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RESILIENCE OF TECHNICIAN ALLOCATION IN MULTI-AGENT SIMULATIONS

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Abstract
As industrial and service systems become more complex, effectively scheduling technicians to boost system resilience is crucial. Traditional scheduling methods often prioritize efficiency but lack adaptability in dynamic environments, highlighting the need for multi-objective optimization. Multi-agent simulation offers a novel approach to enhance the resilience of technician allocation by simulating dynamic collaborations and task distributions more accurately. This method optimizes scheduling strategies and improves adaptability and emergency response capabilities in uncertain conditions. Current methods fall short in managing unexpected events and coordinating multiple tasks. To overcome these limitations, a new technician allocation model using a multi-agent simulation framework has been developed, integrating advanced scheduling optimization techniques to enhance resilience. This approach, supported by a multi-objective optimization algorithm, improves the efficiency, stability, and adaptability of technician scheduling, thereby strengthening system resilience.

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Key Words: Technician Scheduling, Allocation Resilience, Multi-Agent Simulation, Scheduling Optimization, System Robustness, Multi-Objective Optimization

1. INTRODUCTION

With the rapid advancement of technology and the continuous progress of society, modern society has put forward higher requirements for efficient and flexible technician allocation and scheduling [1-3]. Particularly in complex working environments and under dynamically changing task demands, the scientific and rational allocation of technicians to ensure system stability and resilience in unexpected situations has become a critical issue in the field of technical management [4-7]. In the context of the multi-agent system (MAS), how to improve the anti-interference and adaptability of the system through reasonable technician allocation and scheduling has become an important direction for improving work efficiency and ensuring system reliability.

Multi-agent simulation technology offers a novel approach to addressing this challenge. By simulating interactions and coordination among multiple agents, more effective exploration and optimization of technician allocation and scheduling strategies can be achieved [8-10]. Proper allocation not only improves personnel utilization and operational efficiency but also maintains system flexibility and stability in complex and uncertain environments [11-13]. Therefore, investigating how to optimize technician allocation based on actual task requirements and personnel characteristics within multi-agent environments and further enhancing the resilience of such allocations holds significant theoretical and practical importance.

Current research in this domain has predominantly focused on static models for personnel allocation and scheduling, with most models assuming that technician behaviour within the system is entirely predictable and controllable [14-18]. However, in real-world working environments, factors such as fluctuating task demands, variations in personnel capabilities, and the impact of unexpected events often render these static models inadequate for addressing complex scenarios. Existing methodologies exhibit significant limitations in dynamic scheduling and resilience assessment, frequently overlooking environmental

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uncertainties and the interactive effects among personnel. Additionally, insufficient attention has been given to leveraging system feedback mechanisms to enhance allocation resilience.

This study addresses the challenges of technician allocation and scheduling in multi-agent simulation environments by proposing a dynamic allocation model based on simulation technology and enhancing allocation resilience through an optimization algorithm. The research focuses on two key aspects: first, developing a technician allocation model to better capture interactions between personnel scheduling and the working environment; and second, designing an optimization algorithm to improve flexibility, ensuring stable and efficient operations under uncertainties. This study not only provides new theoretical support for technician scheduling but also offers practical solutions for personnel allocation in real-world production and management, with significant application value.

2. CONSTRUCTION OF THE TECHNICIAN SCHEDULING MODEL IN MULTI-AGENT SIMULATION

2.1 Assumptions

To ensure the operability and practicality of the technician allocation and scheduling model within a multi-agent simulation framework and to provide a reasonable framework for resilience assessment, the following assumptions were proposed in this study. First, it is assumed that unexpected events such as system failures, human errors, and equipment malfunctions during maintenance are not considered in the initial model construction. This simplification allows the research to focus on the resilience assessment of technician allocation and scheduling itself, without the added complexity of external disruptive factors. Furthermore, it is assumed that technicians cannot be replaced mid-task during maintenance operations, and each task must be completed independently by a single technician. Additionally, a task can only commence after the preceding task has been completed. This assumption ensures the sequential nature of tasks and the single-task focus of technicians, facilitating a clear simulation of the dynamics of technician scheduling and providing a reasonable basis for subsequent scheduling optimization.

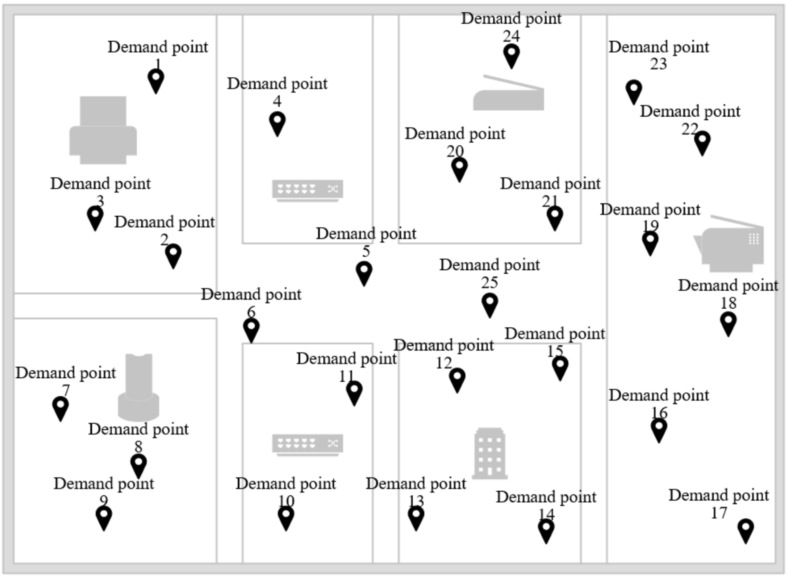

Figure 1: Distribution of technician scheduling demand points in multi-agent simulation.

Fig. 1 illustrates the distribution of technician scheduling demand points established for the multi-agent simulation in this study.

2.2 Model parameters and decision variables

The parameters and decision variables of the model together form the basis for model evaluation and optimization. This study assumes that the device set $U = \{1, 2, ..., UL\}$ represents the devices participating in maintenance, and UL is the number of devices. In addition, the technician set $H = \{1, 2, ..., HL\}$ represents all the technicians involved in maintenance, and HL is the number of personnel. For each device u, the job set $K_u = \{1, 2, ..., KL\}$ represents all jobs on device u, and KL is the number of jobs on that device. The parameters of these devices and jobs collectively define the scope and complexity of the entire maintenance task. In addition, the time discretization set $F = \{1, 2, ..., FL\}$ and the time node f were used to divide the time sequence of job execution, where FL is the total serial execution time of all jobs. The standard job time set $S = [s_1, s_2, s_3, ..., s_{KL}]$ represents the standard execution time of each job as the benchmark for the job plan. The workload balancing AV and cumulative transfer time MO of technicians are important indicators for evaluating model efficiency and resilience. The former measures whether the workload of technicians is uniform, while the latter is used to evaluate the time waste caused by transfer work.

The key decision variables in the model include A_{ukf}, B_{ukrd}, C_{hf}, and E_{ukrd}, which are used to describe the specific situations of job execution and personnel scheduling. The decision variable A_{ukf} is used to indicate whether the k^{th} job P_{uk} of device u is being executed at a discrete time point f. If it is being executed, $A_{ukf} = 1$; otherwise, it is 0. B_{ukrd} is used to describe whether there is technician h executing the k^{th} job P_{uk} of device u at time f, and whether this task is continuous with the d^{th} task P_{rd} of device r. If so, $B_{ukrd} = 1$; otherwise, it is 0. C_{hf} is used to indicate whether technician h is in a transition state at time point f. If it is a transition, $C_{hf} = 1$; otherwise, it is 0. Finally, E_{ukrd} describes whether jobs P_{uk} and P_{rd} are assigned to the same technician and whether job P_{uk} is executed before job P_{rd}. If so, it is 1; otherwise, it is 0.

2.3 Objective function

In multi-agent simulation for resilience assessment of technician allocation, the objective function setting of the technician allocation and scheduling model should fully consider improving the robustness and adaptability of the system in dynamically changing environments. Firstly, minimizing the maintenance completion time TI of the device group is one of the core optimization objectives. The rapid maintenance and repair of the device group is directly related to the probability of quickly putting the devices into use after failure, which in turn affects the stability and continuous operation capability of the production system. In multi-agent simulation, the technician allocation and job scheduling directly affect the efficiency of equipment maintenance. By arranging the tasks and work sequence of technicians reasonably, the repair progress of equipment can be accelerated, maintenance time can be shortened, and the efficiency of equipment fault recovery can be improved. Assuming that the latest maintenance completion time in the device group is represented by $MAX_{u \in U} Z_u$, the corresponding target value calculation method is as follows:

$$MIN(TI) = \underset{u \in U}{MAX}\, Z_u \tag{1}$$

Minimizing the load balancing of technicians is another key goal, reflecting the rationality of task allocation and the balance of technician workload. Equipment maintenance tasks are usually carried out jointly by multiple technicians. If some technicians have a heavy workload while others are idle, it not only reduces the efficiency of the entire team, but may also lead to excessive fatigue or low efficiency. Therefore, this study takes the work time difference AV of technicians as one of the optimization objectives, aiming to balance the workload of technicians. The smaller the target value, the more balanced the distribution of work time among various technicians, and the more reasonable the load distribution. This can effectively improve the work efficiency of technicians and the overall stability of task completion, thereby enhancing the resilience of the system to respond to emergencies and environmental changes. The corresponding target value calculation method is as follows:

$$MIN(AV) = \sqrt{\frac{\sum_{h=1}^{HL}\left(yN_h - \overline{yN}\right)^2}{HL}} \tag{2}$$

The calculation method for the working hours of technician h is as follows:

$$yN_h = \sum_{u=1}^{UL}\sum_{k=1}^{KL}\sum_{f=1}^{FL} B_{ukhf} \tag{3}$$

The calculation method for the average working time of technicians is as follows:

$$\overline{yN} = \frac{\sum_{h=1}^{HL} yN_h}{HL} \tag{4}$$

Minimizing the cumulative transfer time *MO* of technicians is another important objective in optimizing the model. Frequent movement of technicians between different work locations can increase additional time consumption and may cause interference with equipment transportation, reducing system operational efficiency. Therefore, in order to reduce the frequency of technicians' movements and improve the overall efficiency and stability of operations, this study introduces a minimization term for the cumulative transfer time of technicians. By optimizing the scheduling and task allocation of technicians and minimizing ineffective transfer time, it not only helps to improve the efficiency of maintenance operations but also avoids work dispersion and fatigue accumulation caused by frequent movement of technicians, further enhancing the operational resilience of the system. The target value calculation method is as follows:

$$MIN(MO) = \sum_{f=1}^{FL}\sum_{h=1}^{HL} C_{hf} \tag{5}$$

2.4 Constraints

Among the constraints of the model, the temporal constraint of the maintenance process is one of the most fundamental and important constraints. The timing of equipment entry maintenance is influenced by equipment requirements and task priorities; therefore, the entry time of each device must meet the completion order of previous tasks. This constraint is reflected by ensuring that the device must complete the preceding task before proceeding to the next task. In addition, the serial parallel constraints of tasks in the maintenance process cannot be ignored. Some tasks may be executed sequentially, and subsequent tasks can only begin after the previous task is completed. Other tasks can be conducted in parallel. This depends on the independence of the task itself and the availability of technicians.

The transfer constraints of technicians involve time constraints when switching jobs between different devices. When technicians transfer the k^{th} job from device u to the d^{th} job from device r, the transfer time L_{ukrd} is a key factor. In reality, the transfer of technicians is not instantaneous but requires a certain amount of time, and this transfer time must be fully considered. In the model, technicians' job switching cannot exceed their available time window; otherwise, it may lead to job delays or low efficiency. Therefore, it is necessary to incorporate control over transfer time into the objective function and constraints to ensure that the transfer arrangements of technicians do not lead to maintenance schedule stagnation or excessive load.

Resource maintenance capability and allocation constraints are another important aspect of the model, involving limitations on the allocation of technicians and equipment resources. The workload of each technician should be allocated reasonably to avoid inefficiencies or potential safety issues caused by excessive workload. On the other hand, the number of maintenance tasks for devices at a specific time point is also limited, and the allocation of maintenance tasks must ensure that the work of each device is arranged reasonably, without exceeding the carrying capacity of the device or the working time of technicians. The specific constraints are as follows:

$$ST_u \leq ST_k, \forall u \in U, \forall k \in K_u \tag{6}$$

$$RS_{uk} = TS_{uk} + \sum_{f=1}^{FL} A_{ukf}\,, \forall u \in U, \forall k \in K_u \tag{7}$$

$$MAX\left(RS_{ug}\right) \leq TS_{uk}, \forall h \in H; \forall f \in F \tag{8}$$

$$\sum_{u=1}^{UL} \sum_{k=1}^{KL} B_{ukhf} \leq 1\,, \forall h \in H; \forall f \in F \tag{9}$$

$$RS_{uk} + L_{ukrd} + UVD \cdot E_{ukrd} \leq TS_{rd} + UVD, \forall u, r \in U; \forall k \in K_u; \forall d \in K_r \tag{10}$$

$$\begin{gathered} A_{ukf} \in \{0,1\}, B_{ukhf} \in \{0,1\}, C_{hf} \in \{0,1\}, E_{ukrd} \in \{0,1\}, \\ \forall u, r \in U; \forall k \in K_u; \forall d \in K_r; \forall h \in H; \forall f \in F \end{gathered} \tag{11}$$

3. SIMULATION OF SCHEDULING OPTIMIZATION FOR TECHNICIANS AIMED AT IMPROVING ALLOCATION RESILIENCE

3.1 Chromosome coding

This study uses an improved Non-dominated Sorting Genetic Algorithm II (NSGA2) algorithm to achieve more effective and robust technician scheduling, and the principle of chromosome encoding is the key to achieving optimization goals. In order to meet the complexity of one-to-many relationships between maintenance tasks and technicians and simplify the encoding structure, a matrix-based integer encoding method was adopted to represent the allocation relationship between tasks and personnel. Fig. 2 shows the chromosome encoding method of the improved NSGA2 algorithm.

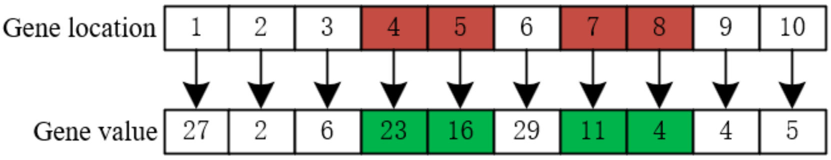

Figure 2: Chromosome encoding method of the improved NSGA2 algorithm.

During the encoding process, chromosomes are represented as a two-dimensional matrix, where rows correspond to different maintenance jobs and columns correspond to different technicians. Each element $X_{v\times l}$ represents that the u^{th} job is executed by the k^{th} technician. For example, if an element is 28, it means that the job was completed by a technician with the number 28, and consecutive identical coding values indicate that multiple technicians worked together to complete a job. This encoding method can flexibly represent the complex allocation relationship between technicians and jobs. During the decoding process, the execution order of jobs is constrained by policy rules to ensure the rationality and feasibility of the scheduling scheme. Assuming that the device number is represented by u of x_{uk} in individual $X_{v\times l}$, and the job number of the device is represented by k, the specific chromosome code is as follows:

$$X_{v\times l}=\begin{bmatrix} x_{11} & x_{21} & \cdots & x_{1l} \\ x_{21} & x_{22} & \cdots & x_{2l} \\ \vdots & \vdots & \ddots & \vdots \\ x_{v1} & x_{v2} & \cdots & x_{vl} \end{bmatrix} \tag{12}$$

The improved NSGA2 algorithm fully considers the characteristics of technician scheduling optimization in crossover and mutation operations. Cross operation aims to generate new individuals by exchanging partial gene segments of different chromosomes, thereby exploring the solution space. In this matrix-based integer encoding method, the crossover operation needs to ensure that the newly generated chromosomes still meet the rationality of maintenance jobs and technician allocation.

3.2 Execution strategy for job simulation sequence

In the simulation of technician scheduling optimization aimed at enhancing resilience, the improved NSGA2 algorithm achieves scheduling optimization through a priority-based job execution sequence rule strategy. This simulation strategy not only avoids unnecessary chromosome length increase and complexity but also ensures a reasonable execution sequence of tasks, reduces waiting time between technicians, and thus enhances the resilience of the entire system.

The first-level indicator determines priority based on the number of subsequent jobs. Specifically, if a certain job requires a large number of subsequent jobs, its priority should be higher to ensure that subsequent jobs can start as early as possible, reducing overall waiting time and delay risks. If a maintenance task for a certain device has five jobs, there are three tasks that need to be completed after job 1 and only one task needs to be completed after job 2. Then job 1 has higher priority than job 2. In the decoding process, the algorithm first arranges tasks with a large number of subsequent jobs to ensure the smooth progress of the entire maintenance process, which reduces the chain effect caused by individual job delays, thereby improving the robustness and efficiency of the scheduling scheme.

The second-level indicator determines priority based on the number of personnel required for the job. The more personnel required for a job, the higher the complexity and resource requirements of the job. Therefore, its priority should also be relatively high. If a maintenance job requires five technicians to complete together, while another job only requires two technicians, then the priority of the former should be higher. In this way, the algorithm can prioritize jobs that require more resources, ensuring efficient utilization of resources and a smooth transition in the scheduling process. This can effectively avoid resource bottlenecks and waiting times caused by unreasonable allocation of technicians during the scheduling process, thereby improving the overall resilience of the system.

The third-level indicator is the total number of jobs assigned to a certain technician for a certain job. The introduction of this indicator is to balance the workload of technicians, avoid efficiency decline and prevent potential security risks caused by excessive busyness of certain technicians. If the total number of technicians assigned to a certain job is high, its priority is relatively high. If the technicians assigned to a certain job have already been responsible for multiple other jobs, then the priority of this job should be raised in order to complete it as soon as possible and reduce the workload of these technicians. In this way, the algorithm can better balance the workload of technicians, avoiding situations where some technicians are too busy while others are idle, thereby improving the rationality and robustness of the scheduling scheme.

By using these three levels of priority indicators, the improved NSGA2 algorithm can effectively determine the execution order of jobs during the decoding process, ensuring the efficient utilization of technicians and the rationality of scheduling schemes.

4. SIMULATION EXPERIMENT RESULTS AND ANALYSIS

Table I shows the maintenance work arrangement of technicians under different optimization objectives. Under the goal of minimizing the completion time of equipment group maintenance, technicians 1, 4, and 5 have their own path arrangements.

Table I: Maintenance work arrangements of technicians.

Result	Technician ID	Path arrangement	Maintenance completion time	Load balancing	Cumulative transfer time
Minimize the completion time of equipment group maintenance	1	0→4→12→14→11→9→5→0	3265.15	97.85	256.4
	4	0→6→10→7→3→1→2→0			
	5	0→13→16→15→17→19→18→8→0			
Minimize technician load balancing	1	0→1→5→2→0	4126.59	44.26	336.1
	2	0→17→10→9→8→0			
	3	0→7→11→3→0			
	5	0→4→14→18→19→16→13→15→12→6→0			
Minimize the cumulative transfer time of technicians	1	0→1→7→2→3	3650.12	55.9	483.5
	2	0→16→11→8→6→0			
	3	0→14→13→12→11→10→14→7→0			

Technician 1's maintenance completion time is 3265.15, load balancing is 97.85, and cumulative transfer time is 256.4. Under the goal of minimizing the load balancing of technician, the paths and various indicators of technician 1, 2, 3, and 5 are different. For example, the maintenance completion time of technician 1 is 4126.59, the load balancing is 44.26, and the cumulative transfer time is 336.1. Under the goal of minimizing the cumulative transfer time of technicians, technicians 1, 2, and 3 also have corresponding paths and indicators, such as technician 1's maintenance completion time of 3650.12, load balancing of 55.9, and cumulative transfer time of 483.5. From the perspective of resilience assessment of technician allocation under multi-agent simulation, different optimization objectives can lead to differences in technician allocation and work arrangements, thereby affecting different performance indicators of the system. When aiming to minimize the completion time of equipment group maintenance, equipment maintenance can be completed quickly, but the load balancing is relatively high. When aiming to minimize the load balancing of technicians, the load balancing is optimized, but the maintenance completion time becomes longer. When aiming to minimize the cumulative transfer time of technicians, there is an improvement in transfer time, but other indicators are not optimal. This indicates that in the actual technician allocation and scheduling, multiple factors need to be comprehensively considered. Optimization goals should be flexibly selected according to different needs and scenarios to achieve the improvement of allocation resilience, ensuring that the system can achieve a good balance in equipment maintenance time, personnel load balancing, and transfer time when facing uncertain factors, thereby ensuring the stability and efficient operation of the system.

This is also in line with the research purpose of improving allocation resilience through an optimization algorithm in this study.

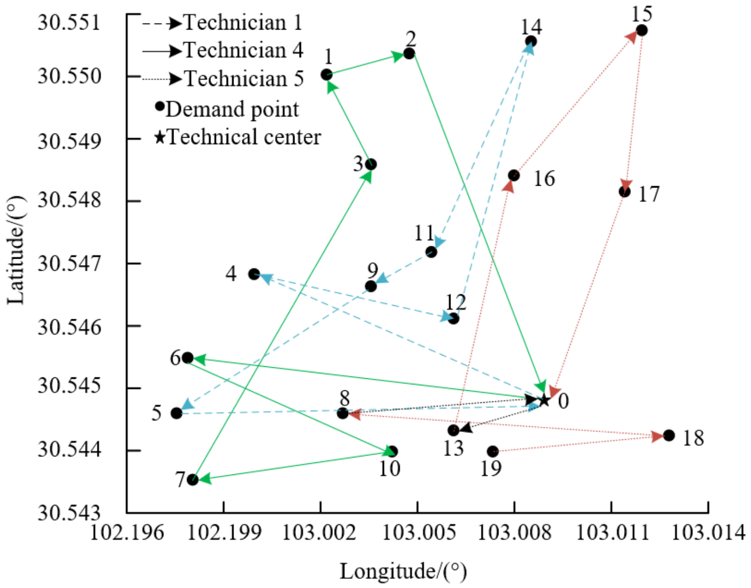

Figure 3: Technician movement route.

Fig. 3 shows the latitude and longitude distribution of three technicians, demand points, and the technical centre. From the perspective of allocation resilience, it can be inferred that if the distribution of demand points is relatively scattered, there may be differences in the distance and response time from different technicians to each demand point. When there are uncertain factors such as emergency needs, the distribution of technicians affects their response speed to demand points. If technicians are concentrated in a certain area and far away from some demand points, they may lack resilience in dealing with dispersed demand, making it difficult to quickly respond to all demand points. Conversely, if technicians are distributed relatively evenly and close to demand points, resilience in response efficiency may be better.

Table II presents the comparison of various results before and after the improvement of the NSGA2 algorithm in ten experiments. In terms of minimizing the completion time of equipment group maintenance, the improved mean is 2563, and the experimental values range from 2531 to 2589. The mean before improvement is 2689, and the experimental value is between 2635 and 2689. For minimizing the load balancing of technicians, the improved mean is 223, and the experimental value range is 221–229. The mean before improvement is 238, and the experimental value fluctuates between 221 and 278. In terms of minimizing the cumulative transfer time of technicians, the improved mean is 21, and the experimental values are 0, 32, 65, etc. The average before improvement is 81, and the experimental values include 0, 32, 98, 156, etc. The average number of optimal solutions after improvement is 4.4, and the average solving time is 26.5 minutes. The average number of optimal solutions before improvement is 4.5, and the average solving time is 25.9 minutes. According to the experimental results, the NSGA2 algorithm performs better on multiple key indicators after improvement. In terms of equipment group maintenance completion time, technician load balancing, and cumulative transfer time, the improved algorithm has lower mean values than before, indicating that the improved algorithm can more effectively optimize technician allocation, reduce equipment maintenance time, improve personnel load balancing, and reduce cumulative transfer time, thereby enhancing the system's ability to respond to tasks and improving allocation resilience. Although there is not much difference in the number of optimal solutions and solution time before and after improvement, considering other indicators, the improved algorithm has a positive significance in achieving allocation resilience improvement, ensuring system stability and efficient operation, which is in line with the research goal of improving allocation resilience through an optimization algorithm in this study.

Table II: Comparison of ten experimental results before and after the NSGA2 algorithm improvement.

Phase	Comparison dimension	Number of experiments								
		1	2	3	4	5	6	7	8	Mean
After improvement	Minimize equipment group maintenance completion time	2568	2569	2541	2562	2563	2589	2531	2589	2563
	Minimize technician load balancing	223	225	224	226	228	221	229	224	223
	Minimize the cumulative transfer time of technicians	32	0	0	65	32	0	0	32	21
	Quantity of optimal solutions	4	5	5	5	5	3	4	5	4.4
	Solving time (minute)	27	26	26	29	28	26	27	27	26.5
Before improvement	Minimize equipment group maintenance completion time	2659	2635	2689	2645	2689	2653	2651	2648	2689
	Minimize technician load balancing	228	278	236	234	221	278	246	249	238
	Minimize the cumulative transfer time of technicians	98	156	32	32	65	32	0	98	81
	Quantity of optimal solutions	5	6	4	3	4	5	5	5	4.5
	Solving time (minute)	26	25	27	25	25	24	25	26	25.9

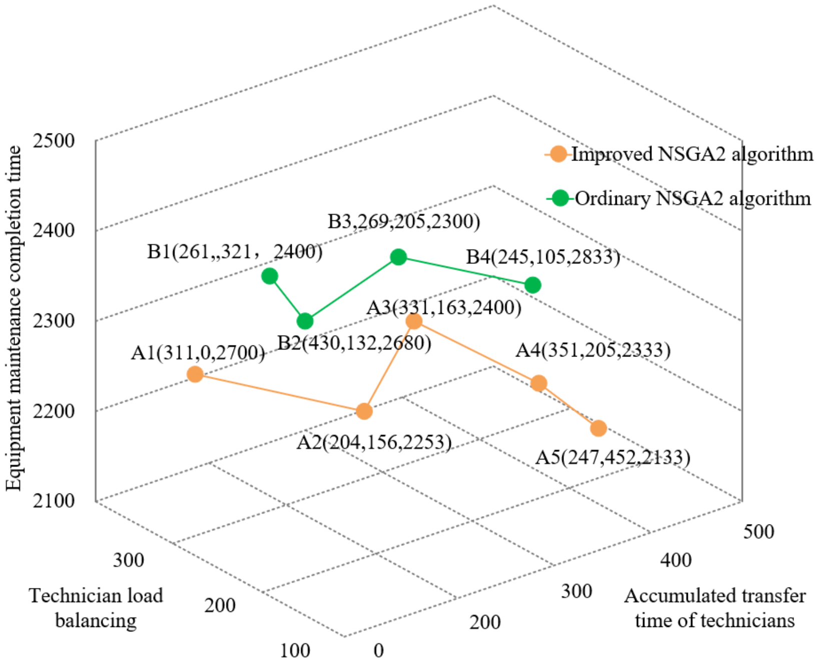

Figure 4: Pareto optimal solution set obtained before and after the NSGA2 algorithm improvement.

The three-dimensional chart shown in Fig. 4 illustrates the relationship between the ordinary NSGA2 algorithm and the improved NSGA2 algorithm in terms of cumulative maintenance time for technicians, technician load balancing, and total maintenance time. From the data point values, it can be seen that there are differences in the total maintenance time of the improved NSGA2 algorithm and the ordinary NSGA2 algorithm under different values of accumulated maintenance time and load balancing by technicians. The data point distribution of the improved NSGA2 algorithm shows that in some cases, it can achieve lower total maintenance time with relatively low cumulative maintenance time of technicians and better load balancing. Experimental results indicate that the improved NSGA2 algorithm has certain advantages in enhancing allocation resilience. A lower total maintenance time means that the system can recover normal operation faster when facing maintenance tasks and other situations, reflecting better stability and efficiency. The relatively low cumulative maintenance time of technicians and good load balancing indicate that the improved algorithm can allocate personnel tasks more reasonably, avoid problems of excessive fatigue or uneven task allocation, and more flexibly adjust personnel allocation when facing uncertain maintenance task demands, thereby improving allocation resilience. This is consistent with the goal of improving allocation resilience, ensuring system stability and efficient operation through a scheduling optimization algorithm in the study, indicating that the improved NSGA2 algorithm plays a positive role in the technician allocation and scheduling in multi-agent simulation.

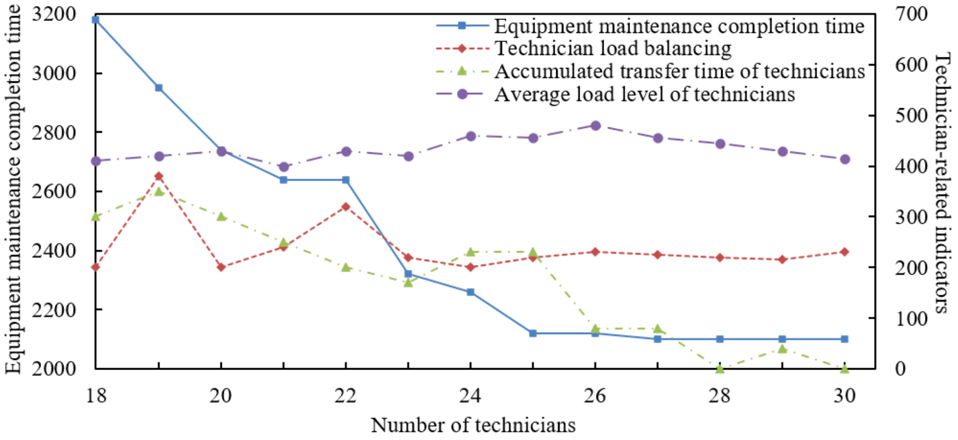

Figure 5: Effect trends under different allocation goals and technician numbers.

Fig. 5 shows the changes in equipment maintenance completion time, technician load balancing, average overtime level, and system average satisfaction as the number of technicians increases from 18 to 30. The completion time of equipment maintenance gradually decreases from about 3200 to around 2100, showing a significant decreasing trend. The load balancing value of technicians fluctuates greatly, reaching a peak when the number of technicians is between 20 and 22, then decreasing and stabilizing. The average overtime level of technicians shows an upward trend when there are 18–22 people, and then decreases slightly. The average satisfaction of the system first increases and then decreases as the number of technicians increases and is relatively high at 24–26 people. According to the experimental results, the completion time of equipment maintenance decreases with the increase of personnel, indicating that increasing the number of technicians can improve the efficiency of the system in handling maintenance tasks to a certain extent, enhance the system's ability to respond to maintenance work, and reflect the improvement of allocation resilience in task processing efficiency. The fluctuation of load balancing among technicians reflects the impact of changes in the number of personnel on the rationality of task allocation. A reasonable number of personnel can help achieve better load balancing and improve allocation resilience. The changes in the average overtime level of technicians and the average satisfaction of the system indicate that the number of personnel is not necessarily better. There is an optimal range within which a lower overtime level can be ensured while maintaining a higher system satisfaction. At this time, the system is more resilient in the face of uncertain maintenance task demands, achieving a balance between stability and efficient operation. This also verifies the research goal of improving system allocation resilience through reasonable personnel allocation in the study.

5. CONCLUSION

This study focuses on the research of technician allocation and scheduling problems in multi-agent simulation. In terms of research content, a technician allocation model under multi-agent simulation was constructed, which aims to better present the interaction between personnel scheduling and work environment. At the same time, based on the goal of improving allocation resilience, a corresponding scheduling optimization algorithm was designed to quickly adjust personnel allocation when faced with uncertain factors, thereby ensuring the stability and efficient operation of the system. From the research results, different optimization objectives can lead to differences in technician allocation and work arrangements, which in turn have different impacts on system performance indicators such as equipment maintenance time, personnel load balancing, and cumulative transfer time. Taking the NSGA2 algorithm as an example, the improved algorithm performs better than before in key indicators such as minimizing the completion time of equipment group maintenance, balancing the workload of technicians, and accumulating transfer time, effectively improving allocation resilience.

However, this study also has certain limitations. In terms of algorithms, insufficient consideration has been given to potential issues that may arise from algorithm improvements, such as increased algorithm complexity and increased demand for computing resources. In terms of experimental verification, the experiment may only be conducted under specific scenarios and data conditions, and its universality in more complex and varied practical scenarios still needs further verification. Based on this, future research directions could be explored from the aspects below. First, how to balance algorithm complexity and computing resources while improving allocation resilience could be explored in depth. Second, the experimental scenarios and data scope could be expanded to test the effectiveness and adaptability of research results in more complex practical scenarios. Third, the integration path with other intelligent algorithms or technologies could be actively explored, further improving the performance of technician allocation and scheduling and the allocation resilience.

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