Supplementary Files

S-I. Problem Description

A. Notations

Before building the mathematical model, the notations utilized are illustrated as follows.

1) *Indices:*
i: index of jobs, $i = 1, 2, ..., n$;
j: index of operations, $j = 1, 2, ..., n_i$;
k: index of processing machines, $k = 1, 2, ..., m$;
l: index of positions on the machine, $l = 1, 2, ..., h_k$;
q: index of machine speed levels, $q = 1, 2, ..., s$;
2) *Parameters:*
J_i: the ith job;
$O_{i,j}$: the jth operation for J_i;
M_k: the kth processing machine;
$D_{k,l}$: the lth position on M_k;
V_q: the qth speed level;
n: number of jobs;
n_i: number of operations for J_i;
m: number of processing machines;
h_k: number of positions for M_k;
SP_k: actual setup power of M_k;
BPP_k: basic processing power of M_k;
$PP_{k,q}$: actual processing power of M_k at V_q;
BIP_k: basic idle power of M_k;
$IP_{k,q}$: actual idle power of M_k at V_q;
ST: setup time of the machines;
$P_{i,j,k}$: basic processing time of $O_{i,j}$ on M_k;
$T_{i,j,k,q}$: actual processing time of $O_{i,j}$ on M_k at V_q;
L: a sufficiently large positive number;
3) *Ordinary variables:*
C_{max}: makespan value;
TEC: total energy consumption value;
SE: setup energy consumption value;
PE: processing energy consumption value;
IE: idle energy consumption value;
$S_{i,j}$: start time of $O_{i,j}$;
$C_{i,j}$: completion time of $O_{i,j}$;
$B_{k,l,q}$: start time of $D_{k,l}$ at V_q;
$F_{k,l,q}$: completion time of $D_{k,l}$ at V_q;
4) *Decision variables:*
$\mathbf{X}_{i,j,k,l,q}$: equal to 1 if $O_{i,j}$ is processed on $D_{k,l}$ at V_q, otherwise equal to 0;
$\mathbf{Y}_{k,l,q}$: equal to 1 if $D_{k,l}$ is processing at V_q, otherwise equal to 0;

B. Model Building

Based on the above, the mathematical model of MMFJSP-S is constructed as follows.

$$\begin{cases} \min \;\; F_1 = C_{max} \\ \min \;\; F_2 = TEC \end{cases} \tag{1}$$

Subject to:

$$\min \;\; F_1 = C_{max} = \max \;\; C_{i,j}, \forall i = 1, ..., n; j = 1, ..., n_i \tag{2}$$

$$\min \;\; F_2 = TEC = SE + PE + IE \tag{3}$$

$$SE = \sum_{k=1}^{m} SP_k \cdot ST \tag{4}$$

$$PE = \sum_{i=1}^{n} \sum_{j=1}^{n_i} \sum_{k=1}^{m} \sum_{l=1}^{m_j} \sum_{q=1}^{s} PP_{k,q} \cdot T_{i,j,k,q} \cdot \mathbf{X}_{i,j,k,l,q} \tag{5}$$

$$IE = \sum_{k=1}^{m} \sum_{l=1}^{h_k-1} \sum_{q=1}^{s} IP_{k,q} \cdot (B_{k,l+1,q} - F_{k,l,q}) \tag{6}$$

$$\begin{aligned} &T_{i,j,k,q} = P_{i,j,k}/V_q, \\ &\forall i = 1, ..., n;\ \forall j = 1, ..., n_i;\ \forall k = 1, ..., m;\ \forall q = 1, ..., s \end{aligned} \tag{7}$$

$$\begin{aligned} &PP_{k,q} = BPP_k \cdot (V_q + \log(V_q)), \\ &\forall k = 1, ..., m;\ \forall q = 1, ..., s \end{aligned} \tag{8}$$

$$\begin{aligned} &IP_{k,q} = BIP_k \cdot (V_q + \log(V_q)), \\ &\forall k = 1, ..., m;\ \forall q = 1, ..., s \end{aligned} \tag{9}$$

$$\begin{aligned} &\sum_{i=1}^{n} \sum_{j=1}^{n_i} X_{i,j,k,l,q} \geq \sum_{i=1}^{n} \sum_{j=1}^{n_i} X_{i,j,k,l+1,q}, \\ &\forall k = 1, ..., m;\ \forall l = 1, ..., h_k - 1;\ \forall q = 1, ..., s \end{aligned} \tag{10}$$

$$\begin{aligned} &\sum_{k=1}^{m} \sum_{l=1}^{h_k} \sum_{q=1}^{s} X_{i,j,k,l,q} = 1, \\ &\forall i = 1, ..., n;\ \forall j = 1, ..., n_i \end{aligned} \tag{11}$$

$$\begin{aligned} &\sum_{i=1}^{n} \sum_{j=1}^{n_i} X_{i,j,k,l,q} \leq 1, \\ &\forall k = 1, ..., m;\ \forall l = 1, ..., h_k;\ \forall q = 1, ..., s \end{aligned} \tag{12}$$

$$\begin{aligned} &C_{i,j} = S_{i,j} + \sum_{k=1}^{m} \sum_{l=1}^{h_k} \sum_{q=1}^{s} T_{i,j,k,q} \cdot X_{i,j,k,l,q}, \\ &\forall i = 1, ..., n;\ \forall j = 1, ..., n_i \end{aligned} \tag{13}$$

$$\begin{aligned} &S_{i,j} + \sum_{k=1}^{m} \sum_{l=1}^{h_k} \sum_{q=1}^{s} T_{i,j,k,l,q} \cdot X_{i,j,k,q} \leq S_{i,j+1}, \\ &\forall i = 1, ..., n;\ \forall j = 1, ..., n_i - 1 \end{aligned} \tag{14}$$

$$\begin{aligned} &F_{k,l,q} = B_{k,l,q} + \sum_{i=1}^{n} \sum_{j=1}^{n_i} T_{i,j,k,q} \cdot X_{i,j,k,l,q}, \\ &\forall k = 1, ..., m;\ \forall l = 1, ..., h;\ \forall q = 1, ..., s \end{aligned} \tag{15}$$

$$\begin{aligned} &B_{k,l,q} + \sum_{i=1}^{n} \sum_{j=1}^{n_i} T_{i,j,k,q} \cdot X_{i,j,k,l,q} \leq B_{k,l+1,q}, \\ &\forall k = 1, ..., m;\ \forall l = 1, ..., h_k - 1;\ \forall q = 1, ..., s \end{aligned} \tag{16}$$

$$\begin{aligned} &B_{k,l,q} \geq S_{i,j} - L \cdot (1 - X_{i,j,k,l,q}), \\ &\forall i = 1, ..., n;\ \forall j = 1, ..., n_i;\ \forall k = 1, ..., m;\ l = 1, ..., h_k;\ \forall q = 1, ..., s \end{aligned} \tag{17}$$

$$B_{k,l,q} \leq S_{i,j} + L \cdot (1 - X_{i,j,k,l,q}), \\ \forall i = 1, ..., n;\ \forall j = 1, ..., n_i;\ \forall k = 1, ..., m;\ l = 1, ..., h_k;\ \forall q = 1, ..., s \tag{18}$$

$$\sum_{l=1}^{h_k} \sum_{q=1}^{s} Y_{k,l,q} \leq \max\ h_k \\ \forall k = 1, ..., m; \tag{19}$$

$$S_{i,j} \geq 0;\ C_{i,j} \geq 0, \\ \forall i = 1, ..., n;\ \forall j = 1, ..., n_i \tag{20}$$

$$B_{k,l,q} \geq 0;\ F_{k,l,q} \geq 0, \\ \forall k = 1, ..., m;\ l = 1, ..., h_k;\ \forall q = 1, ..., s \tag{21}$$

$$X_{i,j,k,l,q}, Y_{k,l,q} \in \{0, 1\}, \\ \forall i = 1, ..., n;\ \forall j = 1, ..., n_i;\ \forall k = 1, ..., m;\ l = 1, ..., h_k;\ \forall q = 1, ..., s \tag{22}$$

Here, Formula (1) represents the optimization objective. Formula (2) calculates the maximum completion time. Formula (3) - (6) calculate the total energy consumption, including setup energy consumption, processing energy consumption and idle energy consumption. Formula (7) calculates the actual processing time of the operations, and Formula (8) and Formula (9) calculate the actual processing power and idle power. Formula (10) ensures that the positions of the machines for processing are allocated sequentially. Formula (11) guarantees that operations corresponds to only one processing position on the machine. Formula (12) indicates that each processing position of the machines can only process a maximum of one operation at a time. Formula (13) defines the relationship between the start time and completion time of operations. Formula (14) demonstrates the processing constraints of adjacent operations for the same job. Formula (15) defines the relationship between the start time and completion time of machines. Formula (16) denotes that a machine can only process one operation at any given time, since each operation needs to occupy a position on the machine in order to be processed. Formula (17) and Formula (18) show the relationship between the start time of machines and the start time of operations. Formula (19) defines constraints on the position of the machine. Formula (20) - Formula (22) define the range of values of ordinary variables and decision variables.

S-II. Our Approach: APHMA

A. Genetic Operators

The IPOX is illustrated in Fig S-1(a), and it is executed as follows:

1) Randomly divide the elements into two subsets S_1 and S_2.

2) Copy the elements of S_1 belonging to parent P_1 into offspring O_1 and the elements of S_2 belonging to parent P_2 into offspring O_2.

3) Move the elements of S_1 belonging to parent P_1 into offspring O_2 and the elements of S_2 belonging to parent P_2 into offspring O_1, keeping their sequences unchanged.

The MPX is illustrated in Fig S-1(b), and it is executed as follows:

1) Randomly generate a 0-1 sequence whose length equals to the scheduling sequence.

2) Finds the position TP in the 0-1 sequence where the value is 1.

3) Swap elements at position TP on parents P_1 and P_2.

The IM is illustrated in Fig S-2(a), and it is executed as follows:

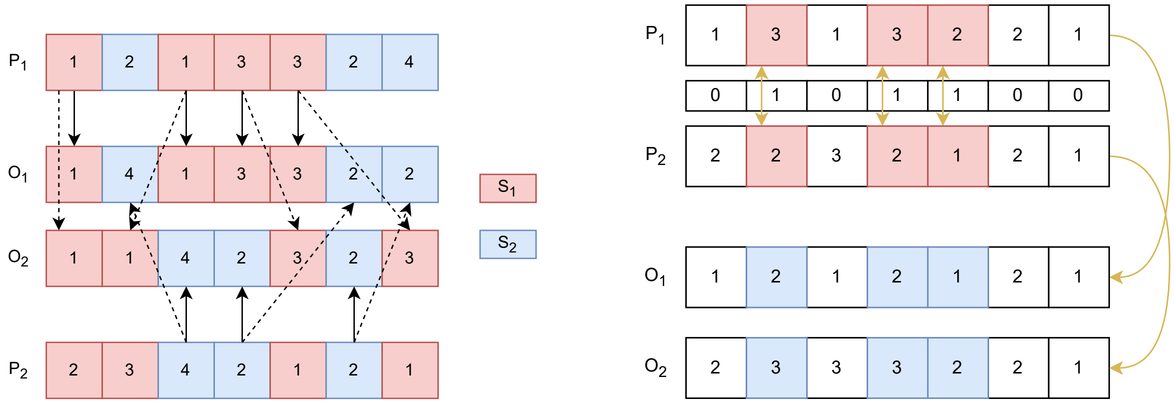
1) Randomly select two different positions TP_1 and TP_2 on the parent P.

2) Reverse all elements between TP_1 and TP_2.

The MPM is illustrated in Fig S-2(b), and it is executed as follows:

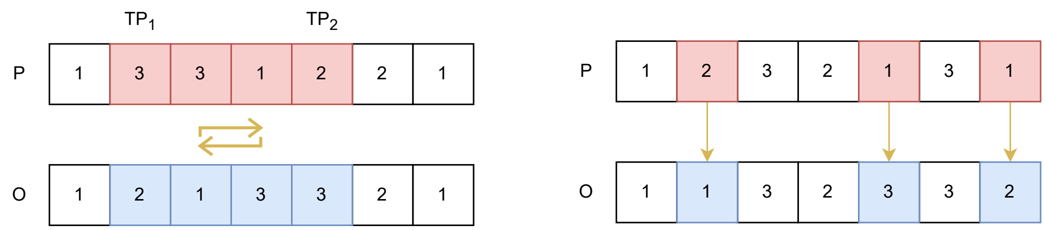
1) Randomly select some positions TP on the parent P.

2) Mutate the elements at position TP.



(a) Example of IPOX.　　(b) Example of MPX.

Fig. S-1. Example of IPOX and MPX.



(a) Example of IM.　　(b) Example of MPM.

Fig. S-2. Example of IM and MPM.

Algorithm S-1 Energy-Saving_Strategy

Input: population (P)
Output: Pareto solution sets (PS), Pareto front (PF)

$PS = \emptyset, PF = \emptyset$;
for $i = 1$ to $size(P, 1)$ **do**
　$[S, C, dig] == \text{DAG}\ (P(i, :).schedule)$; //Transform the scheduling sequence into a directed acyclic graph and record the start and completion times of each operation.
　for $j = length(P(i, :).schedule)$ to 1 **do**
　　$[job, op, idx_o, idx_m] = \text{Operation\_Extraction}\ (P(i, :).schedule(j), dig)$;
　　if $idx_o == \emptyset$ and $idx_m \sim= \emptyset$ **then**
　　　//There is no successor operation of the operation and there exist a successor operation on this processing machine.
　　　$[machNextJob, machNextOp] = \text{Operation\_Extraction}\ (P(i, :).schedule(idx_m), dig)$;
　　　$time = C(job, op) - S(job, op)$;
　　　$C(job, op) = S(machNextJob, machNextOp)$;
　　　$S(job, op) = C(job, op) - time$;
　　else if $idx_o \sim= \emptyset$ and $idx_m \sim= \emptyset$ **then**
　　　//There exists a successor operation of the operation and there exists a successor operation on this processing machine.
　　　$[nextJob, nextOp] = \text{Operation\_Extraction}\ (P(i, :).schedule(idx_o), dig)$;
　　　$[machNextJob, machNextOp] = \text{Operation\_Extraction}\ (P(i, :).schedule(idx_m), dig)$;
　　　$S(job, op) = C(job, op) - time$;
　　　$C(job, op) = \min(S(nextJob, nextOp), S(machNextJob, machNextOp))$;
　　　$S(job, op) = C(job, op) - time$;
　　end if
　end for
　$[PS_{temp}, PF_{temp}] = \text{Update\_TEC}\ (P(i, :), S, C)$;
　$PS = PS \cup PS_{temp}$;
　$PF = PF \cup PF_{temp}$;
end for

B. Energy-Saving Strategy

The specific process of the energy-saving strategy is described in the algorithm S-1. First, abstract the scheduling sequence as a directed acyclic graph. Next, traverse the entire scheduling sequence in reverse order and extract the job, the operation, the pointer to the successor operation and the pointer to the successor operation of the machine. Then, the operation is shifted right according to the constraints. Finally, update the total energy consumption and preserve the PSs and PF.

S-III. Experimental Results and Analysis

A. Experimental Instances and Evaluation Indicators

The IGDX , IGD , HV are used as evaluation indicators, which are calculated as follows.

$$IGDX = \sum_{y \in PS} \frac{\min_{x \in ps} d(x, y)}{|PS|} \tag{23}$$

$$IGD = \sum_{y \in PF} \frac{\min_{x \in pf} d(x, y)}{|PF|} \tag{24}$$

$$HV = \bigcup_{y \in pf} v(y, R) \tag{25}$$

where ps and pf denote the obtained PSs and PF consisting of all algorithms, $d(x, y)$ presents the Euclidean distance between x and y. $IGDX$ and IGD assess the convergence and diversity of ps and pf. The smaller the $IGDX$ and IGD are, with smaller values indicating better algorithm performance. In contrast, HV calculates the hypervolume enclosed by the pf and the reference point R, typically set to (1.01, 1.01). A larger HV signifies superior overall algorithm performance.

Moreover, the power distributions for each machine are listed in Table S-I.

TABLE S-I
The power distribution for each machine.

h	basic setup power	basic processing power	basic idle power
M_1	16.21	6.08	0.96
M_2	18.11	5.89	1.65
M_3	19.73	9.85	2.98
M_4	15.90	8.68	3.61
M_5	19.01	7.41	1.98
M_6	16.05	6.51	4.51
M_7	16.92	5.41	0.77
M_8	19.19	9.88	2.76
M_9	15.97	8.35	2.50
M_{10}	16.61	9.86	4.34
M_{11}	19.24	8.81	4.69
M_{12}	16.18	8.86	0.38
M_{13}	15.13	5.38	0.90
M_{14}	18.61	6.78	3.12
M_{15}	18.77	6.06	2.70

B. Ablation Experiments

The statistical results for the three indicators are presented in Table S-II and the best results are shown in **bold**. The Wilcoxon rank-sum test is implemented in Table S-II and '+', '-', '=' mean the number of the performance of the competitor is significantly better than, worse than, and similar to APHMA.

C. Comparison Experiments and Analysis

The parameter configurations of all algorithms are listed in Table S-III. Moreover, the statistical results for all indicators are presented in Tables S-IV, where the best results are shown in **bold**. The symbols '+', '-', '=' denote whether a competitor algorithm significantly outperforms, underperforms, or performs similarly to APHMA.

TABLE S-II
IGDX, IGD, and HV Statistical Results of All Variant Algorithms.

Instance	IGDX							
	APHMA-BV	APHMA-NS	APHMA-AP	APHMA-ES	APHMA-NNS	APHMA-NAP	APHMA-NES	APHMA
MK01	3.61E+00 -	3.45E+00 =	3.57E+00 -	**3.34E+00 =**	3.68E+00 -	3.52E+00 =	3.59E+00 -	3.47E+00
MK02	3.74E+00 -	3.51E+00 =	3.60E+00 -	3.47E+00 =	3.67E+00 -	3.55E+00 =	3.62E+00 -	**3.44E+00**
MK03	5.66E+00 -	5.28E+00 =	5.48E+00 -	5.49E+00 -	5.57E+00 -	5.43E+00 -	5.49E+00 -	**5.21E+00**
MK04	4.31E+00 -	4.15E+00 -	4.18E+00 -	4.14E+00 -	4.25E+00 -	4.15E+00 -	4.22E+00 -	**3.81E+00**
MK05	4.40E+00 -	4.30E+00 -	4.33E+00 -	**4.07E+00 =**	4.39E+00 -	4.24E+00 =	4.33E+00 -	4.12E+00
MK06	5.92E+00 +	5.84E+00 +	5.92E+00 +	**5.69E+00 +**	6.04E+00 =	5.99E+00 =	5.86E+00 +	6.09E+00
MK07	4.17E+00 -	4.03E+00 -	4.19E+00 -	**3.88E+00 +**	4.30E+00 -	4.06E+00 -	4.17E+00 -	3.95E+00
MK08	6.51E+00 -	6.39E+00 =	6.42E+00 -	6.38E+00 -	6.56E+00 -	6.48E+00 -	6.40E+00 -	**6.20E+00**
MK09	6.88E+00 -	6.69E+00 =	6.79E+00 -	6.82E+00 -	6.83E+00 -	6.79E+00 -	6.80E+00 -	**6.46E+00**
MK10	7.08E+00 -	6.80E+00 =	6.86E+00 =	6.98E+00 -	6.96E+00 -	6.80E+00 -	6.87E+00 =	**6.63E+00**
DP01	6.70E+00 =	6.76E+00 =	6.69E+00 =	**6.40E+00 =**	6.81E+00 -	6.78E+00 =	6.67E+00 =	6.68E+00
DP02	6.87E+00 =	6.94E+00 -	6.89E+00 =	**6.56E+00 =**	6.94E+00 -	6.95E+00 -	6.89E+00 =	6.81E+00
DP03	7.30E+00 -	7.22E+00 -	7.19E+00 -	7.24E+00 -	7.27E+00 -	7.15E+00 -	7.15E+00 -	**6.68E+00**
DP04	6.72E+00 =	6.72E+00 =	6.67E+00 =	**6.37E+00 =**	6.80E+00 -	6.79E+00 -	6.65E+00 =	6.65E+00
DP05	6.92E+00 =	6.87E+00 =	6.85E+00 =	**6.60E+00 =**	6.93E+00 =	6.91E+00 =	6.87E+00 =	6.88E+00
DP06	7.32E+00 -	7.20E+00 -	7.19E+00 -	7.24E+00 -	7.27E+00 -	6.98E+00 -	7.15E+00 -	**6.90E+00**
DP07	7.78E+00 -	7.69E+00 -	7.60E+00 -	7.66E+00 -	7.72E+00 -	7.56E+00 -	7.62E+00 -	**7.42E+00**
DP08	8.18E+00 -	8.11E+00 -	8.09E+00 -	8.14E+00 -	8.19E+00 -	7.99E+00 -	8.10E+00 -	**7.68E+00**
DP09	8.46E+00 -	8.30E+00 -	8.31E+00 -	8.36E+00 -	8.40E+00 -	8.22E+00 -	8.27E+00 -	**7.95E+00**
DP10	7.78E+00 -	7.69E+00 -	7.62E+00 -	7.75E+00 -	7.76E+00 -	7.63E+00 -	7.60E+00 -	**7.22E+00**
+/-/=	1/15/4	1/10/9	1/14/5	2/11/7	0/18/2	0/13/7	1/14/5	NA
Instance	IGD							
	APHMA-BV	APHMA-NS	APHMA-AP	APHMA-ES	APHMA-NNS	APHMA-NAP	APHMA-NES	APHMA
MK01	1.80E-01 -	**7.24E-02 +**	3.57E-01 -	9.54E-02 +	2.28E-01 -	1.09E-01 +	2.60E-01 -	**1.49E-01**
MK02	3.41E-01 -	1.33E-01 =	3.35E-01 -	2.16E-01 -	2.58E-01 -	1.30E-01 =	3.11E-01 -	**1.26E-01**
MK03	3.56E-01 -	1.26E-01 =	5.82E-01 -	1.93E-01 -	4.16E-01 -	1.29E-01 =	5.36E-01 -	**1.15E-01**
MK04	3.12E-01 -	1.97E-01 -	4.86E-01 -	2.43E-01 -	3.92E-01 -	1.30E-01 -	4.93E-01 -	**5.74E-02**
MK05	2.21E-01 -	1.46E-01 -	2.94E-01 -	1.72E-01 -	3.12E-01 -	1.41E-01 -	2.89E-01 -	**1.09E-01**
MK06	3.38E-01 -	**8.96E-02 +**	4.03E-01 -	1.04E-01 +	2.49E-01 -	1.71E-01 =	3.09E-01 -	1.86E-01
MK07	2.06E-01 -	**6.04E-02 +**	2.86E-01 -	6.66E-02 +	1.63E-01 -	9.10E-02 +	2.63E-01 -	1.24E-01
MK08	4.01E-01 -	2.61E-01 -	5.83E-01 -	2.89E-01 -	5.36E-01 -	2.57E-01 -	5.01E-01 -	**1.87E-01**
MK09	4.62E-01 -	1.29E-01 -	4.02E-01 -	2.23E-01 -	3.43E-01 -	1.59E-01 -	3.17E-01 -	**9.79E-02**
MK10	4.95E-01 -	**1.03E-01 =**	4.82E-01 -	2.51E-01 -	5.27E-01 -	1.58E-01 -	3.61E-01 -	1.03E-01
DP01	1.39E-01 =	1.28E-01 =	4.60E-01 -	**7.90E-02 +**	1.36E-01 =	1.46E-01 =	4.51E-01 -	1.45E-01
DP02	2.06E-01 -	1.49E-01 -	3.22E-01 -	**1.02E-01 =**	2.74E-01 -	1.59E-01 -	3.18E-01 -	1.16E-01
DP03	5.25E-01 -	3.69E-01 -	4.50E-01 -	5.11E-01 -	5.64E-01 -	2.55E-01 -	4.42E-01 -	**1.34E-01**
DP04	1.62E-01 =	1.21E-01 =	4.91E-01 -	**6.53E-02 +**	1.66E-01 =	1.72E-01 -	4.98E-01 -	1.29E-01
DP05	2.95E-01 -	1.73E-01 -	4.00E-01 -	1.63E-01 =	3.26E-01 -	1.76E-01 -	4.03E-01 -	**1.15E-01**
DP06	5.03E-01 -	3.12E-01 -	4.21E-01 -	4.45E-01 -	5.48E-01 -	1.86E-01 -	4.22E-01 -	**1.07E-01**
DP07	4.09E-01 -	2.73E-01 -	6.25E-01 -	2.73E-01 -	4.35E-01 -	1.81E-01 -	6.15E-01 -	**1.06E-01**
DP08	6.05E-01 -	4.25E-01 -	5.40E-01 -	5.28E-01 -	6.78E-01 -	2.94E-01 -	5.50E-01 -	**1.55E-01**
DP09	6.09E-01 -	4.55E-01 -	4.93E-01 -	5.57E-01 -	5.77E-01 -	3.15E-01 -	4.81E-01 -	**2.60E-01**
DP10	4.05E-01 -	2.91E-01 -	5.83E-01 -	3.03E-01 -	4.03E-01 -	1.80E-01 -	5.86E-01 -	**7.65E-02**
+/-/=	0/18/2	3/12/5	0/20/0	5/13/2	0/18/2	2/14/4	0/20/0	NA
Instance	HV							
	APHMA-BV	APHMA-NS	APHMA-AP	APHMA-ES	APHMA-NNS	APHMA-NAP	APHMA-NES	APHMA
MK01	1.17E-01 -	4.67E-01 -	6.15E-02 -	3.01E-01 -	1.00E-01 -	5.02E-01 =	1.10E-01 -	**5.35E-01**
MK02	9.06E-03 -	3.94E-01 -	7.75E-03 -	1.67E-01 -	6.54E-02 -	3.98E-01 -	1.75E-02 -	**4.68E-01**
MK03	0.00E+00 -	2.56E-01 -	0.00E+00 -	5.15E-02 -	0.00E+00 -	1.92E-01 -	0.00E+00 -	**3.76E-01**
MK04	8.94E-03 -	1.49E-01 -	0.00E+00 -	1.03E-01 -	2.06E-03 -	2.30E-01 -	0.00E+00 -	**3.16E-01**
MK05	1.81E-02 -	2.05E-01 -	5.17E-03 -	8.42E-02 -	5.43E-03 -	2.53E-01 -	8.36E-03 -	**3.93E-01**
MK06	0.00E+00 -	**4.84E-01 +**	0.00E+00 -	1.02E-01 -	1.20E-03 -	3.04E-01 =	2.33E-03 -	3.62E-01
MK07	0.00E+00 -	3.37E-01 -	1.93E-02 -	1.54E-01 -	1.53E-01 -	3.40E-01 -	2.65E-02 -	**5.31E-01**
MK08	0.00E+00 -	1.94E-01 -	0.00E+00 -	1.19E-01 -	0.00E+00 -	1.93E-01 -	0.00E+00 -	**5.16E-01**
MK09	0.00E+00 -	3.67E-01 -	5.40E-03 -	2.32E-01 -	4.24E-02 -	2.61E-01 -	4.58E-02 -	**4.17E-01**
MK10	0.00E+00 -	**1.39E-01 =**	0.00E+00 -	7.71E-03 -	0.00E+00 -	4.54E-02 -	0.00E+00 -	1.29E-01
DP01	2.58E-02 -	9.60E-02 -	0.00E+00 -	9.40E-02 -	3.97E-02 -	3.50E-01 -	0.00E+00 -	**3.97E-01**
DP02	0.00E+00 -	8.62E-02 -	0.00E+00 -	4.26E-02 -	5.21E-03 -	2.99E-01 -	0.00E+00 -	**4.05E-01**
DP03	1.53E-03 -	1.28E-01 -	8.93E-03 -	3.59E-02 -	0.00E+00 -	3.48E-01 -	6.69E-03 -	**4.80E-01**
DP04	1.12E-02 -	1.49E-01 -	0.00E+00 -	1.28E-01 -	2.58E-02 -	4.25E-01 -	0.00E+00 -	**5.43E-01**
DP05	3.24E-02 -	2.04E-01 -	0.00E+00 -	1.66E-01 -	1.89E-02 -	4.07E-01 -	0.00E+00 -	**5.09E-01**
DP06	0.00E+00 -	4.46E-02 -	0.00E+00 -	1.51E-02 -	0.00E+00 -	2.51E-01 -	0.00E+00 -	**3.61E-01**
DP07	0.00E+00 -	7.37E-02 -	0.00E+00 -	1.10E-01 -	0.00E+00 -	3.26E-01 -	0.00E+00 -	**4.39E-01**
DP08	0.00E+00 -	1.08E-02 -	0.00E+00 -	4.55E-03 -	0.00E+00 -	2.73E-01 -	0.00E+00 -	**3.34E-01**
DP09	0.00E+00 -	0.00E+00 -	0.00E+00 -	0.00E+00 -	0.00E+00 -	1.14E-01 -	0.00E+00 -	**1.93E-01**
DP10	0.00E+00 -	3.06E-02 -	0.00E+00 -	5.18E-02 -	0.00E+00 -	2.87E-01 -	0.00E+00 -	**4.81E-01**
+/-/=	0/20/0	1/18/1	0/20/0	0/20/0	0/20/0	0/18/2	0/20/0	NA

TABLE S-III
PARAMETER CONFIGURATIONS OF ALL ALGORITHMS.

MOEA/D	$N = 100,\ P_c = 1.0, P_m = 0.2, T = 20$
NSGA-II	$N = 100,\ P_c = 1.0, P_m = 0.2$
MOEA/D-AAWN	$N = 100,\ P_c = 1.0, P_m = 0.2, T = 20$ $\alpha = 0.1, \beta = 0.05, \theta = 5$
HREA	$N = 100,\ P_c = 1.0, P_m = 0.2, \epsilon = 0.3$
BOEA	$N = 100,\ P_c = 1.0, P_m = 1/(SH * 3)$ $\sigma = 5, \alpha = 5$
TIE	$N = 2,\ \gamma = 0.3, \lambda = 100, \theta 1 = \theta 2 = 3$ $\epsilon = 0.1, p = 10, \delta = 0.1$
ACML-BCEA	$N = 126,\ P_c = 0.9, P_m = 0.3, \alpha = 2$
APHMA	$N = 100,\ P_c = 1.0, P_m = 0.2, \beta = 20, \sigma = 0.3$ $n_{dt} = 100, MaxIter = 500, \lambda = 0.5$

TABLE S-IV
IGDX, IGD, and HV Statistical Results of All Comparison Algorithms.

Instance	IGDX							
	MOEA/D	NSGA-II	MOEA/D-AAWN	HREA	BOEA	TIE	ACML-BCEA	APHMA
MK01	3.90E+00 -	3.57E+00 -	3.90E+00 -	3.71E+00 -	3.40E+00 =	3.93E+00 -	3.70E+00 -	**3.37E+00**
MK02	4.20E+00 -	3.88E+00 -	4.19E+00 -	4.03E+00 -	3.76E+00 -	4.20E+00 -	4.01E+00 -	**3.33E+00**
MK03	5.85E+00 -	5.60E+00 -	5.87E+00 -	5.58E+00 -	5.52E+00 =	5.77E+00 -	**5.41E+00 +**	5.45E+00
MK04	4.36E+00 -	4.12E+00 -	4.30E+00 -	4.19E+00 -	**3.92E+00 =**	4.43E+00 -	4.27E+00 -	3.99E+00
MK05	4.61E+00 -	4.39E+00 -	4.45E+00 -	4.54E+00 -	4.30E+00 -	4.48E+00 -	4.58E+00 -	**3.93E+00**
MK06	8.08E+00 -	7.28E+00 -	7.91E+00 -	6.97E+00 -	6.66E+00 -	7.85E+00 -	6.63E+00 -	**6.38E+00**
MK07	4.40E+00 -	4.13E+00 -	4.37E+00 -	4.18E+00 -	4.01E+00 =	4.45E+00 -	4.24E+00 -	**3.90E+00**
MK08	6.68E+00 -	6.40E+00 -	6.57E+00 -	6.42E+00 -	6.31E+00 =	6.52E+00 -	**6.22E+00 +**	6.25E+00
MK09	7.20E+00 -	7.02E+00 -	7.20E+00 -	7.07E+00 -	6.89E+00 -	7.23E+00 -	7.07E+00 -	**6.47E+00**
MK10	7.47E+00 -	7.21E+00 -	7.40E+00 -	7.28E+00 -	7.03E+00 -	7.42E+00 -	7.25E+00 -	**6.72E+00**
DP01	6.97E+00 -	6.85E+00 -	6.92E+00 -	6.96E+00 -	6.68E+00 -	6.93E+00 -	6.89E+00 -	**6.46E+00**
DP02	7.16E+00 -	7.03E+00 -	7.06E+00 -	7.24E+00 -	6.91E+00 -	7.12E+00 -	7.11E+00 -	**6.56E+00**
DP03	7.41E+00 -	7.27E+00 -	7.32E+00 -	7.47E+00 -	7.08E+00 -	7.32E+00 -	7.35E+00 -	**6.85E+00**
DP04	6.98E+00 -	6.84E+00 -	6.92E+00 -	7.02E+00 -	6.68E+00 -	6.96E+00 -	6.91E+00 -	**6.46E+00**
DP05	7.15E+00 -	7.03E+00 -	7.10E+00 -	7.21E+00 -	6.85E+00 -	7.13E+00 -	7.07E+00 -	**6.58E+00**
DP06	7.35E+00 -	7.20E+00 -	7.31E+00 -	7.36E+00 -	**7.00E+00 =**	7.33E+00 -	7.03E+00 -	7.03E+00
DP07	7.83E+00 -	7.68E+00 -	7.78E+00 -	7.78E+00 -	7.54E+00 -	7.80E+00 -	7.78E+00 -	**7.33E+00**
DP08	8.22E+00 -	8.11E+00 -	8.22E+00 -	8.17E+00 -	7.97E+00 -	8.20E+00 -	8.22E+00 -	**7.72E+00**
DP09	8.44E+00 -	8.33E+00 -	8.42E+00 -	8.39E+00 -	**8.01E+00 =**	8.46E+00 -	8.37E+00 -	8.18E+00
DP10	7.84E+00 -	7.74E+00 -	7.78E+00 -	7.76E+00 -	7.62E+00 -	7.79E+00 -	7.83E+00 -	**7.24E+00**
+/-/=	0/20/0	0/20/0	0/20/0	0/20/0	0/13/7	0/20/0	2/18/0	NA

Instance	IGD							
	MOEA/D	NSGA-II	MOEA/D-AAWN	HREA	BOEA	TIE	ACML-BCEA	APHMA
MK01	4.57E-01 -	1.28E-01 -	5.60E-01 -	1.30E-01 -	**8.59E-02 =**	5.18E-01 -	1.46E-01 -	8.94E-02
MK02	5.10E-01 -	1.95E-01 -	6.00E-01 -	1.80E-01 -	1.42E-01 -	5.48E-01 -	2.34E-01 -	**3.15E-02**
MK03	9.09E-01 -	1.92E-01 =	9.68E-01 -	1.16E-01 +	**7.00E-02 +**	6.74E-01 -	9.76E-02 +	1.65E-01
MK04	4.92E-01 -	1.60E-01 -	5.97E-01 -	1.06E-01 =	**1.04E-01 =**	5.86E-01 -	1.64E-01 -	1.18E-01
MK05	3.53E-01 -	3.91E-01 -	3.91E-01 -	2.07E-01 -	3.40E-01 -	3.97E-01 -	4.62E-01 -	**7.51E-02**
MK06	8.66E-01 -	2.51E-01 -	9.15E-01 -	1.89E-01 -	**7.98E-02 +**	6.15E-01 -	1.13E-01 +	1.48E-01
MK07	6.26E-01 -	1.85E-01 -	7.27E-01 -	1.42E-01 -	1.42E-01 -	6.64E-01 -	1.77E-01 -	**8.45E-02**
MK08	7.28E-01 -	1.94E-01 +	7.51E-01 -	1.55E-01 +	**8.13E-02 +**	5.34E-01 -	1.17E-01 +	2.84E-01
MK09	6.91E-01 -	2.99E-01 -	7.57E-01 -	2.69E-01 -	2.19E-01 -	5.22E-01 -	2.61E-01 -	**1.08E-01**
MK10	7.60E-01 -	2.92E-01 -	8.48E-01 -	2.91E-01 -	1.63E-01 -	5.70E-01 -	2.02E-01 -	**1.15E-01**
DP01	5.05E-01 -	3.16E-01 -	5.39E-01 -	2.32E-01 -	3.18E-01 -	5.16E-01 -	3.16E-01 -	**1.30E-01**
DP02	5.09E-01 -	3.58E-01 -	5.74E-01 -	3.94E-01 -	3.55E-01 -	4.69E-01 -	3.61E-01 -	**1.38E-01**
DP03	4.44E-01 -	3.26E-01 -	5.20E-01 -	3.76E-01 -	2.85E-01 -	5.17E-01 -	2.98E-01 -	**1.52E-01**
DP04	4.99E-01 -	3.61E-01 -	5.55E-01 -	3.38E-01 -	3.58E-01 -	4.92E-01 -	3.56E-01 -	**1.65E-01**
DP05	4.87E-01 -	3.03E-01 -	5.02E-01 -	3.40E-01 -	2.76E-01 -	4.24E-01 -	2.92E-01 -	**1.16E-01**
DP06	4.63E-01 -	2.19E-01 -	5.21E-01 -	4.74E-01 -	**1.31E-01 +**	4.72E-01 -	1.69E-01 =	1.77E-01
DP07	5.65E-01 -	3.89E-01 -	6.01E-01 -	3.54E-01 -	3.63E-01 -	4.93E-01 -	3.64E-01 -	**1.74E-01**
DP08	6.21E-01 -	4.00E-01 -	6.71E-01 -	4.27E-01 -	3.90E-01 -	5.19E-01 -	3.93E-01 -	**1.89E-01**
DP09	7.53E-01 -	3.12E-01 -	8.08E-01 -	4.54E-01 -	**1.68E-01 +**	6.04E-01 -	2.03E-01 +	2.56E-01
DP10	5.09E-01 -	3.61E-01 -	5.46E-01 -	3.33E-01 -	3.76E-01 -	4.58E-01 -	3.58E-01 -	**1.16E-01**
+/-/=	0/20/0	1/18/1	0/20/0	2/17/1	5/13/2	0/20/0	4/15/1	NA

Instance	HV							
	MOEA/D	NSGA-II	MOEA/D-AAWN	HREA	BOEA	TIE	ACML-BCEA	APHMA
MK01	7.63E-05 -	2.78E-01 -	0.00E+00 -	3.07E-01 -	4.34E-01 -	0.00E+00 -	2.64E-01 -	**4.99E-01**
MK02	0.00E+00 -	2.35E-02 -	0.00E+00 -	7.61E-02 -	1.63E-01 -	0.00E+00 -	2.63E-02 -	**4.57E-01**
MK03	0.00E+00 -	0.00E+00 -	0.00E+00 -	2.88E-02 -	1.33E-01 -	0.00E+00 -	2.61E-02 -	**3.49E-01**
MK04	0.00E+00 -	1.66E-01 -	0.00E+00 -	3.38E-01 =	**3.86E-01 +**	0.00E+00 -	2.25E-01 -	2.93E-01
MK05	1.25E-02 -	1.10E-01 -	2.55E-03 -	1.53E-01 -	2.60E-01 -	2.02E-03 -	1.29E-01 -	**3.69E-01**
MK06	0.00E+00 -	0.00E+00 -	0.00E+00 -	1.06E-02 -	2.31E-01 -	0.00E+00 -	9.03E-02 -	**4.26E-01**
MK07	0.00E+00 -	2.76E-02 -	0.00E+00 -	2.14E-01 -	2.32E-01 -	0.00E+00 -	1.04E-01 -	**5.41E-01**
MK08	0.00E+00 -	0.00E+00 -	0.00E+00 -	2.28E-02 -	1.67E-01 -	0.00E+00 -	4.42E-02 -	**3.74E-01**
MK09	0.00E+00 -	0.00E+00 -	0.00E+00 -	0.00E+00 -	1.26E-01 -	0.00E+00 -	8.75E-04 -	**3.42E-01**
MK10	0.00E+00 -	0.00E+00 -	0.00E+00 -	0.00E+00 -	5.82E-02 -	0.00E+00 -	2.51E-03 -	**1.24E-01**
DP01	0.00E+00 -	5.92E-03 -	0.00E+00 -	1.06E-01 -	6.96E-02 -	0.00E+00 -	1.73E-02 -	**3.07E-01**
DP02	0.00E+00 -	1.09E-02 -	0.00E+00 -	2.52E-02 -	1.04E-01 -	0.00E+00 -	2.35E-02 -	**3.97E-01**
DP03	5.67E-04 -	6.05E-03 -	0.00E+00 -	3.48E-02 -	1.78E-01 -	0.00E+00 -	8.54E-02 -	**3.33E-01**
DP04	0.00E+00 -	4.26E-02 -	0.00E+00 -	1.33E-01 -	1.55E-01 -	0.00E+00 -	1.00E-01 -	**4.60E-01**
DP05	0.00E+00 -	1.41E-02 -	0.00E+00 -	8.47E-02 -	1.58E-01 -	0.00E+00 -	5.34E-02 -	**4.27E-01**
DP06	0.00E+00 -	1.31E-02 -	0.00E+00 -	1.02E-02 -	2.09E-01 -	0.00E+00 -	6.60E-02 -	**2.85E-01**
DP07	0.00E+00 -	0.00E+00 -	0.00E+00 -	1.84E-03 -	2.71E-02 -	0.00E+00 -	0.00E+00 -	**2.76E-01**
DP08	0.00E+00 -	0.00E+00 -	0.00E+00 -	0.00E+00 -	8.68E-02 -	0.00E+00 -	1.61E-02 -	**1.95E-01**
DP09	0.00E+00 -	0.00E+00 -	0.00E+00 -	4.96E-03 -	1.23E-01 -	0.00E+00 -	5.26E-02 -	**2.22E-01**
DP10	0.00E+00 -	4.31E-05 -	0.00E+00 -	1.86E-02 -	4.13E-02 -	0.00E+00 -	1.59E-02 -	**3.64E-01**
+/-/=	0/20/0	0/20/0	0/20/0	0/19/1	1/19/0	0/20/0	0/20/0	NA