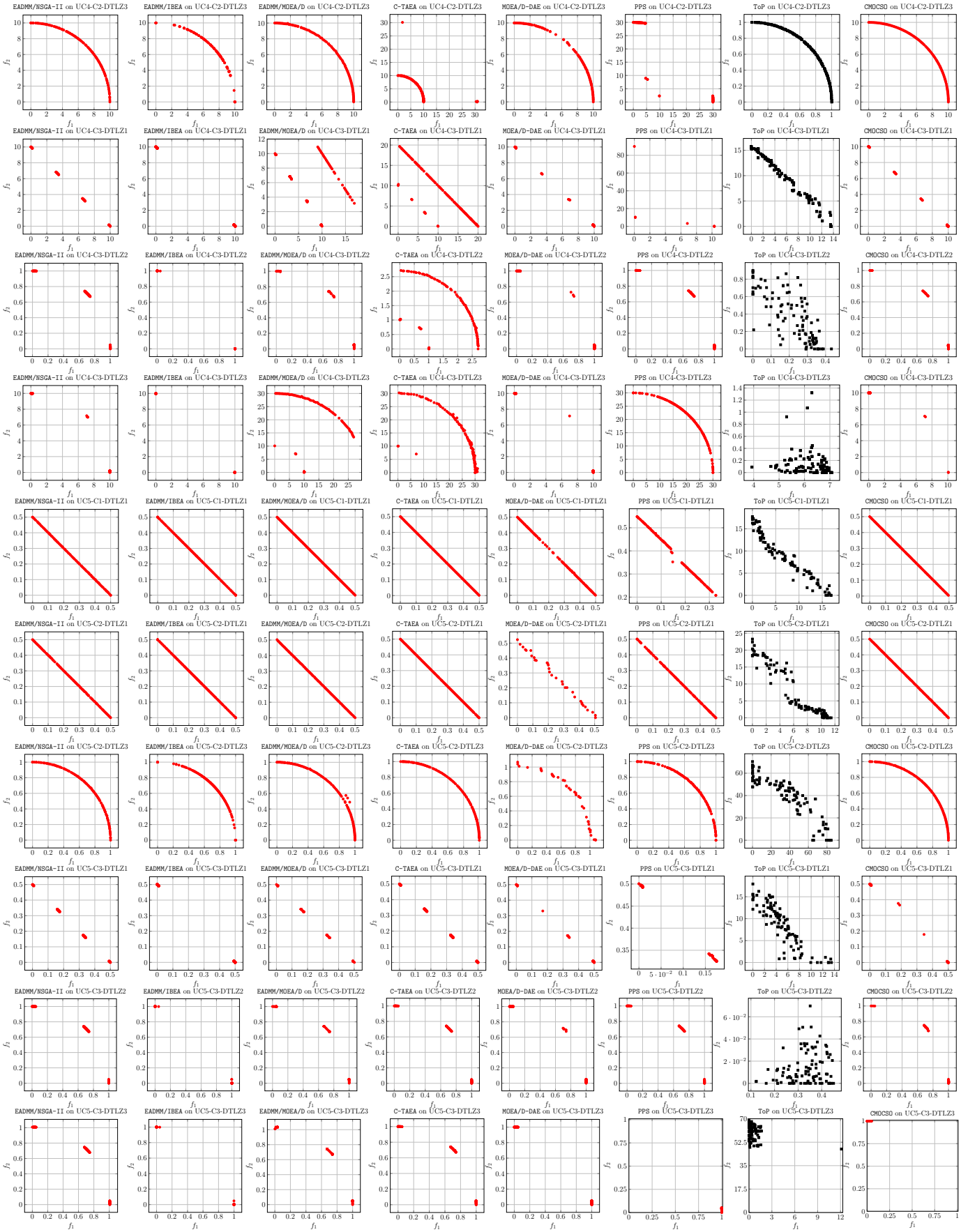

Fig. 8. Scatter plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten bi-objective synthetic test problems (UC4-C2-DTLZ3 to UC5-C3-DTLZ3) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red circles and black squares, respectively.

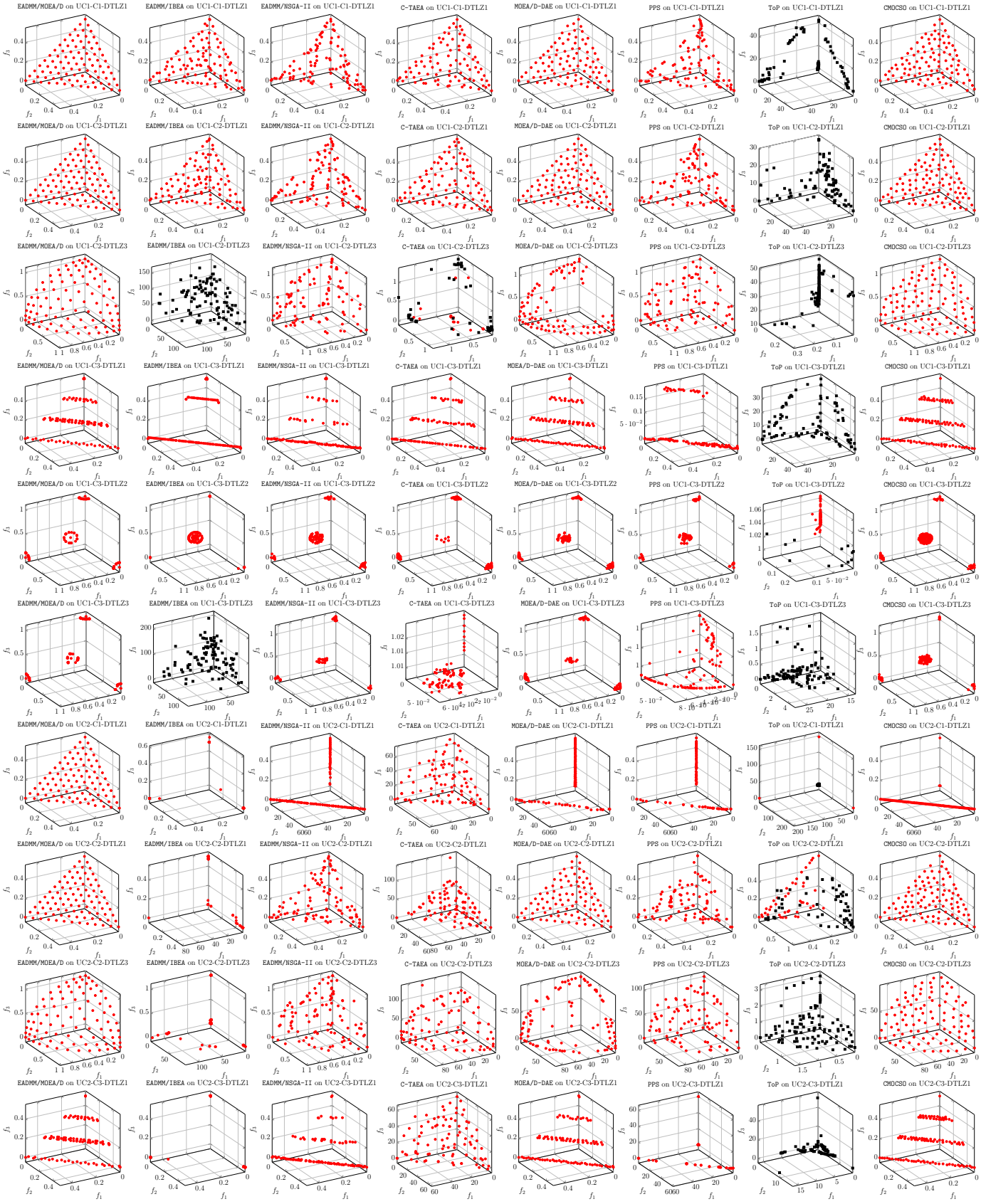

Fig. 9. Scatter plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten three-objective synthetic test problems (UC1-C1-DTLZ1 to UC2-C3-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red circles and black squares, respectively.

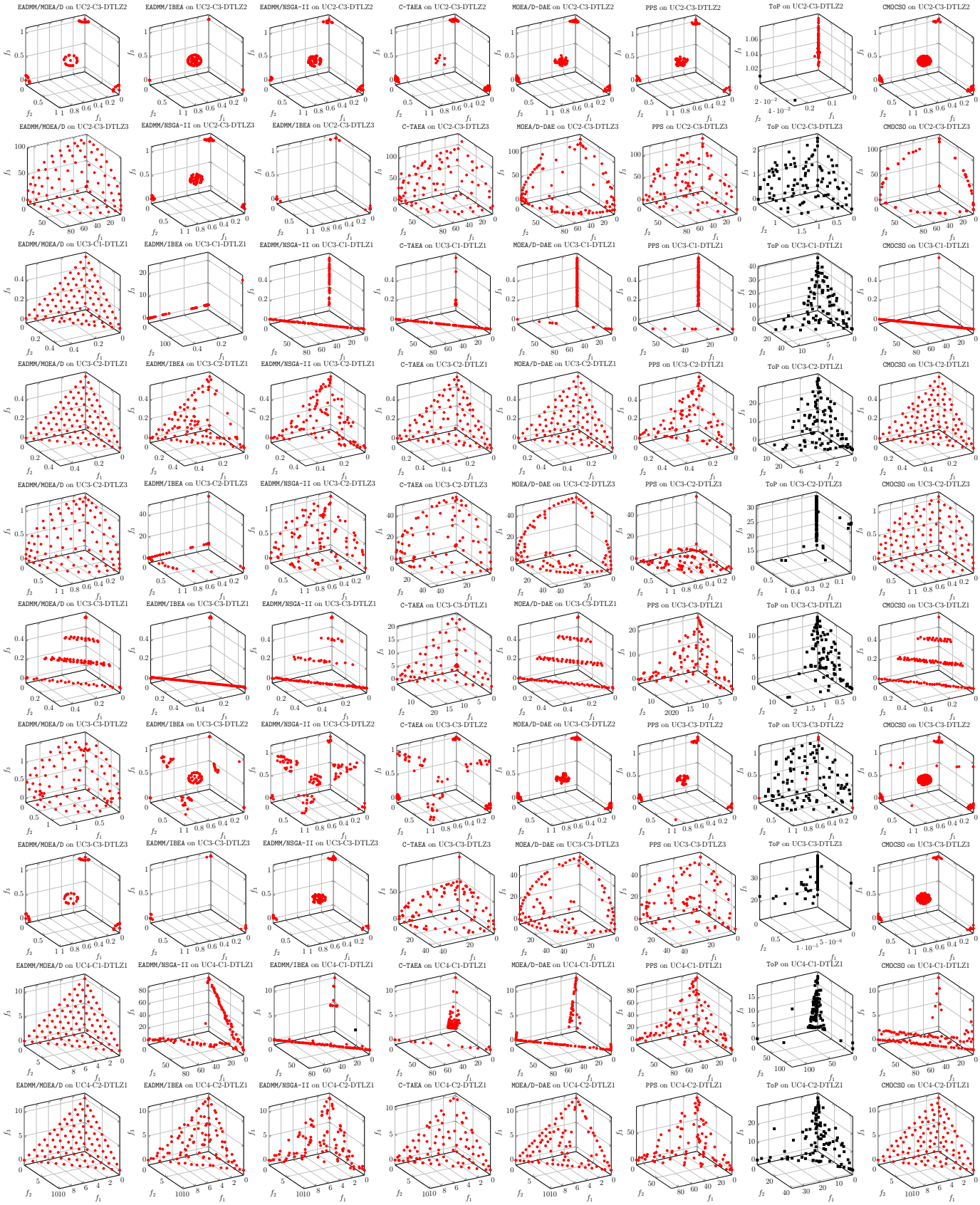

Fig. 10. Scatter plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten three-objective synthetic test problems (UC2-C3-DTLZ2 to UC4-C2-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red circles and black squares, respectively.

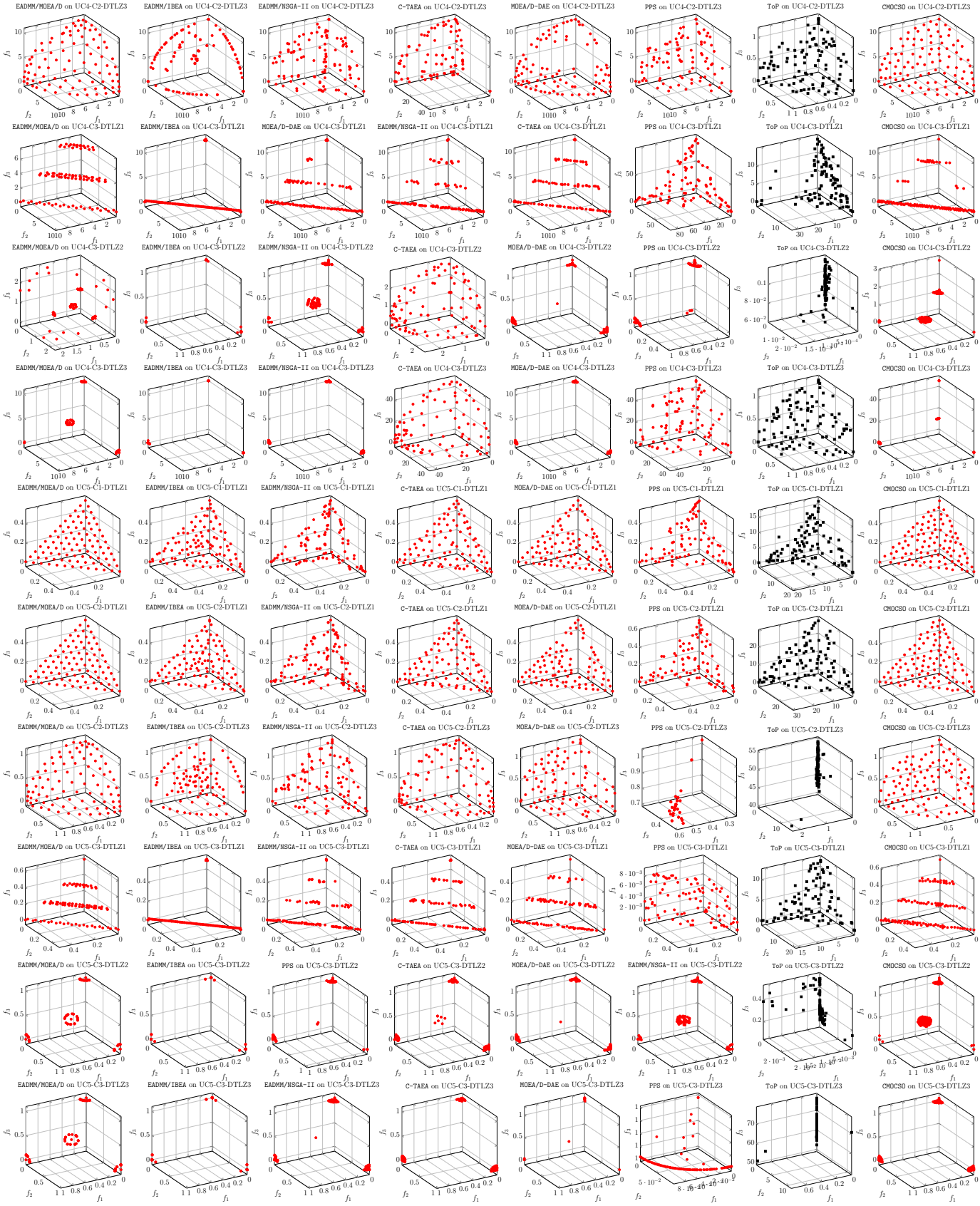

Fig. 11. Scatter plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten three-objective synthetic test problems (UC4-C2-DTLZ3 to UC5-C3-DTLZ3) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red circles and black squares, respectively.

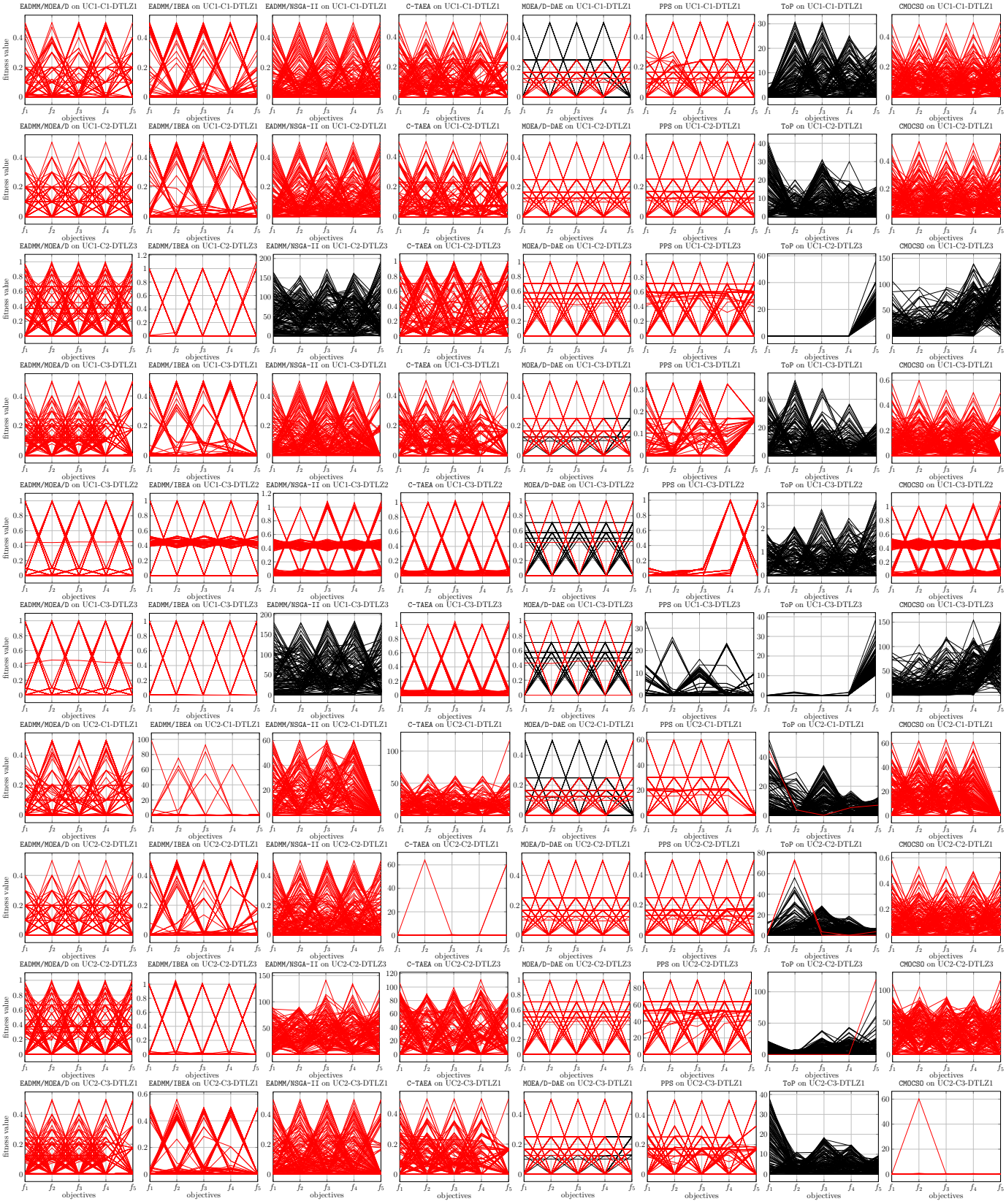

Fig. 12. Plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten five-objective synthetic test problems (UC1-C1-DTLZ1 to UC2-C3-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red lines and black lines, respectively.

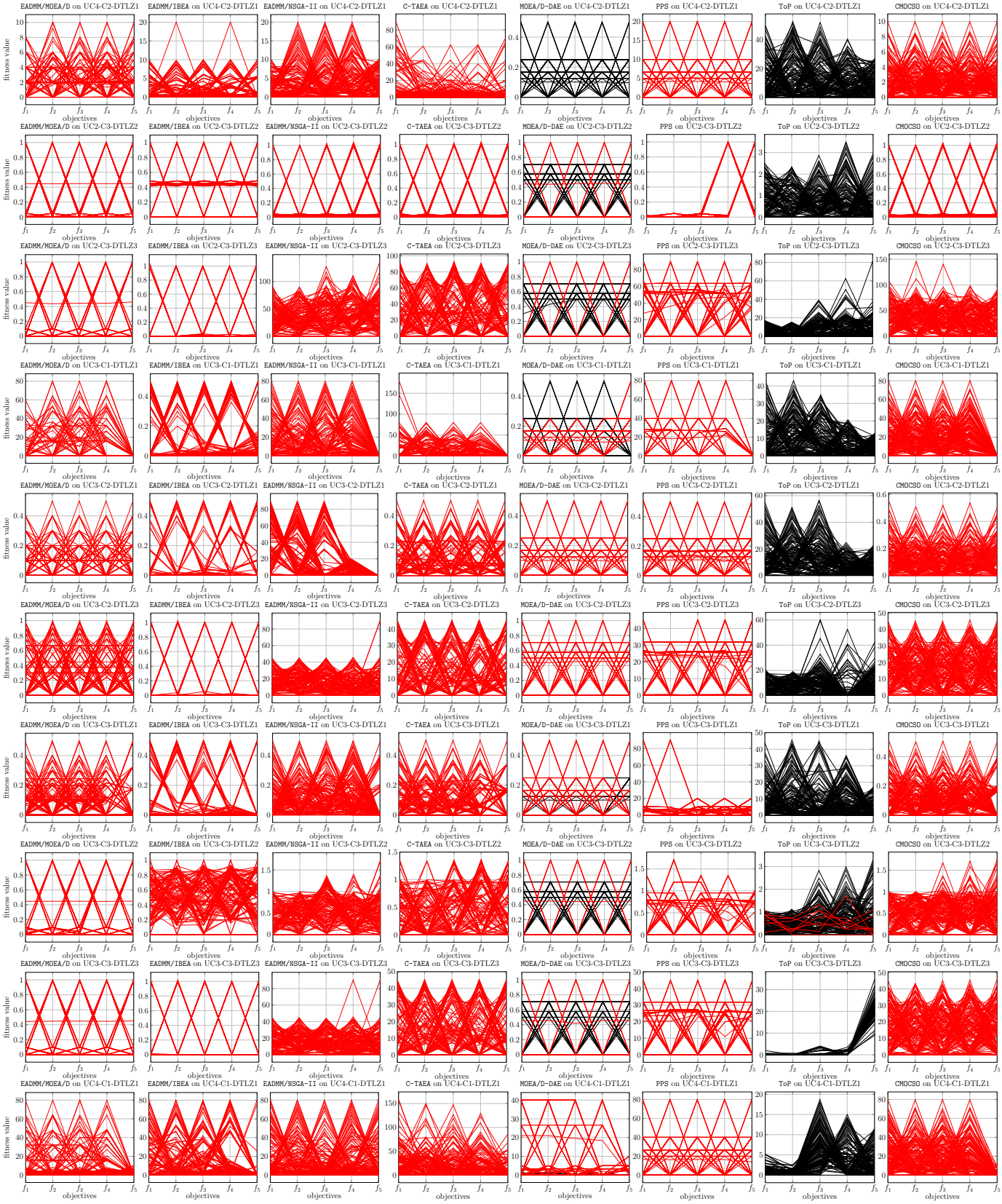

Fig. 13. Plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten five-objective synthetic test problems (UC2-C3-DTLZ2 to UC4-C2-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red lines and black lines, respectively.

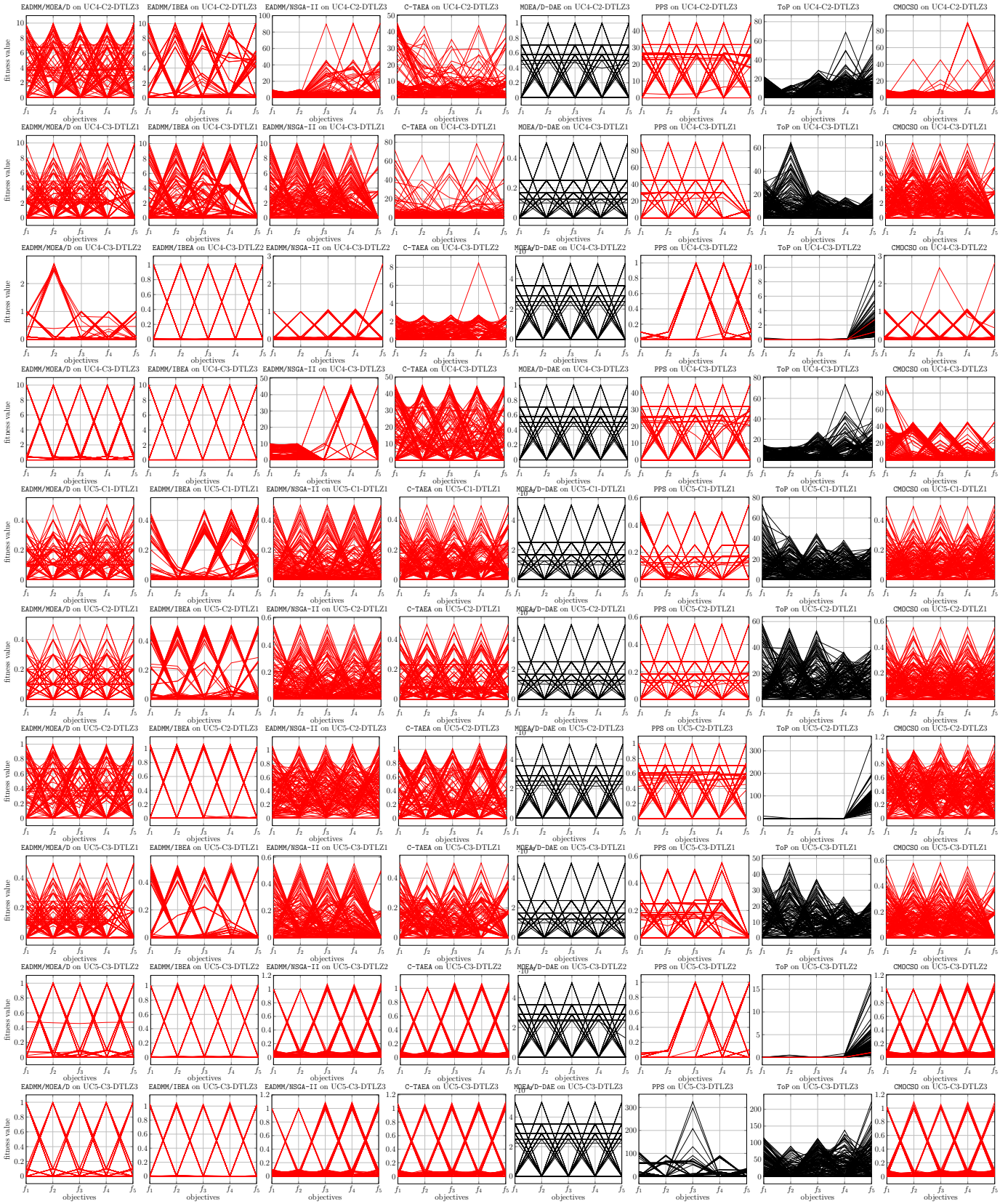

Fig. 14. Plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten five-objective synthetic test problems (UC4-C2-DTLZ3 to UC5-C3-DTLZ3) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red lines and black lines, respectively.

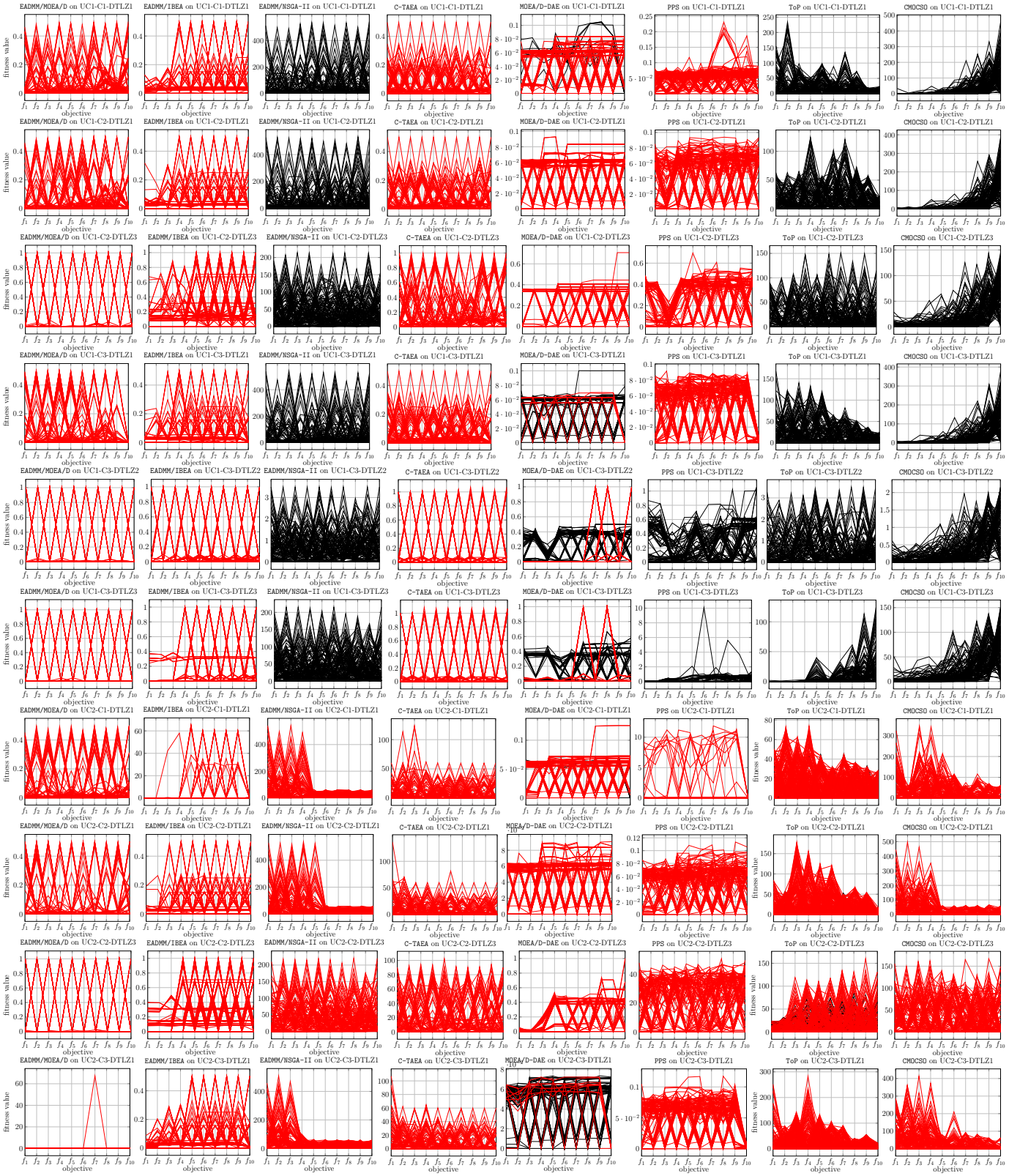

Fig. 15. Plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten ten-objective synthetic test problems (UC1-C1-DTLZ1 to UC2-C3-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red lines and black lines, respectively.

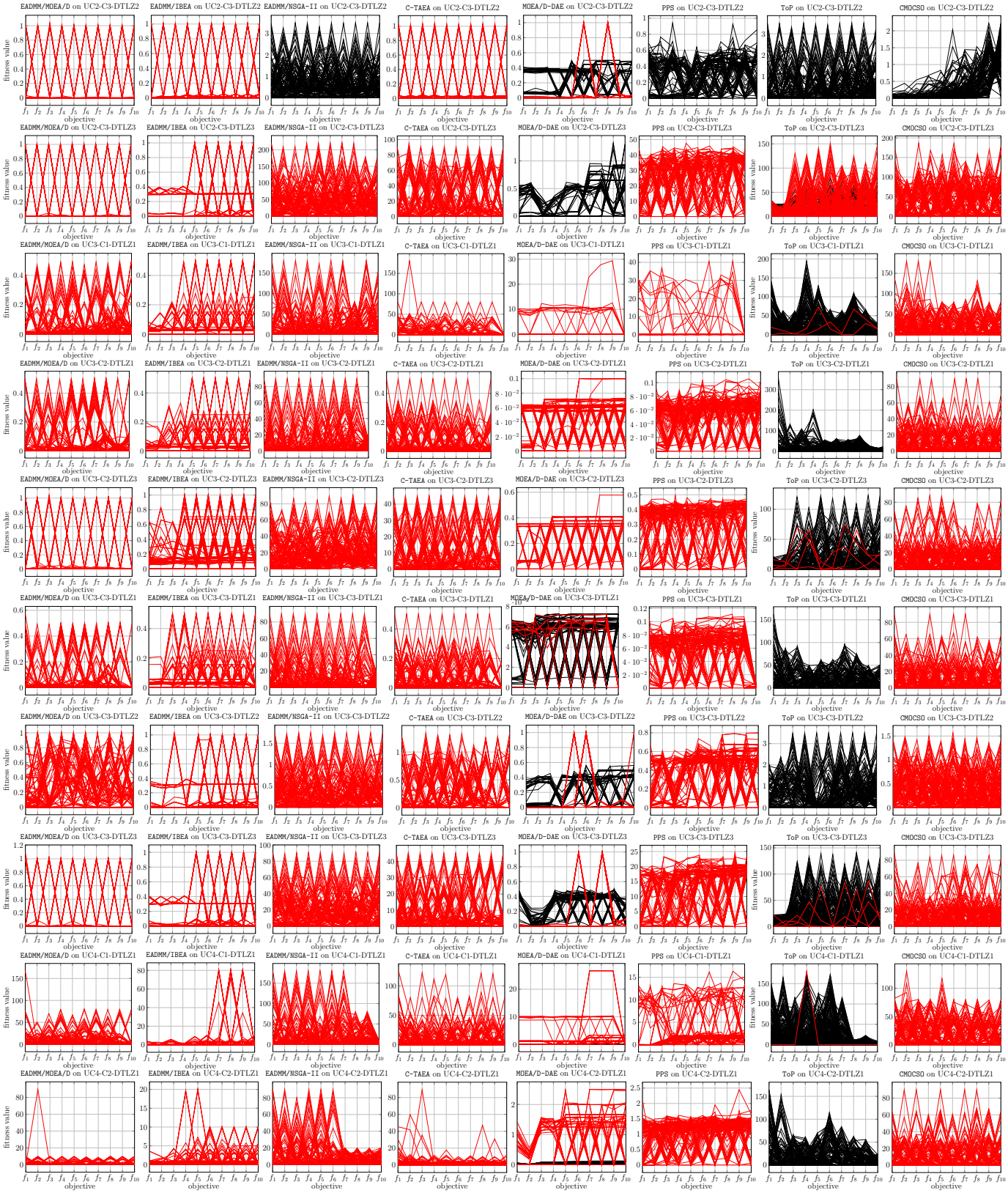

Fig. 16. Plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten ten-objective synthetic test problems (UC2-C3-DTLZ2 to UC4-C2-DTLZ1) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red lines and black lines, respectively.

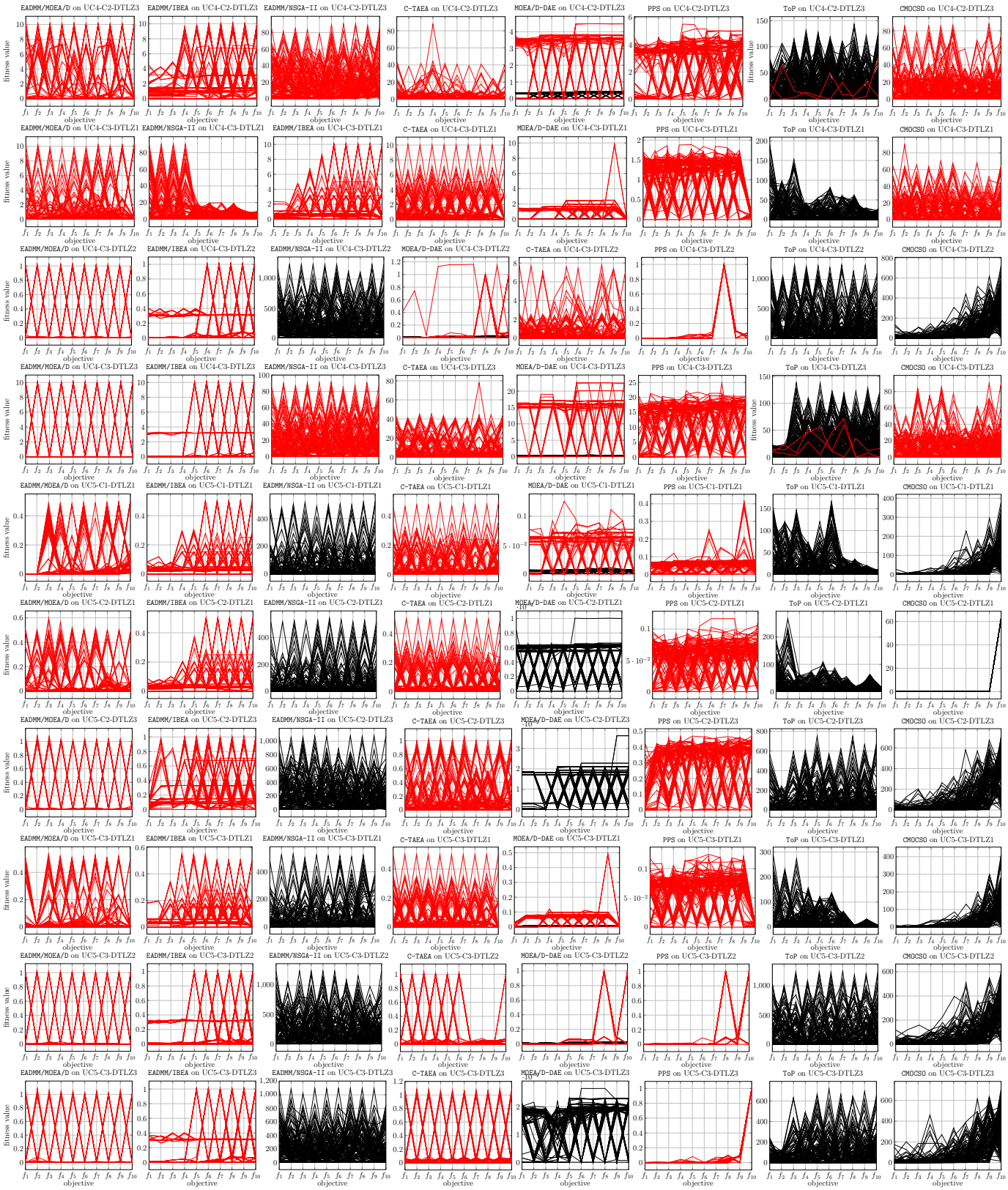

Fig. 17. Plots of the final solutions obtained by each of the three algorithm instances of our proposed framework and five peer algorithms on ten ten-objective synthetic test problems (UC4-C2-DTLZ3 to UC5-C3-DTLZ3) with the median IGD values. In particular, feasible solutions and infeasible solutions are denoted as red lines and black lines, respectively.