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(Research Paper)

An Assignment-Scheduling Model to Improve Employee Workload Using Job Rotation

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Abstract

Purpose: The importance of employees and their role in an organisation's sustainable success is so significant that it has become one of the pillars of Industry 5. Employees are now viewed not merely as cost centres, but as valuable assets whose satisfaction and capabilities directly influence the organisation's success and longevity. In production environments, a key aspect of job satisfaction is the company's proactive approach to safeguarding employees from harmful workplace conditions. This paper examines the adjustment of workload through job rotation among workstations, highlighting it as a critical strategy for mitigating workplace hazards.

Design/methodology/approach: This approach is formulated as a multi-objective mixed-integer mathematical scheduling model with the following objectives: i) optimising employee workload, ii) minimising the distance travelled, and iii) reducing the discrepancy between assigned vacation days and employees' requests. The model has been implemented in a real-world case.

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Findings: Findings indicated that implementing this model not only adjusted and reduced employee workload but also enhanced satisfaction by aligning rest day allocations with employee requests. Additionally, the model accounted for the costs associated with its implementation, such as travel costs, while simultaneously increasing the variety of tasks assigned to employees, thereby reducing job monotony.

Practical implications: The results and the sensitivity analysis demonstrate the proposed model's effectiveness in achieving the research objectives. Investing time and resources in skill development and multi-skilling, combined with implementing the proposed model, can positively impact ergonomic conditions in the workplace, ultimately enhancing employee satisfaction and loyalty in alignment with the objectives of Industry 5.

Originality/value: No study in the literature has yet considered ergonomic factors, skills, efficiency, rest day preferences, and economic aspects simultaneously. In this study, a novel, efficient job rotation schedule is proposed that meets three primary objectives: i) adjusting workloads to uphold ergonomic standards, ii) minimising employee transfer times between workstations, and iii) accommodating rest day preferences.

Keywords: Job rotation, Scheduling, Workload, Ergonomics; Multi-Objective Decision-Making model

1. Introduction

Industrial environments frequently expose workers to numerous risks stemming from elevated physical and mental workloads, particularly in factories with elevated safety hazards. Continuous exposure to conditions such as vibration, uneven surfaces, heat, steam, smoke, and noise, as well as the physical demands of moving heavy objects, aggravates the detrimental effects of the work environment on employee health. Additionally, the increasing age of the employees in some regions further intensifies these health risks. The working conditions that impact employee health are critical as they directly influence performance and productivity. Workload encompasses various task-related factors, including intensity, stress, effort, time constraints, complexity, and the mental effort required for control and monitoring. A heavy workload can diminish employee commitment, job performance, and productivity, while increasing the risk of accidents, work-related illnesses, and work-life imbalance ([Türkoglu & Cansoy, 2020](#)).

Significant efforts have been made to alleviate workload and mitigate risks through automation and enhancements in production and assembly lines, emphasising ergonomic considerations.

Redesigning workstations may not always be feasible due to work nature or costs; therefore, alternative strategies like task redesign and workload balancing should be explored. Job rotation is an effective approach that balances workloads, reduces ergonomic risks, boosts employee motivation, and enhances job satisfaction by preventing monotony in high-risk tasks.

Job rotation is grounded in several key theories: Job Characteristics Model (JCM) emphasizes that jobs with variety, autonomy, and feedback enhance motivation and satisfaction ([Hackman & Oldham, 1976](#)); Social Exchange Theory suggests that positive experiences, such as skill development through job rotation, foster loyalty and commitment (Blau, 1964); and Ergonomics and Human Factors focus on minimizing workplace injuries. In addition, since task combination can affect employee performance, it has attracted the attention of researchers in relevant cases (e.g., [Mortazavi et al., 2020](#)).

Furthermore, the significance of employee satisfaction is a fundamental aspect of Industry 5.0, which transitions towards a human-centric, sustainable production model. Job rotation aligns with Industry 5.0 by fostering well-being, enhancing skills, reducing injury risks, and promoting collaboration with diverse technologies. It also cultivates agility and advanced problem-solving by encouraging employees to engage in varied responsibilities.

Research has shown that job rotation can enhance job satisfaction ([Van Wyk et al., 2018](#); [Hampongo & Foya, 2020](#)), increase skill variety ([Kirkpatrick & Locke, 1996](#)), reduce health risks ([Shin et al., 2021](#)), and improve organisational performance ([Giga et al., 2003](#)). However, challenges such as potential drops in productivity during role transitions ([Friedman & Greenhaus, 2011](#)) and resistance to change ([Cohen & McWilliams, 2021](#)) must be managed carefully. Effective job rotation schedules can dynamically assign workers to different roles while considering their preferences for rest days, ultimately enhancing satisfaction and maintaining productivity.

Several studies have explored the ergonomic impacts of job rotation, aiming to minimise exposure to hazards ([Otto & Battaia, 2017](#); [Botti et al., 2020](#)), while others focus on optimising efficiency ([Mossa et al., 2016](#)) or incorporating employee skills into scheduling. Many job rotation studies have been conducted in the field of line balancing.

Asensio-Cuesta et al. ([2012](#)) introduced a genetic algorithm to develop job rotation schedules aimed at preventing work-related musculoskeletal disorders by taking into account the risk of repetitive motions as assessed by the OCRA ergonomic evaluation method. They incorporated organisational constraints and individual disabilities into the schedule. Rajabalipour Cheshmehgaz et al. ([2012](#)) proposed a fuzzy goal programming and a genetic algorithm for the assembly line balancing problem, considering balancing the tasks of workers in assembly lines during repetitive jobs to reduce work-related musculoskeletal disorders. Yoon et al. ([2016](#)) presented a mathematical model to determine job rotation for three automobile assembly lines to reduce the cumulative workload of consecutive use of the same body region. They evaluated the workload for different body areas and determined the job rotation program, respectively. Battini et al. ([2022](#)) presented a mathematical model for job rotation by considering experience, physical limitations, and productivity, considering ergonomic dimensions. They also tested the results in an industrial setting.

This paper develops a multi-objective mathematical model to determine a job rotation schedule, studying the following considerations:

- i) Different skill levels of employees
- ii) Workload and mental load of each employee for each station using the NASA questionnaire
- iii) Production interruption due to job rotation
- iv) Rest-day preferences
- v) Manpower requirement for each station

No study in the literature has yet considered ergonomic factors, skills, efficiency, rest day preferences, and economic aspects simultaneously.

This study aims to develop a novel, efficient job rotation schedule that meets three primary objectives: i) adjusting workloads to uphold ergonomic standards, ii) minimising employee transfer times between workstations, and iii) accommodating rest day preferences. Additionally, we will adhere to constraints related to required skill levels and company policies.

2. Problem description

Employees are among the most valuable assets of an organisation, playing a crucial role in its survival and success. Implementing a strategy that emphasises job-employee compatibility, comfort, and health is essential for effectively assigning tasks and significantly impacts the achievement of organisational goals. Typically, production line employees are assigned to fixed workstations based on their skills, which fosters expertise in specific areas and enhances production efficiency. However, neglecting other aspects of this strategy can negatively affect employee satisfaction, individual performance, and overall productivity. Variations in workload across different workstations can disrupt the balance that ergonomics aims to maintain in both physical and psychological aspects. Differences in average workload and the monotony of tasks can lead to feelings of injustice, job burnout, and ultimately dissatisfaction. This discontent can result in serious consequences, including increased fatigue-related accidents and employee turnover. Satisfaction in a job is often influenced more by an individual's perception of workload (mental workload) than by the actual physical demands of the role. Additionally, variations in employees' skills and physical strengths mean that the pressure experienced at a given workload can differ significantly among individuals.

One effective approach to mitigate these issues is job rotation, which allows employees to transfer between workstations based on their skills. Furthermore, adjusting employees' rest days—particularly in multi-shift environments—should be tailored to individual requests while adhering to organisational policies and staffing requirements. However, job rotation

may also result in production disruptions, which could conflict with the organisation's economic interests.

In this article, we present a novel mathematical programming model for the job rotation scheduling problem, designed to assign employees to job shifts to achieve the following objectives:

- i) Adjusting workloads among employees to balance the average exposure during the planning horizon.
- ii) Minimising travel distances during job rotation to reduce production losses due to production interruptions.
- iii) Aligning employees' rest days with their preferences to enhance job satisfaction.

3. Model assumptions

This study focuses on a production unit with J workstations over a planning horizon of N working days. Due to a constant production rate, the number of each workstation remains fixed throughout this period. Each working day consists of h hours divided into three equal working periods (Figure 1).

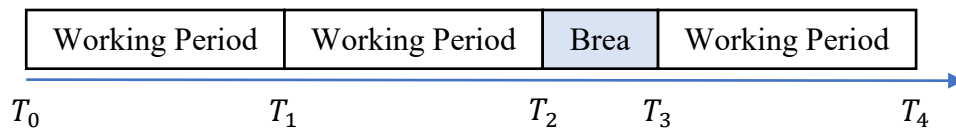


Fig. 1. Hourly status of the production line in a day

Job rotation can only occur at the end of these periods (T_1, T_2, T_4). The distance between the current and next workstation is a key indicator of production loss during job rotation. A meal break occurs between the second and third periods (T_2, T_3), during which the production line stops; thus, production loss during this time is not attributed to job rotation. A similar condition applies between the third and first periods. Employee allocation to workstations is based on their skills and the job requirements of each station. Hourly leave is not permitted during any of the three working periods. Each employee is allowed a maximum of m rest days within the N -day planning horizon. The number of workstations is determined by the production rate, and the minimum number of employees needed each day must be considered when allocating leave. More assumptions are listed below:

- The planning horizon comprises N working days, excluding public holidays.
- Each working day features a h -hour shift divided into three identical periods for job rotation.
- Hourly leave is not permitted during shifts.
- The production rate is fixed.

- Workload levels at each station are based on employees' subjective perceptions.
- Identical workstations share the same mental workload level.
- The required manpower for each workstation is fixed throughout the planning horizon.
- Each employee's skill level is predetermined.
- Employees can only be assigned to workstations matching their minimum competency requirements.
- Each employee is entitled to a maximum of m rest days during the planning horizon.
- Employees move between workstations at a constant speed.
- Production losses due to job rotation are accounted for only between the first and second periods.
- No production loss is considered for job rotation between the second and third periods, as it coincides with the meal break.
- No production loss is incurred for job rotation at the start of each working day.

This study utilises data collected from the shaft production process (e.g., ordinary shafts, gearbox shafts, pump shafts, fan shafts) at a maintenance centre of a steel company, which is responsible for servicing, repairing, and restoring defective parts, as well as producing spare parts. To evaluate the mental workload at the stations, we employed the NASA Task Load Index (NASA-TLX) standard questionnaire ([Hart & Staveland, 1988](#)).

This questionnaire consists of two main parts. The first part assesses the total workload of a task, which is divided into six subscales:

- Mental Pressure: This measures the amount of mental and cognitive activity required, including the level of difficulty or ease and the complexity of the task.
- Physical Pressure: This evaluates the physical activity required, and the ease or difficulty associated with it and the intensity of physical exertion needed.
- Time Pressure: This gauges the sense of urgency felt by the individual, based on the speed of task completion and the pace of progress.
- Efficiency: This reflects the individual's success in performing the task and their satisfaction with their performance in that role.
- Effort: This measures the mental and physical effort exerted by the individual to achieve the desired level of performance.
- Frustration (Failure): This captures feelings of resentment, anger, and stress in contrast to feelings of satisfaction and peace during the task.

The second part of the questionnaire asks participants to evaluate the importance of each index relative to the others through binary comparisons. By multiplying the score of each index by its corresponding weight, the average workload of each workstation can be calculated from the individual's perspective. The validity and reliability of this index were confirmed, with a Cronbach's alpha of 0.83. This questionnaire was distributed and

completed during a joint meeting attended by the company's occupational health department representative and production line employees, covering four types of workstations: cutting, turning, milling, and grinding.

3.1 Notations

All symbols used to represent the variables and parameters of the problem are listed below:

Sets

$\mathcal{T}^w$	Set of working days in the planning horizon
$\mathcal{I}$	Set of employees
$\mathcal{J}$	Set of jobs (workstations)
$\mathcal{P}$	Set of working periods $\mathcal{P} = \{1,2,3\}$

Parameters

S_{ij}	A binary value shows if employee i has the necessary skills for workstation j
h_j	The number of manpower required for workstation j
w_{ij}	The workload of station j from the perspective of employee i
$d_{jj'}$	The distance between workstations j and j'
Pr_{it}	A binary value indicates whether employee i prefers day t to be their rest day
m_{max}	The maximum number of rest days for each employee during the planning horizon
m_{min}	The minimum number of rest days for each employee during the planning horizon

Decision Variables

X_{ijtp}	Binary decision variable indicating the assignment of employee i to workstation j in period p on day t
A_{it}	Binary decision variable indicating day t is a working day for employee i
R_{it}	Average workload imposed on employee i on working day t
$Rmax_t$	The maximum difference between the average workload imposed on employees on working day t
F_{it}	Total distance travelled by employee i on day t during job rotation
$L_{ijj't}$	A binary decision variable indicating whether employee i is rotated from job j to job j' during the first period of working day t
φ_i	The number of rest days for employee i that differ from the requested rest days
φ_{it}^o	Auxiliary variables used to calculate φ_i $o \in \{+, -\}$

3.2 Mathematical formulation

This section outlines the objective functions and constraints. The first objective function focuses on balancing workload among employees by minimising the maximum daily difference in average workload, expressed as:

$Min Z_1 = \sum_{t \in \mathcal{T}^w} Rmax_t$ The second objective aims to reduce costs associated with production interruptions, specifically minimising total time lost during employee transfers between workstations. For simplicity, we assume uniform transfer speeds for all employees; thus, we use the distance between workstations instead of time.

$$Min Z_2 = \sum_{t \in \mathcal{T}^w} \sum_{i \in \mathcal{J}} F_{it}$$

The third goal is to minimise the discrepancy between the days off requested by employees and the days off they are granted. This objective function is expressed as follows:

$$Min Z_3 = \sum_{i \in \mathcal{J}} \varphi_i$$

The problem constraints are as follows:

Constraints (1-2) ensure that the minimum labour requirements for each workstation are met, taking into account holidays and rest days.

$$\sum_{i \in \mathcal{J}} X_{ijtp} \geq h_j \quad \forall j \in \mathcal{J}, p \in \mathcal{P}, t \in \mathcal{T}^w \quad (1)$$

$$\sum_{j \in \mathcal{J}} X_{ijtp} \leq A_{it} \quad \forall i \in \mathcal{J}, t \in \mathcal{T}^w, p \in \mathcal{P} \quad (2)$$

Constraint (3) considers the skill level in the assignment. Constraints (4-5) calculate the distance travelled by employee i due to the job rotation in period 1, considering that only the time of movement between the periods 1 and 2 reduces efficiency.

$$X_{ijtp} \leq S_{ij} \quad \forall i \in \mathcal{J}, j \in \mathcal{J}, p \in \mathcal{P}, t \in \mathcal{T}^w \quad (3)$$

$$(X_{ijt1} + X_{ij't2}) \leq L_{ijj't} + 1 \quad (j \neq j') \quad \forall i \in \mathcal{J}, j, j' \in \mathcal{J}, t \in \mathcal{T}^w \quad (4)$$

$$\sum_{j \in \mathcal{J}} \sum_{j' \in \mathcal{J} - \{j\}} d_{jj'} L_{ijj't} = F_{it} \quad \forall i \in \mathcal{J}, t \in \mathcal{T}^w \quad (5)$$

Constraint (6) calculates the average workload imposed on each employee during a working day. Constraint (7) determines the maximum difference between the average workload of the employees.

$$\sum_{j \in \mathcal{J}} \sum_{p \in \mathcal{P}} w_{ij} X_{ijtp} = 3R_{it} \quad \forall i \in \mathcal{J}, t \in \mathcal{T}^w \quad (6)$$

$$R_{it} - R_{i't} \leq Rmax_t \quad \forall i, i' \in \mathcal{J}, t \in \mathcal{T}^w \quad (7)$$

Constraint (8) ensures that the number of rest days for each employee is at most equal to the permitted number. Constraints (9-10) calculate the amount of discrepancy between the determined rest days and the requested ones. Constraint (11) indicates the range of decision variables.

$$m_{min} \leq \sum_{t \in \mathcal{T}^w} (1 - A_{it}) \leq m_{max} \quad \forall i \in \mathcal{J} \quad (8)$$

$$1 - A_{it} + \varphi_{it}^+ - \varphi_{it}^- = Pr_{it} \quad \forall i \in \mathcal{I}, t \in \mathcal{T}^w \quad (9)$$

$$\sum_{t \in \mathcal{T}^w} \varphi_{it}^- = \varphi_i \quad \forall i \in \mathcal{I} \quad (10)$$

$$X_{ijtp}, A_{it}, L_{ijj't} \in \{0,1\}, \quad \varphi_{it}^+, \varphi_{it}^-, \varphi_i, R_{it}, Rmax_t, F_{it} \geq 0 \quad \forall i \in \mathcal{I}, j, j' \in \mathcal{J}, p \in \mathcal{P}, t \in \mathcal{T}^w \quad (11)$$

We present a case study to demonstrate the performance of the proposed mathematical model, which is a mixed-integer linear programming formulation. The complexity of the mathematical model is NP-complete. To identify the optimal solution for the case study, we utilise IBM CPLEX. Two cases have been solved optimally in a reasonable time (less than 20 minutes).

4. Case study

This case study focuses on a section of the mechanical workshop within the central maintenance unit of a steel company. The workshop is organised into several sections, each tailored to the type of product being produced. The number and variety of machines, as well as the labour requirements, vary depending on the specific product. In the production sector, the primary focus is on manufacturing "rock-corroded shafts." This product is produced in a dedicated area due to its high demand and the specialised nature of its production process. The machines utilised in this production line include cutting, turning, milling, and grinding machines. The number of workers required for each workstation is determined by the nature of the tasks involved (Table 1).

Table 1. The number of workers required for each type of workstation

Workstation type	Number of machines	Workers required per workstation	Total workers required
Cutting	1	2	$2 \times 1 = 2$
Lathe	3	1	$1 \times 3 = 3$
Milling	2	1	$1 \times 2 = 2$
Grinding	3	1	$1 \times 3 = 3$

A total of eleven employees are assigned to this production line, with ten needed to be present each working day. This production unit operates six consecutive days a week, excluding official holidays, and the minimum number of workers must be on-site each day. The planning horizon for this model is established at two months, with the holiday schedule detailed in Table 2.

Table 2. Holidays during the two-month planning horizon

Day	Week							
	1	2	3	4	5	6	7	8
1			*					
2			*					*
3								
4								
5								
6	*							
7	*	*	*	*	*	*	*	*

Currently, employees in this unit work a single shift from $T_0 = 8:00$ to $T_4 = 16:00$. The work schedule for this production line is illustrated in Figure 2.

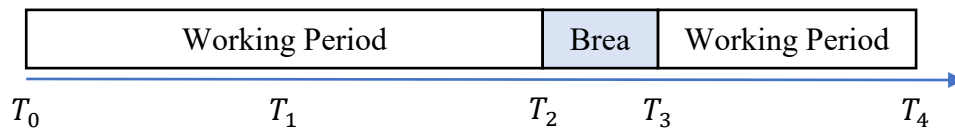


Fig. 2. Current hourly status of the production line

To implement the job rotation approach, we divide the first working period into two time segments: (T_0, T_1) and (T_1, T_2) . This division creates three equal-length work periods each day. If job rotation for an employee occurs at T_0 or T_2 , it can be executed during non-productive time, thereby not interrupting the production line. However, if rotation occurs at T_1 , it will result in a production interruption. The duration of this interruption will depend on the distance between the two workstations. The distances between workstations are outlined in Table 3, calculated based on the minimum distance between each pair of stations.

Table 3. Distance between workstations (m)

	Cutting	Lathing1	Lathing2	Lathing3	Milling1	Milling2	Grinding1	Grinding2	Grinding3
Cutting		20	22	25	86	93	106	96	151
Lathing 1	20		10	15	82	72	72	90	138
Lathing 2	22	10		25	93	82	86	98	146
Lathing 3	25	15	25		69	62	72	106	151
Milling 1	86	82	93	69		5	34	30	56
Milling 2	93	72	82	62	5		29	29	64
Grinding 1	106	72	86	72	34	29		65	10
Grinding 2	96	90	98	106	30	29	65		55
Grinding 3	151	138	146	151	56	64	10	55	

One of the primary objectives of workload adjustment is to enhance employee satisfaction. An individual's perception of workload at each station can be influenced by various factors, including prior experiences, knowledge, skills, physical strength, and other relevant indicators. The distribution of tasks across different stations is crucial in this context. To assess employees' perceptions of workload, we utilised the standard questionnaire based on NASA's Workload Index. It's important to note that, according to the assumptions, similar workstations (e.g., two milling stations) share comparable task characteristics.

Implementing a job rotation approach requires aligning the skills necessary for each workstation with the employees' capabilities. To gather relevant information, we conducted interviews with employees, accompanied by the unit supervisor, to validate their responses. This process considers employees' education, expertise, and experience, and performance evaluation scores from the past two years, assessed through skill checklists. Skill status is represented as a binary variable (Inadequate talent (1)/insufficient skill (0)) and can be further developed to reflect various skill levels. Employees can transition between stations only if

they possess the necessary skills for those positions. Furthermore, employees stationed at one workstation may not possess the same skills as others. The NASA Workload Index measurement questionnaire is designed along a qualitative spectrum, quantifying workload from very low (1) to very high (9). It is essential to examine and interpret the workload employees experience under current conditions. The acceptable level of workload, which is the level at which a worker can perform a task without experiencing excessive stress, burnout, and decreased performance, varies depending on the individual, job, and industry ([Braarud, 2020](#)). Here, scores below five (average and below) indicate acceptable workload levels.

The collected data on employees' current positions, associated mental workload, employees' perceptions of workload and capabilities for different workstations are detailed in Table 4. This table provides insights into employees' current roles and their competencies for other positions.

Table 4. Current workload information and skill status of employees

Employee	Current information		Cutting		Lathing		Milling		Grinding	
	Current	Workload	Workload	Skill	Workload	Skill	Workload	Skill	Workload	Skill
1	Cutting	5 *	5	1	8	0	3	1	5	0
2	Cutting	6 *	6	1	6	0	3	1	4	1
3	Lathing	6 *	2	1	6	1	6	0	5	0
4	Lathing	6 *	4	0	6	1	4	1	8	0
5	Lathing	6 *	3	1	6	1	6	0	4	0
6	Milling	6 *	4	0	5	0	6	1	3	1
7	Milling	5 *	4	0	3	1	5	1	7	0
8	Grinding	5 *	3	1	7	0	5	0	5	1
9	Grinding	6 *	5	0	4	1	7	0	6	1
10	Grinding	7 *	3	1	4	1	6	0	7	1
11	Cutting	5 *	5	1	4	1	5	1	6	0

(*) Unacceptable workload levels

Based on the information in Table 4, it is clear that most employees on this production line are experiencing unfavourable workload conditions. A closer examination indicates that many employees are at a disadvantage in terms of their workload, which may contribute to their dissatisfaction with the work environment. Additionally, it identifies alternative job positions that meet the necessary skill requirements while offering a more favourable workload. By transferring employees between these workstations, taking their skill levels into account, it may be possible to improve working conditions and enhance overall job satisfaction through better workload distribution.

In the next section, we will examine the job rotation approach based on the proposed model and evaluate its effectiveness in adjusting workloads and improving the current situation.

5. Results

The priorities of the three objectives for the studied case have been evaluated as follows:

First priority: Adjusting the workload among employees.

Second priority: Minimising the distance travelled by employees during job rotation.

Third priority: Reducing the discrepancy between the days off requested by employees and the leave allocated to them.

The optimal solution derived from the model using a single objective function indicates a conflict among the objectives. Table 5 presents the Pareto optimal solutions obtained through the Epsilon Constraint method. The first three rows of Table 5 display the absolute optimal solutions for each of the three objective functions.

Table 5. Pareto optimal solutions of the case study

Pareto Solution	Objective #1	Objective #2	Objective #3
1	437.00*	14739.00	45.00
2	566.67	0.00*	39.00
3	567.00	20945.00	2.00*
4	447.00	0.00*	2.00*
5	437.67	0.00*	22.00
6	437.67	0.00*	39.00
7	436.67	13461.00	19.00
8	445.67	11775.00	44.00

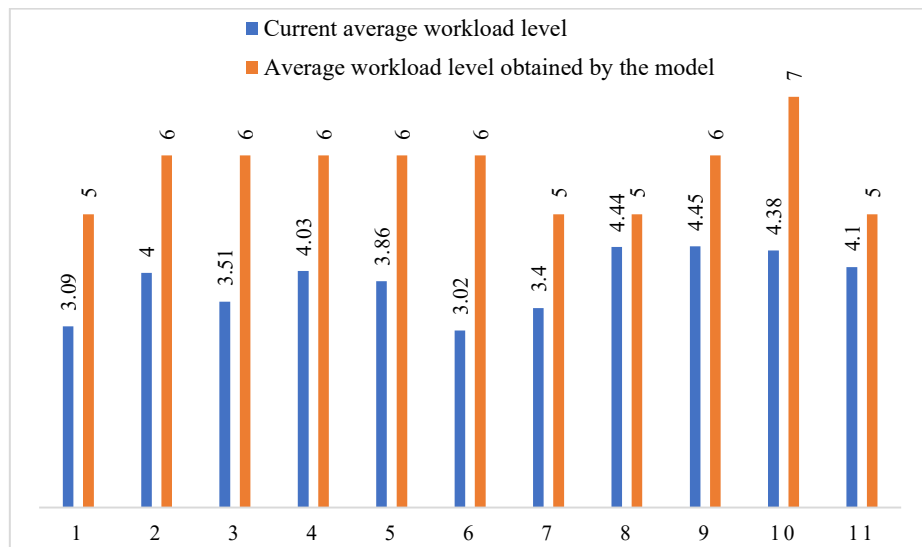
Among these solutions, Pareto solution number 5 is preferred based on the priority of the objectives by the supervisor. A comparison with the solution derived by optimising only the first objective function reveals a significant improvement in the second and third objectives, with the first objective experiencing a minor decline of less than 0.2%. The results in Table 5 show the conflict between objectives. The first objective function, balancing the workload of employees, is achieved with job rotation (moving employees between workstations). This objective increases the rotations, which in turn may increase the possibility of production interruptions and worsen the second objective value. Besides, on the other hand, since applying rest day preferences can interfere with achieving optimal workload balance, the first and third objective functions may not be optimised simultaneously.

Table 6 outlines the main decision variables for each employee, highlighting changes in workload compared to the pre-job rotation scenario, for both single-objective (first objective) and multi-objective modes.

Table 6. Specifications of the desired solution

Employee	Average workload (Before)	Average workload (Single objective)	Average workload (Multi-objective)	Days off discrepancies (Single objective)	Days off discrepancies (Multi-objective)	Distance travelled (Single objective)	Distance travelled (Multi-objective)
1	5	3.27	3.30	5	2	1244	0
2	6	4.00	4.00	2	2	1105	0
3	6	3.51	3.39	4	2	653	0
4	6	4.03	4.13	5	1	311	0
5	6	3.86	3.58	5	2	556	0
6	6	3.02	3.00	1	0	1255	0
7	5	3.40	3.44	5	3	1847	0
8	5	4.44	4.45	5	2	2532	0
9	6	4.45	4.57	4	2	1456	0
10	7	4.38	4.41	3	3	2918	0
11	5	4.10	4.13	5	3	1224	0

Figure 3 compares the current and optimal average workloads for all the employees. Furthermore, Figure 3 demonstrates the changes in average workload resulting from the implementation of the single-objective model in the studied production unit compared to the current state, which indicates a 32.3% improvement in workload.

**Fig. 3. Workloads for the current situation and the optimal single objective model**

The collected workload data depends on the abilities, differences, and perceptions of employees. However, since the percentage of workload improvement is calculated from the difference in workloads reported by the employee, the effect of individual differences in this indicator is neutralised.

5.1 Sensitivity analysis

In this section, we conduct a sensitivity analysis using an example involving 4 workstations, 8 workers, and a 16-day planning horizon. Based on the research assumptions, each working day is divided into three sections. Employees can be transferred between these

sections, but only transfers between the first and second sections halt production, leading to waste. Each employee is allowed a maximum of two days off during the planning horizon, contingent on maintaining the minimum required workforce each day. Additional details are provided in Tables A1 and A2. The optimal solutions obtained using the weighted sum method are shown in Table A3 and Figure 4. The objective function is defined as a weighted sum of objectives in the Weighted sum method.

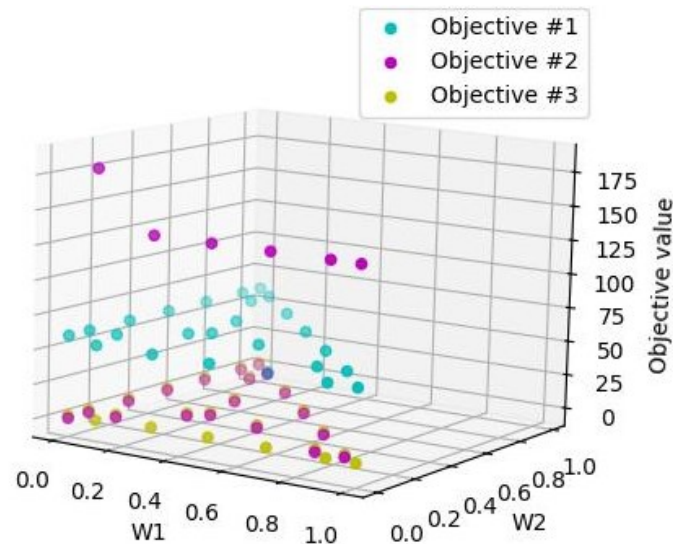


Fig. 4. Optimal solutions obtained by the weighted sum method

The details of the optimal solutions to the single-objective case for all three objectives are given in Tables 7, 8, and 9. The tables show the job that each employee in a shift is assigned to. For example, employee 3 on day 1 is off (rest day) and is assigned to workstation 4 on the first shift of day 2 and workstation 3 on the second and third shifts of day 2.

Table 7. Optimal employee-job assignment for single objective model (objective 1)

Day	Employees							
	1	2	3	4	5	6	7	8
1	(3,3,3)	(4,4,4)	off	(4,4,4)	(1,2,2)	(1,1,1)	(3,3,3)	(2,1,1)
2	(3,3,3)	(4,4,4)	(4,3,3)	(14,4)	(2,1,1)	off	(3,1,1)	(1,2,2)
3	off	(4,4,4)	(3,3,3)	(4,4,4)	(1,2,2)	(1,1,1)	(3,3,3)	(2,1,1)
4	(3,3,3)	(4,4,4)	(4,4,4)	(1,1,1)	off	(1,1,1)	(3,3,3)	(2,2,2)
5	(3,3,3)	(4,4,4)	off	(4,4,4)	(2,1,1)	(1,1,1)	(3,3,3)	(1,2,2)
6	(4,3,3)	(4,4,4)	(3,4,4)	off	(1,2,2)	(1,1,1)	(3,3,3)	(2,1,1)
7	(3,3,3)	(4,4,4)	(4,4,4)	(1,1,1)	(2,2,2)	(1,1,1)	(3,3,3)	off
8	(3,3,3)	(4,4,4)	(4,4,4)	(1,1,1)	(1,2,2)	off	(3,3,3)	(2,1,1)
9	(3,3,3)	(4,4,4)	(4,4,4)	(1,1,1)	off	(1,1,1)	(3,3,3)	(2,2,2)
10	(3,3,3)	(4,4,4)	(4,4,4)	(1,1,1)	(2,2,2)	(1,1,1)	(3,3,3)	off
11	(3,3,3)	(4,4,4)	(3,4,4)	(4,4,4)	(1,2,2)	(1,1,1)	(4,3,3)	(2,1,1)
12	off	(4,4,4)	(3,3,3)	(4,4,4)	(1,2,2)	(1,1,1)	(3,3,3)	(2,1,1)
13	(3,3,3)	(4,4,4)	(3,3,3)	(4,4,4)	(1,2,2)	(1,1,1)	off	(2,1,1)
14	(3,3,3)	off	(4,4,4)	(4,4,4)	(1,2,2)	(1,1,1)	(3,3,3)	(2,1,1)
15	(3,3,3)	(4,4,4)	(3,3,3)	(4,4,4)	(2,1,1)	(1,1,1)	off	(1,2,2)
16	(3,4,4)	off	(3,3,3)	(4,4,4)	(2,1,1)	(1,1,1)	(4,3,3)	(1,2,2)

Table 8. Optimal employee-job assignment for single objective model (objective 2)

Day	Employees							
	1	2	3	4	5	6	7	8
1	(4,4,4)	(1,1,1)	(3,3,3)	(3,3,3)	(1,1,1)	(4,4,4)	off	(2,2,2)
2	(4,4,4)	(1,1,1)	off	(3,3,3)	(2,2,2)	(4,4,4)	(3,3,3)	(1,1,1)
3	(3,3,3)	(2,2,2)	off	(1,1,1)	(1,1,1)	(4,4,4)	(4,4,4)	(3,3,3)
4	(1,1,1)	(4,4,4)	(3,3,3)	off	(1,1,1)	(4,4,4)	(3,3,3)	(2,2,2)
5	(3,3,3)	(1,1,1)	(2,2,2)	(4,4,4)	off	(4,4,4)	(3,3,3)	(1,1,1)
6	off	(1,1,1)	(2,2,2)	(4,4,4)	(3,3,3)	(4,4,4)	(1,1,1)	(1,1,1)
7	(3,3,3)	(4,4,4)	(4,4,4)	(3,3,3)	(2,2,2)	(1,1,1)	off	(1,1,1)
8	(3,3,3)	(1,1,1)	(3,3,3)	(4,4,4)	off	(4,4,4)	(3,3,3)	(2,2,2)
9	(1,1,1)	off	(3,3,3)	(4,4,4)	(3,3,3)	(1,1,1)	(4,4,4)	(2,2,2)
10	(3,3,3)	(4,4,4)	(3,3,3)	(1,1,1)	(2,2,2)	off	(4,4,4)	(1,1,1)
11	(3,3,3)	(1,1,1)	(4,4,4)	(3,3,3)	(2,2,2)	(4,4,4)	(1,1,1)	off
12	(3,3,3)	(4,4,4)	(2,2,2)	(4,4,4)	(1,1,1)	off	(1,1,1)	(3,3,3)
13	(3,3,3)	(2,2,2)	(4,4,4)	(3,3,3)	(1,1,1)	(4,4,4)	(1,1,1)	off
14	(3,3,3)	(2,2,2)	(4,4,4)	off	(1,1,1)	(4,4,4)	(3,3,3)	(1,1,1)
15	off	(1,1,1)	(2,2,2)	(4,4,4)	(1,1,1)	(4,4,4)	(3,3,3)	(3,3,3)
16	(1,1,1)	off	(3,3,3)	(1,1,1)	(2,2,2)	(4,4,4)	(4,4,4)	(3,3,3)

Table 9. Optimal employee-job assignment for single objective model (objective 3)

Day	Employees							
	1	2	3	4	5	6	7	8
1	(1,3,3)	(2,2,2)	(4,4,4)	(3,1,1)	(1,1,1)	(4,4,4)	(3,3,3)	off
2	(3,3,3)	(4,1,1)	(4,4,4)	off	(1,1,1)	(1,4,4)	(3,3,3)	(2,2,2)
3	off	(4,2,2)	(2,4,4)	(3,1,1)	(3,3,3)	(1,1,1)	(4,4,4)	(1,3,3)
4	(3,3,3)	off	(4,2,2)	(1,4,4)	(3,3,3)	(1,1,1)	(4,4,4)	(2,1,1)
5	(3,1,1)	(4,4,4)	(4,3,3)	(1,4,4)	(3,3,3)	(1,1,1)	off	(2,2,2)
6	(3,3,3)	(4,4,4)	(2,4,4)	(1,1,1)	(3,2,2)	(1,1,1)	(4,3,3)	off
7	(3,3,3)	off	(4,4,4)	(4,4,4)	(2,2,2)	(1,1,1)	(3,1,1)	(1,3,3)
8	(3,3,3)	(2,2,2)	off	(4,4,4)	(1,1,1)	(4,4,4)	(1,1,1)	(3,3,3)
9	(3,1,1)	(2,4,4)	(4,2,2)	(4,3,3)	(3,1,1)	off	(1,4,4)	(1,3,3)
10	(3,3,3)	(2,1,1)	(3,2,2)	(4,4,4)	(2,2,2)	(1,4,4)	(4,3,3)	(1,1,1)
11	(3,1,1)	(4,4,4)	(2,2,2)	(1,4,4)	(1,3,3)	off	(4,1,1)	(3,3,3)
12	(4,3,3)	(4,4,4)	off	(4,3,3)	(3,2,2)	(1,1,1)	(1,4,4)	(2,1,1)
13	(3,1,1)	(1,4,4)	(4,4,4)	off	(2,3,3)	(1,1,1)	(3,3,3)	(3,2,2)
14	(3,3,3)	(4,4,4)	(3,2,2)	(1,1,1)	off	(1,1,1)	(4,4,4)	(2,3,3)
15	off	(4,4,4)	(2,4,4)	(1,1,1)	(3,2,2)	(1,1,1)	(4,3,3)	(3,3,3)
16	(1,1,1)	(4,4,4)	(3,3,3)	(4,4,4)	(2,2,2)	(1,1,1)	off	(3,3,3)

The job rotation suggested by the model for employee number 8 is shown in Figure 5. Each box has four parts corresponding to four different workstations. Job rotation has been performed on all days except days 4 and 9. The employee has not been assigned to workstation 4 due to the skill limitation (Table A1). The rest days for Employee 8 are days 7 and 10. Given that the corresponding single-objective model does not minimise production interruptions, job rotations were all scheduled between shifts 1 and 2, which all resulted in production interruption.

The solutions were derived by optimising the model based on a single objective function, illustrating the inherent conflicts among the objectives. Based on the supervisors' opinion, the solution corresponding to numbers 19 to 25 from Table A3 was recognised to be preferred. Detailed information regarding this solution is presented in Table 10.

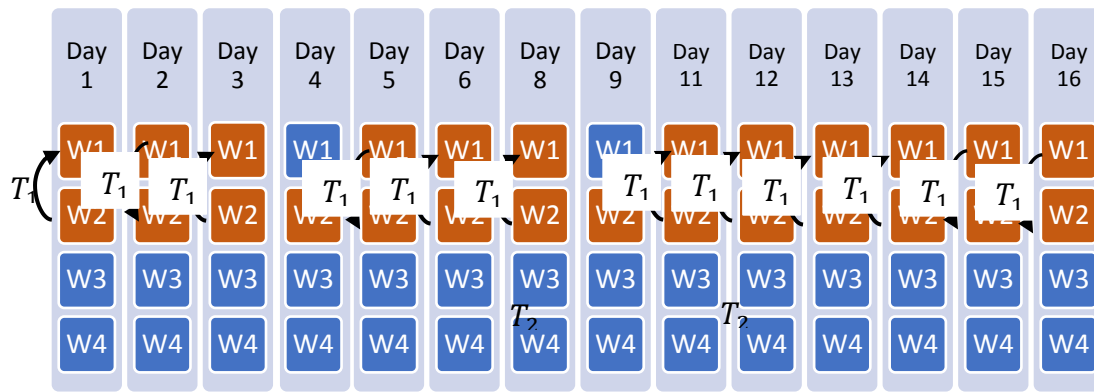


Fig. 5. Job rotation plan for employee 3

Table 10. Specifications of the desired solution

Employee	Average workload (Before)	Average workload (Multi-objective)	Days off discrepancies (Multi-objective)	Costly distance travelled (Multi-objective)	Average daily shift changes (Multi-objective)
1	9	3.00	0	0	0.86
2	8	3.00	0	0	1.07
3	7	3.00	0	0	1.43
4	7	2.57	0	0	1.43
5	8	3.36	0	0	1.43
6	8	3.00	0	0	0.86
7	7	2.00	0	0	1.14
8	9	3.50	0	0	1.36

Figure 6 shows a comparison between the average workload in the current situation and after implementing the results obtained from the multi-objective model, which shows a 59.7% improvement in workload.

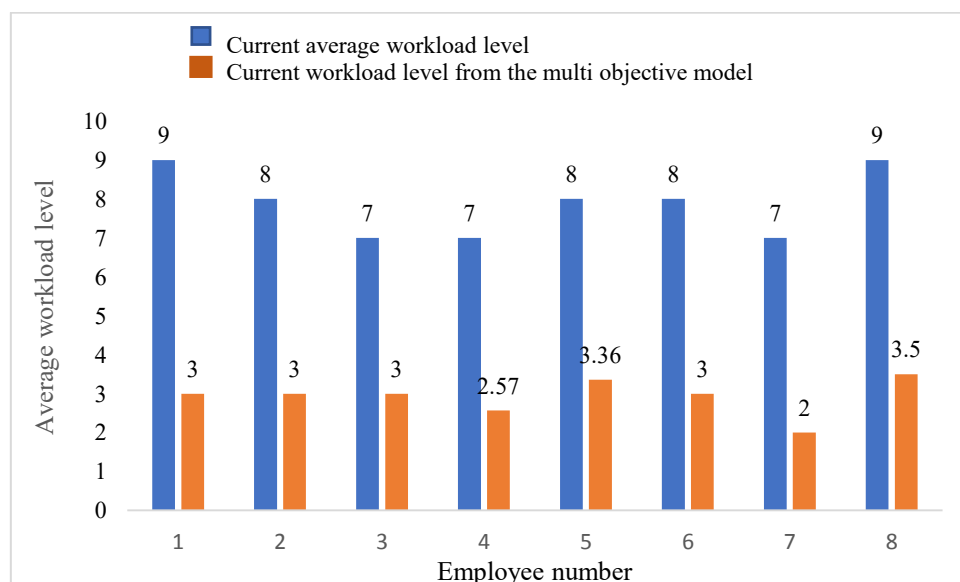


Fig. 6. Comparison of the current situation and the multi-objective model

To assess the results' sensitivity to changes in the employees' current skill levels, we compare scenarios where full-skilled employees constitute 25%, 50%, 75%, and 100% of the total workforce. The resulting changes in the objective function values are analysed, and two

efficient solutions corresponding to two different objective weights for each scenario are presented in Table 11. In the weights' column, #1 and #2 correspond to objective weights (0.5, 0, 0.5) and (0.25, 0.5, 0.25), respectively.

Table 11. Sensitivity analysis on employees' skills

		Weights	Objective #1	Objective #2	Objective #3	Total rotations	Average workload
Full-skill employee percentage	Current situation	#1	56	140	4	167	3.389
		#2	60	000	2	133	2.973
	25%	#1	56	140	2	159	3.366
		#2	60	000	2	135	2.964
	50%	#1	56	120	2	146	3.360
		#2	60	000	2	140	2.955
	75%	#1	56	120	2	143	3.340
		#2	60	000	2	141	2.946
	100%	#1	56	120	2	143	3.336
		#2	60	000	2	146	2.901

The results for case #1 show an improvement in the third objective function because by increasing the number of skilled employees and using appropriate job rotation, the goal of reducing the variance in requested vacation days can be largely achieved. The last two columns show that the number of job rotations and the average workload have decreased. On the other hand, the objective values for cases #2 remain constant as the third objective cannot be improved anymore by increasing the skill level of employees, although the solutions may improve in terms of metrics such as total rotation and average workload.

Moreover, a sensitivity analysis is performed on the dispersion of the number of employees required for each type of workstation for objective weights (0.5, 0, 0.5). The results are illustrated in Table 12.

Table 12. Effect of the number of employees dispersion

Employee required	Objective #1	Objective #2	Objective #3	Total rotations	Average workload
(2,1,2,2)	56	140	4	167	3.389
(3,1,1,2)	61	140	2	151	3.51
(4,1,1,1)	64	57	2	125	3.90

The results show that although the total number of workers required is intact, as the dispersion of required employees across stations increases, the average workload increases due to the reduced possibility of job rotation, which subsequently reduces the average cost travelled distance.

6. Discussion and conclusions

Maintaining employees as the primary asset of an organisation is crucial. Research indicates that employee satisfaction with their roles and work environment significantly influences their desire to remain with the organisation. Key factors affecting employee satisfaction include job fit, perceived fairness in the workplace, and the level of workload exposure, defined as the amount of work an individual must complete within a specific timeframe. Although different factors, such as cultural differences, affect how people perceive job justice, which in turn impacts job satisfaction ([Slocum & Topichak, 1972](#); [Imonikhe & Lukic, 2022](#)), we focus on job rotation as a factor that can improve job satisfaction.

To address workload challenges and improve job fit, a task rotation strategy can be employed. We developed a multi-objective mathematical model for work rotation scheduling aimed at balancing workload among employees, minimising production line downtime due to turnover, and reducing discrepancies between requested and granted leave days. Since the mathematical model is of type MILP, it is necessary to use more efficient methods such as heuristic or meta-heuristic algorithms to solve larger-scale instances of the problem.

To demonstrate the model's effectiveness, a case study was conducted in the mechanical workshop of the maintenance and repair unit of a steel production company. The results indicated that implementing this model not only adjusted and reduced employee workload but also enhanced satisfaction by aligning rest day allocations with employee requests. Additionally, the model accounted for the costs associated with its implementation, such as travel costs, while simultaneously increasing the variety of tasks assigned to employees, thereby reducing job monotony.

The outcomes of the single-objective implementation of this model confirmed its capability to lower the average workload for employees. However, a more detailed analysis revealed that this reduction sometimes resulted in production interruptions due to employee transfers between workstations. Moreover, the model did not adequately address the alignment of employees' requested leave days with granted leave, leading to significant discrepancies (an ongoing challenge for the organisation). While achieving perfect alignment of leave requests and allocations is impractical, given the necessity of maintaining a minimum workforce, enhancing this alignment as a third objective of the model notably improved the overall solution quality. Comparisons between the three-objective and single-objective implementations demonstrated that the multi-objective approach maintained optimal workload levels, reduced wasted time to zero, and significantly improved the match between allocated and requested leave days.

These findings underscore the model's effectiveness in balancing workload among employees. Therefore, it can be applied not only within the studied company but also in

similar organisations facing challenges related to work difficulty and employee workload imbalance. By adapting the model to address specific organisational needs, other detrimental workplace factors, such as noise levels, can also be mitigated.

While the job rotation approach has traditionally conflicted with production efficiency goals, neglecting ergonomic considerations jeopardises employee health and well-being, leading to physical and mental health issues. This model's focus on aligning employee leave requests with actual allocations can help alleviate problems associated with job changes and mismatched leave days. Moreover, sensitivity analysis results indicated that as employees develop their skill levels and become multi-skilled, workload adjustment becomes more effective. Thus, investing time and resources in skill development and multi-skilling, combined with the implementation of this model, can positively impact ergonomic conditions in the workplace, ultimately enhancing employee satisfaction and loyalty in alignment with the objectives of Industry 5.

There are various challenges to implementing a job rotation program, such as resistance to change, increased training costs, and potential disruptions to productivity. Moreover, in practice, middle managers are often resistant to change, so job rotation is not welcomed by middle managers for reasons including work disruption, reduced productivity, and higher workload (Daley & Lovrich, 2007; Wang et al., 2024).

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Appendix

The information related to the first example discussed in the sensitivity analysis is provided in the following tables. Table A1 outlines employees' current workstations, their preferred rest days, the mental workload of each workstation from the employees' perspectives, and their skill levels for each station.

Table A1. Employee perspectives on workstation workload

Employee	current workstation	Preferred rest days	Station #1		Station #2		Station #3		Station #4	
			workload	skill	workload	skill	workload	skill	workload	skill
1	1	3, 15	9	1	4	0	3	1	4	1
2	1	4, 7	8	1	4	1	5	0	3	1
3	2	8, 12	5	0	7	1	3	1	3	1
4	3	1, 2	2	1	7	0	7	1	3	1
5	3	10, 14	4	1	3	1	8	1	8	0
6	4	9, 11	3	1	3	0	3	0	8	1
7	4	2, 5	4	1	3	0	2	1	7	1
8	3	1, 6	4	1	3	1	9	1	9	0

The required number of employees for each workstation and the distances between workstations are summarised in Table A2.

Table A2. Workstation requirements and distance

	Distance				Required workforce
	Workstation #1	Workstation #2	Workstation #3	Workstation #4	
Workstation #1	0	5	7	4	2
Workstation #2	5	0	8	15	1
Workstation #3	7	8	0	10	2
Workstation #4	4	15	10	0	2

All the solutions obtained by the weighted sum method are summarised in Table A3.

Table A3. Optimal solutions

Optimal Solution	Weights	Objective #1	Objective #2	Objective #3	Execution time (seconds)
1	(1,0,0)	56*	140	4	1000.255
2	(0,1,0)	60	0*	2	1000.102
3	(0,0,1)	60	0	2*	1000.110
4	(0.9,0.1,0)	60	0*	2	1000.514
5	(0.7,0.3,0)	60	0*	2	1000.359
6	(0.5,0.5,0)	60	0*	2	1000.352
7	(0.3,0.7,0)	60	0*	2	1000.360
8	(0.1,0.9,0)	60	0*	2	1001.015
9	(0.9,0,0.1)	56	140	4	1000.284
10	(0.7,0,0.3)	56	140	4	1000.241
11	(0.5,0,0.5)	56	140	4	1000.286
12	(0.3,0,0.7)	56	140	4	1000.373
13	(0.1,0,0.9)	56	182	2	7.198
14	(0, 0.9,0.1)	60	0	2	0.200

Optimal Solution	Weights	Objective #1	Objective #2	Objective #3	Execution time (seconds)
15	(0,0.7,0.3)	60	0	2	0.700
16	(0,0.5,0.5)	60	0	2	0.700
17	(0,0.3,0.7)	60	0	2	0.700
18	(0,0.1,0.9)	60	0	2	0.700
19	(0.8,0.1,0.1)	60	0	2	1000.434
20	(0.5,0.25,0.25)	60	0	2	1000.335
21	(0.33,0.33,0.33)	60	0	2	1000.397
22	(0.1,0.8,0.1)	60	0	2	1000.315
23	(0.25,0.5,0.25)	60	0	2	1000.385
24	(0.1,0.1,0.8)	60	0	2	192.920
25	(0.25,0.25,0.5)	60	0	2	1000.251