Multi-objective Dynamic Scheduling of Circuit Repair Based on Improved NSGA-II

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Abstract. To deal with the problem of tight wartime repair time, heavy repair task, and complicated constraints during wartime, the multi-objective dynamic scheduling study of circuit repair equipment maintenance task scheduling was carried out. The military problem of equipment maintenance task scheduling for circuit repair under complex constraints was proposed. Considering the uncertainty of the repair status of the equipment to be repaired, the constraints such as repair time window, non-traversal, and variety of repair capability were introduced on the basis of the repair capability and the repair time limit. A multi-objective dynamic scheduling model that takes the total number of repaired equipment, the sum of equipment importance degree, and the total time of secondary operations as the scheduling target is established. An improved multi-objective genetic algorithm based on NSGA-II is designed to solve the model, and the rationality and effectiveness of the model and algorithm are verified through example simulation and analysis.

1. Introduction
With the pace of modern warfare getting faster and faster, the combat process is shortening, and the combat space is gradually widening, which makes more damaged equipment and less equipment support time in the wartime, this leads to heavy maintenance tasks and the timeliness of equipment maintenance in wartime is put forward higher requirements. The circuit repair, as one of the main repair methods for wartime equipment maintenance, performs rescue repairs on numerous equipment to be repaired distributed on the battlefield by dispatching multiple circuit repair teams to achieve the maintenance and recovery of combat forces.

Faced with numerous randomly appearance equipment to be repaired with varying damage degrees, the support commander should reasonably arrange the circuit repair task after comprehensive balance the information of damaged equipment such as location, workload, important degree, and other complex factors such as repair ability and ability change of each circuit repair teams. It is of great significance to solve the wartime equipment maintenance task scheduling problem of “which equipment will be repaired first?”, “which team will repair it?”, “when to repair?” and “how to repair?”, so as to achieve the overall optimization of maintenance efficiency. This task scheduling problem is a military problem that needs to be solved urgently.

Due to the complex situation of the battlefield and numerous constraint conditions, the research is difficulty. Many scholars have carried out in-depth exploration of equipment maintenance task scheduling, which has certain guiding significance. From the perspective of model abstraction, the
equipment maintenance task scheduling problem can be abstracted into Shop Scheduling Problem [1], Resource-Constrained Project Scheduling Problem [2] and Vehicle Routing Problem [3], the first two of which are suitable for equipment depot-level repair and fixed-point repair, the latter is more suitable for accompanying repairs and circuit repairs. With the continuous deepening of equipment maintenance task scheduling research, the scheduling objectives are continuously enriched according to the task requirements, such as maintenance efficiency [4], equipment important degree [5], secondary combat time [6], etc., but most of them are limited to single-target scheduling; On the other hand, the constraints are constantly changing according to the battlefield situation, but mainly focus on the traditional constraints, such as considering the equipment maintenance process [7], considering the maintenance profession [8], considering the rest of maintenance human [9], considering uncertainty [10][11], etc.. Literature [6] considered the limitation of repair capability during battlefield repair, and proposed non-traversal scheduling, which is in line with the actual wartime repair and has certain guiding significance. Although the literature [10] considered the repair status of equipment to be repaired, it only stayed in its influence on the number of completed tasks, and did not consider the impact of the repair status on the repair time and importance degree.

In general, the background and problems of the equipment maintenance task scheduling research at this stage are not exactly the same. The in-depth study of how to reasonably plan maintenance tasks and dynamically process uncertainty information under many practical constraints is not explored. Existing researches use the maximum support time or the longest second combat time as the single scheduling target for task scheduling. It may be difficult to fully consider the maintenance task requirements, and the constraints are relatively ideal, ignoring the uncertainty of the repair state and the impact on maintenance time and equipment important degree. It is not considered in the impact of time window constraints on maintenance task scheduling.

In view of the above problems, this paper takes the complex military problem of wartime equipment maintenance task scheduling as the research object, considers the uncertainty of the repair status of the equipment to be repaired and its impact on the maintenance time and equipment important degree, and introduces the repair time window constraint and non-traversal constraints of the equipment to be repaired, considering the uncertainty of the equipment to be repaired, construct a dynamic scheduling model for equipment maintenance tasks of multi-circuit repair teams, design the algorithm to solve the model, and verify the validity and rationality of the model and algorithm through examples.

2. Basic Description

2.1. Problem Description

Modern warfare under the conditions of informationization, with the advancement of the operational process and the progressive operation of combat missions, affected by the enemy's firepower, our combat equipment will inevitably have different degrees of damage at different times and in different locations. According to the distribution of the damage equipment, the circuit repair force is compiled into multiple circuit repair teams and planned to circuit repair. Under the support of the integrated command information platform, the information of equipment to be repaired can be known through corresponding means, such as the location, the estimated repair time to repair to different states and the important. During the implementation of the repair task, the support commander will dynamically schedule the repair schedule of each circuit repair team based on the continuously updated equipment and the information of each circuit repair team.

Putting forward the question: Under the premise that the equipment to be repaired constantly appears and the repair time and repair capacity are limited, considering the influences of repair time, important degree, uncertainty of the repair status of the equipment to be repaired, and the change of the repair capability of the circuit repair team, and other factors, this problem is aim to assign repair tasks for each circuit repair team, to determine the repair sequence of each repair equipment of each circuit repair team, to dynamically adjust repair tasks according to damaged equipment that constantly
appears and other uncertainty factor, so that the overall circuit repair effect is optimized, which is most conducive to the rapid recovery of combat power and the completion of combat missions.

2.2. Hypothetical Description
In order to simplify the problem and highlight the key points, the following assumptions are made:
- All the equipment to be repaired in the circuit repair equipment repair task schedule are within the repair capability of the circuit repair team, regardless of the shortage of spare parts;
- The research object is the synthetic brigade circuit repair force, and a number of circuit repair teams are compiled to implement the whole field circuit repair for the troops;
- During the implementation of the repair task, each circuit repair team independently completed their respective repair tasks and did not support each other;
- Relevant information such as the location of the equipment to be repaired, the estimated repair time, the repair time window, and the equipment important degree have been known through technical reconnaissance before the repair task is scheduled;
- The repair task will not be suspended due to task adjustment during the repair process;
- After the completion of the repair mission, each circuit repair team does not return to the initial territory, but waits for the follow-up command and dispatch of the support commander;
- After the equipment to be repaired is repaired, it will be directly return to the combat troops and involved in the war, ignoring the return time.

3. Model Building

3.1. Parameter Definition
- $T_{stu}$ indicates the start time of the battle, $T_{rep}$ indicates the start time of the circuit repair, and $T_{end}$ indicates the end time of the battle.
- $E$ is the collection of equipment to be repaired, and $|E| = n$; $n$ is the number of equipment to be repaired; $H$ is the originating point set, $G = E \cup H$.
- $R$ is the circuit repair team collection, and $|R| = m$; $m$ is the number of circuit repair teams, the initial position of the $k$ circuit repair team is recorded as $R_0^k$, its coordinate is $(x_0^k, y_0^k)$.
- $t_i$ is the moment when damage equipment $i$ appears, $(x_i, y_i)$ is the coordinate of $i$, its repair time window is $[t_i, t_i^{up}]$.
- $S_1$ indicates that the equipment to be repaired is repaired to the “normal operation” state, and its damage function is completely repaired; $S_2$ indicates that the equipment to be repaired is repaired to the state of “enable emergency operation”, and its damaged function is not completely repaired; the equipment important degree of $i$ when it repaired to $S_1$ notes as $\delta_i^1$, the equipment important degree of $i$ when it repaired to $S_2$ notes as $\delta_i^2$.
- $d_{ij}$ indicates that the distance of equipment $i$ and equipment $j$, $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ and $d_{ij} = d_{ji}$; Taking into account the influence of topographic factors, the introduction of the winding coefficient $\omega$; note $v$ is the average maneuver speed of the circuit repair team.
- $T_i$ indicates the repair time of equipment $i$ to be repaired; $T_i^c$ is the time spent planning to repair $i$; $T_i^{c_t}$ and $T_i^{c_s}$ respectively indicate the expected repair work hours for repairing the equipment $i$ to the $S_1$ and $S_2$ states.
- $p^i$ indicates the repair capability of the $k$ circuit repair team.
\( \xi_s^k \) indicates the repair efficiency of the \( k \) circuit repair team when performing the \( s \) repair task, which decreases with the implementation of the repair task.

- \( \alpha \) is the penalty coefficient, which is used to characterize the influence of time window on equipment important degree.

- \( \tau_i^k \) is a 0-1 variable, when equipment \( i \) is repaired by the circuit repair team \( k \), then \( \tau_i^k = 1 \); otherwise, \( \tau_i^k = 0 \).

- \( \omega_i^k \) is a 0-1 variable. When the circuit team \( k \) goes from point \( i \) to point \( j \), then \( \omega_i^k = 1 \); otherwise, \( \omega_i^k = 0 \).

- \( O = \{ o^1, o^2, \ldots, o^m \} \) indicates a feasible solution to the problem, \( o^k \) is a planned repair route for the \( k \) circuit repair team, representing the equipment number sequence for the repair team to perform the repair task; \( | o^k | \) indicates the number of elements in the planning sequence, that is, the number of equipment in the planning path; \( o_l^k \) indicates the \( l \) equipment in the planned path.

- \( q^k \) is the cut-off point in the repair path of the \( k \) circuit repair team, indicating the last equipment of the final actual repair of the team.

### 3.2. Scheduling Model Establishment

On the basis of analyzing the multi-target parameters of equipment repair task scheduling of the circuit repair, combined with the characteristics of the circuit repair, this paper considers the repair time relationship, traversal and non-traversal characteristics of each repair equipment, and determine the relevant Constraint conditions, build a circuit repair equipment maintenance task scheduling model as

\[
\text{max } F_1 = \max \sum_{k=1}^{m} \sum_{i=1}^{n} \xi_s^k \\
\text{max } F_2 = \max \sum_{k=1}^{m} \sum_{i=1}^{n} \tau_i^k \delta_j \\
\text{max } F_3 = \max \sum_{k=1}^{m} \sum_{i=1}^{n} \tau_i^k [T - T_i^k] \\
s.t.
\]

\[
T_i^k = \omega d_{o^k_l} / \sqrt{v + T_i^c} \\
T_i^k = T_i^k + \omega d_{o^k_l} / \sqrt{v + T_i^c} \\
T_i^k = T_i^k / \xi_s^k p = T_i^c / \beta p^{l-1} \xi_s^l p^l \\
T_i^l = \begin{cases} T_i^k \leq T_{end}, \forall l, l \leq | o^k |, \text{ traversal} \\ T_i^k < T_{end} < T_i^l, \exists l, l \leq | o^k |, \text{ no-traversal} \end{cases}
\]

4
Among them, formulas (1), (2) and (3) indicate that the equipment repair task scheduling targets for the circuit repair are the largest total number of repaired equipment, the greatest importance of repaired equipment, and the largest total time of repaired equipment participate in combat. Among them, the total number of repairing equipment is the sum of the number of repaired equipment repaired by each circuit repair team during the whole combat. It reflects the speed of the circuit repair, which directly affects the participation rate of the equipment; The total importance of repaired equipment is the sum of the importance of repaired equipment, reflecting the contribution of the repaired equipment to the entire equipment system; The total time of repaired equipment participate in combat refers to the length of time from the repair time to the end of the battle. The sum reflects the effective duration of returning to the battlefield after the repair of the equipment, which is the embodiment of the timely repair. The above three reflect the effect of the circuit repair from different aspects, and affect each other and restrict each other. Therefore, it is necessary to construct a multi-objective optimization model to realize the overall comprehensive trade-off.

Equation (4) indicates the time relationship between the circuit repair team from the initial position and repairing the first equipment to be repaired in the team; and the formula (5) indicates the constraint relationship of repaired time between two adjacent equipment in the repair team of the circuit repair team; Equation (6) indicates the constraint relationship of repair time and repair capability; Equation (7) represents the traversal and non-traversal constraints of the circuit repair team; Equation (8) means that each equipment to be repaired is repaired at most once by only one circuit repair team; The formula (9) and (10) indicate the end point (starting point) of any arc to be repaired and only one starting point (end point) to be repaired is connected to it.

3.3. Scheduling Model Analysis

3.3.1 Multi-objective analysis. The circuit repair task scheduling model weighs the advantages and disadvantages of the repair task scheduling scheme from three aspects: the number, the importance of repair objects and the timeliness of repairs. It can overcome the problem that the traditional repair task scheduling simply pursues a certain target and causes the scheduling scheme to deviate greatly from other requirements, so that the advantages and disadvantages of the repair task scheduling scheme can be more comprehensively weighed.

The Pareto solution set judges the advantages and disadvantages of the scheduling scheme through the dominant relationship, and can achieve the balance between the scheduling targets. It is a better idea to deal with multi-objective scheduling. By coordinating the balance among multiple targets, a set of acceptable solutions (Pareto optimal solution sets) can be obtained, thereby increasing the decision-making room for the support commander. The support commander can select a satisfactory scheduling plan from the Pareto optimal solution set according to the actual needs of the battlefield and decision preferences.

The decision-making strategy of setting the satisfactory scheme is as follows: the normalization of the solution in the Pareto optimal solution set is adopted, and the weighting method is used to sort and optimize, so that the satisfactory solution is selected.

\[
F' = \mu_1 F'_1 + \mu_2 F'_2 + \mu_3 F'_3
\]
In the formula, \( F_i' \) is the normalized solution, \( \mu_1, \mu_2 \) and \( \mu_3 \) are the preferred command weight coefficients of the commander, which can be adjusted according to the battlefield needs and situation.

3.3.2. Uncertainty of repair status. Due to the limitation of repair time, in order to repair the equipment and make it return to the battlefield as soon as possible, the repair status of the equipment to be repaired is not completely repaired, and it is possible that only some functions are restored, that is, the repair status of the equipment to be repaired is divided into “Can fight normally” \( S_1 \) and "Emergency combat" \( S_2 \).

The repair of the equipment to be repaired to different states will have a greater impact on the repair task scheduling. On the one hand, the repair status is different, and the required repair work time is also different. On the other hand, the repair status is different, and the importance of the equipment obtained after the repair is also different. Therefore, in the repair task scheduling, the repair status of the equipment to be repaired needs to be considered.

3.3.3. Repair time window. For the circuit repair, each of the equipment to be repaired hopes to be repaired in time to quickly return to the battlefield to exert its operational effectiveness, and due to the limitation of repair capability, it is difficult to realize that the equipment to be repaired is repaired at the first time. As time goes by, due to changes in the combat phase, combat missions, etc., when the equipment to be repaired is not repaired at a certain moment, the importance of the equipment to be repaired will be affected. Therefore, drawing on the concept of time window \([13]\) in VRP, this practical problem is characterized by introducing the time window for repair of equipment to be repaired, and the importance of the equipment to be repaired that has not been repaired beyond the repair time window is punished. The penalty formula is as follows:

\[
\eta_i^j = \begin{cases} 
\delta_i^j, & T_i \leq T_{i,\text{up}} \\
\alpha \delta_i^j, & T_{i,\text{up}} < T_i < T_{i,\text{end}} \\
0, & T_i \geq T_{i,\text{end}} 
\end{cases}
\]

(12)

In the formula, \( \eta_i^j \) \((j = 1, 2)\) is the equipment importance of the repaired equipment \( i \) to the state \( S_j \) after being repaired by the repair time window, and \( \alpha \) is the penalty coefficient.

3.3.4. Non-ergodicity. Due to the large number of equipment to be repaired, the difficulty of repairing is relatively large, and the limitation of repair time and repair capacity, it is difficult for the circuit repair team to fully repair all the equipment to be repaired scattered on the battlefield. In the initial stage of scheduling, there are fewer equipment to be repaired, and traversal repairs (repairs of all equipment to be repaired) can be achieved during mission planning. However, as the combat progress progresses, the number of equipment to be repaired is increasing, and it is impossible to completely repair the many equipment to be repaired. The maintenance task scheduling at this time is non-traversal scheduling.

3.3.5. Changes in repair capacity. There are differences in the repair capabilities of each circuit repair team during the war, and due to many factors, such as the battlefield environment, the repair capabilities of each circuit repair team will gradually change with the progress of the repair task. Mainly reflected in the implementation of the repair task, the repair staff will produce fatigue, which will affect the repair efficiency, so that the repair capability of the circuit repair team changes.

The change in repair capability caused by the fatigue of the repairman can be measured by the efficiency of the repair. The formula is:

\[
\xi_i = \beta \xi_{i-1}^k
\]

(13)
In the formula, $\xi_s^t$ is the repair efficiency when performing the $s (s \geq 2)$ repair task, $\xi_1 = 1$, and $\beta$ is the repair efficiency attenuation coefficient.

### 3.3.6. Dynamic driving strategy analysis

When dealing with the dynamic scheduling problem of equipment maintenance tasks, the rolling time domain idea is introduced. According to the scheduling requirements, the whole task profile is transformed into a series of static scheduling problems at discrete time points. Through multiple repair task scheduling, dynamic problem static processing is realized. The dynamic driving strategy is to set a certain driving condition to determine whether the repair task needs to be re-scheduled at this moment, which is the basis of dynamic scheduling.

The dynamic driving strategy for the dynamic scheduling of the equipment repair task for the circuit repair is set as follows: when the number of newly-restarted equipment reaches a certain threshold, the re-scheduling is performed according to the information of each circuit repair team and the equipment to be repaired at that time. At the time of rescheduling, the repaired or repaired equipment being repaired by the circuit repair team is recorded as a key point.

The dynamic scheduling strategy updates the circuit repair team and the equipment information to be repaired during each rescheduling, and eliminates the scheduling error caused by the difference between the actual repair time and the planned repair time of the equipment to be repaired, and realizes the dynamic scheduling of the maintenance task. It also improves the reliability of dynamic scheduling.

### 4. Model Solving

#### 4.1. Pareto Optimal Solution Set Construction

The traditional multi-objective optimization method deals with multi-objective scheduling problems by linear weighting or target planning. Its essence is to transform multi-objective problems into one or a series of single-objective optimization problems, which is difficult to solve the conflict relationship between multiple optimization targets. There are problems such as relying on prior knowledge and difficulty in dealing with Pareto optimal front end non-convex. As one of the best multi-objective evolutionary algorithms, NSGA-II algorithm reduces computational complexity while ensuring population diversity and protecting elite individuals in the population \[14\]. Therefore, this paper adopts the NSGA-II algorithm's elite strategy, adopts the non-dominated sorting method and combines the congestion degree comparison operator to obtain the Pareto optimal solution set, which provides the decision-making basis for the commander. The commander can choose the most satisfactory solution in the Pareto optimal solution set according to the battlefield situation and actual needs, relying on decision-making preferences and decision-making strategies.

#### 4.2. Coding and Decoding Design

Considering the characteristics of the circuit repair task scheduling, a 3-stage code is designed to achieve the relevant constraints. The front segment adopts sequential coding to indicate the division of tasks of the circuit repair team; The middle segment uses the "1-2" integer code to indicate the repair status of the equipment to be repaired. 1 indicates that the repair status is $S_1$, and 2 indicates that the repair status is $S_2$; The last part uses integer coding to indicate the position of the breakpoint, which is used to divide each circuit repair team. The coding method can realize the non-traversal constraints of the multi-circuit repair team and the uncertainty of the repair state of the equipment to be repaired, and the chromosomes have a one-to-one correspondence with the solution, which avoids the generation of infeasible solutions in the genetic operation and greatly improves the convergence speed of the algorithm. When decoding, the objective function is selected as the fitness function, and the information of the intercept point and the corresponding fitness value are calculated through the relevant constraints, thereby realizing decoding.
Encoding and decoding examples are shown in Figure 1, 2. The chromosome is \(X=(4,8,2,6,3,10,7,5,1,9,1,1,2,1,2,2,1,2,1,1,3,7)\), and \(n=10, m=3\). After decoding, there are 3 circuit repair teams responsible for the repair tasks of 10 equipment. The task scheduling are as follows: the task arrangement and repair sequence of the circuit repair team 1 is 4-8-2, and the repair status is \((S_1, S_1, S_1)\); The task arrangement and repair sequence of the circuit repair team 2 is 6-3-10-7, and the repair status is \((S_2, S_1, S_1, S_1)\); The task arrangement and the repair sequence of the circuit repair team 3 is 5-1-9, and the repair states are \((S_3, S_1, S_1)\). The interception information is \((1, 5, 8)\), indicating that it is affected by the constraints, and some of the equipment to be repaired has not been repaired. Finally, the actual repair task is completed: the repair team 1 repairs the equipment 4, and the repair status is \(S_1\); The circuit repair team 2 repairs the equipment 6-3, the repair status is \((S_1, S_2)\); The circuit repair team 3 repairs the equipment 5, and the repair status is \(S_3\). The fitness are \(F_1, F_2, F_3\).

![Figure 1. Coding example](image1)

![Figure 2. Decoding example](image2)

### 4.3. Genetic Operator Design

#### 4.3.1. Parent chromosome selection

According to the non-dominated sorting and inter-individual crowding distance in the NSGA-II algorithm, the comparison operator was obtained, and then Binary Circuitnament Selection was used to select 20% of the individuals from the previous generation chromosome as the parent chromosome for subsequent cross mutation.

#### 4.3.2. Cross variation

Since the chromosome adopts 3-segment coding, the coding mode of each segment and its actual meaning are different, and the cross-variation cannot be performed in the traditional way. In order to increase the diversity of the population and improve the convergence speed, the idea of "the former segment only performs the mutation operation, the middle segment and the last segment can be crossed and the mutation operation" is determined for the coding characteristics. The corresponding genetic operators are designed. The following genetic operations are performed on each parent chromosome:

- The previous paragraph is followed by random update operation;
- The previous stage adopts random update, and the latter stage adopts inverted operation;
- The front stage adopts the inverted operation, the latter stage adopts the random update operation;
- The front stage adopts the inverted operation, and the back stage adopts the sliding translation operation;
- The first paragraph does not take action, and the latter stage uses random update operation.
4.4. Algorithm Flow Design
The flow of the model solving algorithm is as follows:

\[ \text{step1: Initialize related parameters (determine the population size } \text{pop}_\text{size}, \text{ the maximum number of iterations } \text{num}_\text{gen}, \text{ etc.)}; \]

\[ \text{step2: Randomly generated initial population}; \]

\[ \text{step3: Decoding any chromosome in population } P_0 \text{, calculating its fitness value and interception information, and obtaining the initial feasible solution population } O \text{, recorded as } \text{pop}_\text{chrom}. \]

\[ \text{step4: Fast non-dominated sorting of feasible solution population } O \text{ by NSGA-II, calculating the crowding distance between non-dominated sets}; \]

\[ \text{step5: let } \text{gen} = 1; \]

\[ \text{step6: Randomly select the parental chromosome population } \text{parent}_\text{chrom} \text{ of size } \text{pool}_\text{size} \text{ from } \text{pop}_\text{chrom} \text{ according to Binary Circuitnament Selection}; \]

\[ \text{step7: Genetic manipulation by genetic operators to generate progeny chromosome } \text{offspring}_\text{chrom}; \]

\[ \text{step8: Calculate the interception information of any chromosome in } \text{offspring}_\text{chrom} \text{ and its fitness}; \]

\[ \text{step9: Using NSGA-II algorithm to perform fast non-dominated sorting of } \text{pop}_\text{chrom} \text{ and } \text{offspring}_\text{chrom}, \text{ calculate the crowding distance between non-dominated sets}; \]

\[ \text{step10: A new generation of chromosome } \text{pop}_\text{chrom} \text{ of size } \text{pop}_\text{size} \text{ was screened from } \text{pop}_\text{chrom} \text{ and } \text{offspring}_\text{chrom} \text{ by Binary Circuitnament Selection to achieve elite retention of the outstanding individual genes of the father}; \]

\[ \text{step11: Judge } \text{gen} < \text{num}_\text{gen} \text{? Yes, transfer to step12; No, transfer to step13}; \]

\[ \text{step12: } \text{gen} = \text{gen} + 1, \text{ transfer to step6, continue to find excellence}; \]

\[ \text{step13: Stop the iteration, obtain the Pareto optimal solution set for this maintenance task scheduling, and select a satisfactory solution based on the decision strategy, transfer to step14}; \]

\[ \text{step14: Is the rescheduling drive strategy satisfied? Yes, transfer to step1 for rescheduling; no, transfer to step15}; \]

\[ \text{step15: Ending of operation, outputting scheduling result.} \]

5. Sample simulation and analysis

5.1. Sample simulation
A synthetic brigade was instructed by a higher level to perform a maneuvering offensive mission. Due to attacked by the enemy’s firepower, equipment to be repaired are appeared. Under the support of the integrated command information network, through technically reconnaissance, the relevant information on repairing equipment has been known. The support commander dispatched three circuit repair teams to implement global coverage for the entire brigade based on known information. Each circuit repair team is responsible for repairing the equipment to be repaired within 120 minutes.

Set the combat start time to 0min, \( \bar{v}=25\text{km/h}, \omega=1.2, \hat{N}=5, \beta^1=25, \beta^2=20, \beta^3=22, \alpha=0.7, \beta=0.9, T_{end}=600\text{min} \). Due to the delay of wartime support, the circuit repair began to be implemented 50 minutes after the start of operations. At this time, the position of each circuit repair team is (-2.1, 0.2), (0.5, 0.6), (3.7, 0.3). The information of equipment to be repaired are showed as
Table 1, such as the location information, the repair time window, and the expected repair time to return to different states.

| i   | t_i | (x_i,y_i) | \( \delta_i^1 \) | \( \delta_i^2 \) | \( T^{\alpha}_i \) | \( T^{\beta}_i \) |
|-----|-----|-----------|-----------------|-----------------|-----------------|-----------------|
| 1   | 23  | (-2.7,3.8)| 0.48            | 0.37            | 120             | 16              |
| 2   | 29  | (3.4,2.5)| 0.67            | 0.52            | 120             | 20              |
| 3   | 50  | (-3.8,4.2)| 0.82            | 0.55            | 120             | 18              |
| 4   | 64  | (-4.4,9)| 0.67            | 0.52            | 140             | 25              |
| 5   | 72  | (-1.2,5.1)| 0.74            | 0.66            | 140             | 24              |
| 6   | 86  | (0.9,6.8)| 0.52            | 0.38            | 200             | 32              |
| 7   | 91  | (6.1,7.2)| 0.48            | 0.32            | 200             | 22              |
| 8   | 105 | (0.7,8)| 0.59            | 0.39            | 280             | 20              |
| 9   | 129 | (3.2,8.9)| 0.55            | 0.41            | 320             | 28              |
| 10  | 158 | (-2.3,7.8)| 0.44            | 0.36            | 320             | 24              |
| 11  | 179 | (-4.8,9.3)| 0.55            | 0.41            | 360             | 20              |

At the beginning of the battle \((t \leq 300\text{min})\), it need to move more and more important equipment to participate in the battle, so set \(\mu_1=0.2, \mu_2=0.6, \mu_3=0.2\). Late in the battle \((t > 300\text{min})\), it need to provide more combat time, so set \(\mu_1=0.3, \mu_2=0.2, \mu_3=0.5\).

According to the actual maneuver time, actual repair time and scheduling strategy of the circuit repair team, the equipment repair tasks are dynamically scheduled, and the results of the scheduling plan are shown in Table 2.

| Scheduling time | Equipment involved in dispatching | Task sequence and recovery status | \( F_i \) | \( F_s \) | \( F_i^* \) | \( F_s^* \) |
|-----------------|-----------------------------------|----------------------------------|---------|---------|-----------|-----------|
| 50              | 1,2,3                             | 3(1)                             | 1       | 0.82    | 492       | 106       |
| 105             | 4,5,6,7,8                         | 3(1)-6(1)-5(1)                   | 3       | 1.93    | 1230      | 265       |
| 206             | 8,9,10,11,12,13                    | 3(1)-6(1)-5(1)-12(2)             | 4       | 2.45    | 1492      | 338       |
| 335             | 9,14,15,16,17,18                   | 3(1)-6(1)-5(1)-12(2)-15(2)-9(2) | 6       | 3.00    | 1698      | 443       |
| 393             | 9,16,19,20,21,22,23                | 3(1)-6(1)-5(1)-12(2)-15(2)-21(2) | 8       | 3.74    | 1981      | 549       |
| 481             | 20,22,24,25,.26,27,28              | 3(1)-6(1)-5(1)-12(2)-15(2)-21(2) | 9       | 4.44    | 2117      | 550       |

Table 2 Scheduling planning result

| Overall circuit repair data |
|-----------------------------|
| \( F_i^* \) | \( F_s^* \) |
|-----------|-----------|
| 146       | 0         |
| 297       | 1         |
| 439       | 6         |
| 522       | 7         |
| 584       | 8         |
| 609       | 9         |
\( F_i \) is the actual target value of each team, \( F^* \) is the overall actual target value, \( T \) is the planned repair time of the key point, and \( T^* \) is the actual repair time of the key point.

The circuit repair task schedule has experienced 6 scheduling processes, and the time of the Matlab software platform is 11.45s, 10.87s, 9.68s, 9.75s, 8.32s and 9.06s. The planning path for the final repair plan is shown in Figure 3.

| 1(1)-4(1)-13(1)-11(1)-17(2)-23(2)-16(2)-24(2) | 9 | 3.78 | 2017 | 592 | 595 |
| 2(1)-7(1)-10(2)-8(1)-14(2)-18(2)-19(2)-27(2)-22(2) |

\( F^* \) is the overall actual target value, \( T^* \) is the actual repair time of the key point.

5.2. Result analysis

- From the circuit repair team to the completion of the circuit repair to the end of the battle, a total of 26 sets of equipment were repaired, the total importance of the equipment obtained was 12.17, and the second combat time obtained was 6099min, about 101h, which provided a powerful force for restoring the combat effectiveness of the troops. It indirectly proves the importance of wartime repairs.

- The scheduling time is within 12s, which satisfies the effectiveness requirements of wartime equipment maintenance task scheduling, and also proves the feasibility of the constructed model and algorithm.

- It can be seen from Table 2 that under the influence of the dynamic driving strategy, a total of 6 schedulings were performed, which realizes the dynamic adjustment of the repair task under the condition that the equipment to be repaired continuously appears. Among them, the first five scheduling is traversal scheduling, and the sixth scheduling is non-ergodic scheduling; the equipment to be repaired 20, 28, 29, 30 is not included in the final circuit repair equipment repair mission planning, which is mainly due to the time limit in wartime caused the repair task to not be completed, reflecting the non-ergodic nature of the circuit repair.

- At the time of the third dispatch at 206 min, the equipment 9 is included in the fifth repair position of the circuit repair team 3, and the planned repair state is \( S_1 \), but in the 4th, 5th, and 6th rescheduling, the equipment 9 are all involved in the rescheduling, and finally in the 7th repair position of the circuit repair team 1 is repaired, and the repair status is \( S_2 \). This reflects that at the time of rescheduling, the task sequence of each circuit repair team and the repair status of each repair equipment are dynamically adjusted according to the global information.

![Figure 3. Equipment circuit repair route planning diagram](image-url)
at that moment to achieve global optimization, which reflects the reasonable scheduling model from the side.

- In the planning path of the circuit repair team 1, there are fold lines 3-6-5 and 15-21-9-25-26. The former is because the equipment 5 has high importance and shorter repair time than equipment 6 when repaired to the same state. Therefore, after repairing the equipment 3, the team 1 discards the relatively nearer equipment 6, and repairs the high-impaired and more easily repairable equipment 5, which satisfies the “Repair important equipment first” and “Repair equipment that is easy to repair first”. It also reflects the rationality of the scheduling model. The latter is because the plan is a comprehensive result of multiple rescheduling, equipment 15 is repaired after the fourth dispatch, equipment 21, 9 is repaired after the fifth dispatch, and equipment 25, 26 are included in the dispatch plan in the sixth schedule and finally repaired. This reflects that the core of dynamic dispatch is to optimize the overall repair efficiency, rather than pursuing the optimality of a circuit repair team.

6. Conclusions
Reasonable and efficient equipment circuit repair task dynamic scheduling can provide mathematical support for the wartime support commander’s maintenance decision, and can make timely and effective adjustment according to the changing maintenance requirements during wartime, which greatly reducing the decision-making workload and human decision-making risk. Based on the military problem of dynamic scheduling of circuit repair tasks, this paper constructs a multi-objective dynamic scheduling model for repair tasks. Considering the uncertainty of the repair status of equipment to be repaired, introduce complicated constraints such as time window, non-ergodicity and changes in repair capability, which makes the model more realistic and enhance the rationality of the model. Through the development of dynamic scheduling strategy, the dynamic adjustment of the repair plan is realized, and the NSGA-II improved genetic algorithm is designed to solving the model. The rationality of the model and algorithm is verified by an example. In the next step, we will conduct a study on the dynamic scheduling of equipment maintenance tasks in fixed-point repairs.

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