The Application of The Key Chain Method in The Annual Maintenance Project of The Ship

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Abstract. The annual maintenance project is an important measure to further advance the maintenance reform of ship equipment in a certain direction. It is a powerful grasp of strengthening the control of the equipment technology status of the ship. At present, the progress control of the annual maintenance project is still in the traditional management and control mode, and the maintenance cycle is longer. In order to improve the traditional schedule control method, this article introduced the uncertain factor coefficient, process location coefficient, time elasticity coefficient, and resource utilization on the basis of key chain technology theory, and obtained the calculation method of the project buffer. A model control model of annual maintenance projects based on key chain technology is constructed. This provides a certain basis for the subsequent annual maintenance work.

Keywords: annual maintenance project; key chain technology; buffer zone; progress control model

1 Introduction

Since the "Twelfth Five -Year Plan", the construction of my country's navy equipment has entered a stage of rapid development, and new research and new ships have successively delivered to the troops in batches. Each new type of ship is equipped with the normalized use of high sea, high strength, and multi -tasks, and puts forward strict requirements on the integrity and fast and precise guarantees of equipment. The annual maintenance project achieves an organic linkage between in-service maintenance and grade maintenance by adjusting the preventive maintenance that was not required for ship maintenance during the original grade maintenance to be carried out in a timely manner during navigation, thus ensuring that equipment continues to maintain a good technical state and improving the in-service combat capability of ships. However, the annual inspection and maintenance project is a huge and complex system engineering project, with a tight inspection and maintenance cycle and no suitable progress control model.

The quality of schedule control is one of the important factors that test project management, as it can directly affect whether the project can be delivered on schedule. At present, the main methods for project schedule control include Gantt chart, critical path

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method, PERT plan review technology. Although these methods are mature and widely used, they only consider the logical relationship between processes and optimize local work units. At the same time, leaving more safety time in each activity unit can lead to the occurrence of student syndrome and Perkins' law phenomenon. In order to further improve the level of progress control, significantly reduce the safety time during project implementation, and further optimize the overall project, many scholars have begun to study the critical chain technology method, on the basis of introducing the critical chain method (CCPM), Sun Hui [5] compared the traditional critical path method (CPM) with the critical chain method, and applied the critical chain method to project management based on the characteristics of project management. She established a critical chain project management process and finally verified the effectiveness of applying the critical chain method to project management through case analysis. Cao Xiaolin [6] pointed out that the size of the project buffer zone is related to factors such as the uncertainty of the duration of project processes, the risk preferences of project managers, resource constraints, the complexity of processes, and the flexibility of project process commencement. She proposed a buffer zone calculation method based on the comprehensive attribute characteristics of the project. In response to the shortcomings in existing research on critical chain project management and the limitations in actual project execution, Gao Xiaoyu drew on the serial scheduling algorithm in resource constrained project scheduling problems to find the critical chain, used genetic algorithms to optimize the schedule plan, and finally constructed a critical chain schedule control process based on the schedule plan. Tan Zetao focuses on the development, updating, and maintenance process of the schedule plan, with the determination of critical paths and dynamic management as the core. He analyzes various factors that affect the reliability of the schedule plan from multiple perspectives, explains their impact mechanisms, and provides practical guidance. He Yuxing used Kalman filtering to obtain the optimal state estimation of activities, and used a grey model to predict buffer consumption and activity completion time. Liu Xiaojuan constructed a schedule control model based on critical chain technology, utilizing the theoretical advantages of critical chain technology and adopting the insertion of buffer zones to reduce risks and cope with uncertain factors. [1~4]

Based on the research of numerous scholars, this article will systematically describe the application of critical chain technology method in annual ship maintenance projects, and creatively propose a buffer zone setting method combined with the characteristics of annual maintenance projects, which can greatly reduce the annual maintenance cycle and increase the project management's ability to control project progress.

2 The Connotation of Critical Chain Technology and the Method of Setting Buffer Zones

2.1 Connotation of Critical Chain Technology

Critical chain (CC) is an advanced project management technology that fully considers the mutual calling of resources compared to traditional project schedule control. At the same time, CC technology sets a buffer zone at the end of the project planning path. As shown in the figure, a is the traditional activity arrangement, which reserves safety time for each process in the activity. b is an activity arrangement that consolidates the safety time in each process into a buffer zone. In the figure, n represents the number of processes for a certain project, d_i represents the time taken to complete the i-th process in the project, d_{si} represents the safe time left to complete the i-th process, and d_B represents the number of days in the buffer zone set at the end of the activity link. [9-11]

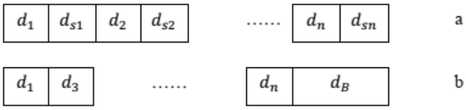

Fig. 1. Schematic diagram of different safety time settings

Using σ_a^2 and σ_b^2 to represent the uncertainty under two different activity arrangements, a and b, would be:

$$\sigma_a^2 = \sum_{i=1}^{n}[(d_i + d_{si}) - d_i]^2 = \sum_{i=1}^{n} d_{si}^2 \quad (1)$$

$$\sigma_b^2 = [(\sum_{i=1}^{n} d_i + d_B) - \sum_{i=1}^{n} d_i]^2 = d_B^2 \quad (2)$$

Assuming that the uncertainty under two different activity arrangements, a and b, is the same, then:

$$\sigma_a^2 = \sigma_b^2 \quad (3)$$

Therefore:

$$\sum_{i=1}^{n} d_{si}^2 = d_B^2 \quad (4)$$

According to the fundamental inequality, there are:

$$d_B^2 = \sum_{i=1}^{n} d_{si}^2 \le (\sum_{i=1}^{n} d_{si})^2 \quad (5)$$

Therefore:

$$d_B \le \sum_{i=1}^{n} d_{si} \quad (6)$$

It is not difficult to see from the above equation that for two different activity arrangements, a and b, under the same uncertainty, the safety days of the buffer zone are less than or equal to the sum of the safety time reserved for each process in the traditional activity arrangement. From this, it can be seen that the setting of buffer zones can achieve the goal of shortening the construction period to a certain extent.[12]

2.2 Buffer setting method

For buffer settings, there are usually Cut and Paste Method (C&PM) proposed by Goldratt and Root Square Error Method (RSEM) proposed by Newbold.

C&PM, also known as the 50% method, Goldratt believes that for the setting of buffer zones, the sum of half of the safe time of each process in the activity arrangement should be taken. Therefore, the time d_C of the buffer zone can be expressed as: [7-8]

$$d_C = \frac{1}{2}\sum_{i=1}^{n} d_{si} \tag{7}$$

Newbold believes that the setting of the buffer should be based on the risk set of each process in the activity arrangement. Therefore, Newbold proposes to calculate the buffer time using the standard deviation of the activity duration. The buffer time d_D can be expressed as:

$$d_D = \left[\sum_{i=1}^{n} \left(d_{imax} - d_{iavg}\right)^2\right]^{1/2} \tag{8}$$

In the formula, d_{imax} represents the longest time taken for the i-th process, and d_{iavg} represents the average time taken for the i-th process.

The C&PM and RSEM methods are proposed based on the independence of each process in the activity arrangement. However, in practical work, it is difficult to achieve independence for each process due to the complexity of the project chain, the utilization of project resources, and the difficulty level of each process. This article will further improve the RSEM method from the above three aspects to make it more accurate in calculating the size of the buffer zone.

3 The Main Steps of Critical Chain Technology in Project Schdule Management

3.1 Identification of critical chains

3.1.1 Duration estimation.

The estimation of process duration refers to the theoretical time required for each activity unit. When calculating the duration of an activity, three-point estimation is usually used (three times are required for each activity), that is, the expert's optimistic time a, the most likely time m, and the pessimistic time b for the activity are weighted and averaged to obtain the estimated time t for the activity, that is:

$$t = \frac{a+4m+b}{6} \tag{9}$$

3.1.2 Determine the critical path.

Calculate the time required for each activity unit using the three-point estimation method, accumulate and sum the time for each activity unit on each line in the project network diagram, and find the link with the longest required time as the critical path.

3.1.3 Re determine the critical path after balancing resource constraints.

In the project network diagram, resource conflicts may occur between various links

3.2 Determination of Buffer Size

This article is based on the RSEM method, introducing uncertainty factor coefficients, process location coefficients, time elasticity coefficients, and resource utilization factors, considering the uncertainty level of each process, to calculate the buffer size from non critical chain to critical chain, as well as the buffer size of projects on the critical chain.

3.2.1 Uncertainty factor coefficient.

Ship military enterprises sometimes encounter unforeseeable factors when retrofitting and repairing ships, such as the expansion of engineering units and natural environmental factors (rainy days, typhoons, etc.). In order to eliminate the influence of such uncertain factors, this article introduces the coefficient of uncertain factors δ ($\delta \in [0,1]$). When δ tends to 0, it indicates that the project is not affected by uncertain factors and can proceed normally. As δ gradually increases, the project is increasingly affected by uncertain factors. When δ tends to 1, the project is most affected by uncertain factors and cannot continue. This article divides the coefficients of uncertain factors, as shown in the table 1 below:

Table 1. the coefficients of uncertain factors

δ	0	0.25	0.5	0.75	1
The impact of δ on the project	Low	Lower	Middle	Higher	High

Prior to the commencement of the project, experts from the shipbuilding and military industry will be invited to review the uncertain factors of the project and determine the coefficient of uncertainty based on their experience.

3.2.2 Process Position Coefficient.

When arranging activities for a project, since each process is carried out in chronological order, the prediction of the process is more accurate when it is located closer to the starting point of the project. As the process moves backward, the difficulty of predicting the process will continue to increase. Therefore, it is necessary to introduce the process position coefficient α ($\alpha \in [0,1]$) to determine the uncertainty of different process positions in the activity chain. The text uses the midpoint of the time required for different positions of the process to represent the process position coefficient, which is the ratio of the time t_s required for the start of the project to the total time t_t required for the activity link:

$$\alpha_i = \frac{t_{si}}{t_t} \tag{10}$$

Among them, i represents the number of processes in the active unit of the link. When α_i tends towards 0, it indicates that the process is closer to the starting point of the project and has less uncertainty. When α_i tends towards 1, it indicates that the process is closer to the ending point of the project and has greater uncertainty.

3.2.3 Time elasticity coefficient.

When estimating the process time, this article uses a three-point estimation method. In order to monitor the progress of the project in each process in real time, this article introduces the time elasticity coefficient β ($\beta \in [0,1]$), which is:

$$\beta_i = \frac{t_{mi}-t_{ai}}{t_{bi}-t_{ai}} \tag{11}$$

When β_i tends towards 0, it indicates that t_m tends towards t_a, which means that the process is closer to the most optimistic completion time. When β_i tends towards 1, it indicates that t_m tends towards t_b, which means that the process is closer to the most pessimistic completion time. At this time, certain measures need to be taken to ensure the smooth progress of the process.

3.2.4 Resource utilization factor.

During the project, there may be different processes that require the same resource. Resources not only include the use of machinery and materials, but also the utilization of people. If two simultaneous processes require the same person to handle them, a resource conflict occurs, which is likely to affect the project schedule. Therefore, this article introduces the resource utilization factor γ ($\gamma \in [0,1]$), which is:

$$\gamma_i = \max_{k \in K}\left(\frac{\sum_{i=1}^{N} r_{ilk}}{R_{lk}}\right) \tag{12}$$

Among them, γ_i represents the tightness of the resources utilized by activity i, N is the total number of active units in the link, K is the total number of resources in the project, r_{ilk} is the type of resources required by activity i in segment l, and R_{lk} is the upper limit of resources available in segment l.

When γ_i tends towards 0, it indicates that the resources required for activity i in segment l are sufficient. When γ_i tends towards 1, it indicates that the k resources required for activity i in segment l have reached the upper limit of the resources available in segment l. At this point, a resource conflict will occur and resources need to be allocated.

If we calculate $\gamma_i \in (0,1)$, we need to consider the impact of resource conflicts when calculating the buffer, and multiply the calculated buffer by the correlation coefficient.

3.2.5 Buffer Setting.

On the basis of RSEM method, this article considers the influence of uncertainty factor coefficient, process location coefficient, time elasticity coefficient, and resource utilization factor on buffer setting, and calculates the buffer of each link considering the uncertainty level of each process, namely:

$$PB = \sum_{i=1}^{N}(1+\delta)\,(1+\alpha_i)\,(1+\beta_i)\,(1+\gamma_i)\left[\sum_{i=1}^{n}\left(d_{imax}-d_{iavg}\right)^2\right]^{1/2} \tag{13}$$

3.3 Critical Chain Buffer Monitoring and Progress Control

During the project implementation, various unexpected events may occur, which can lead to deviations in the schedule. Therefore, it is necessary to monitor the project progress during the project implementation.

This article will adopt Goldratt's three color monitoring method (also known as static three-point method), which sets the buffer zone into three segments through two contacts and assigns three different colors: red, yellow, and green. Project management determines the current status of the project based on the consumption ratio of the buffer zone.

When the buffer is in the first third (green), the buffer consumption is within the normal range, indicating that the project can be completed according to the scheduled plan. At this time, no relevant measures need to be taken, and the project continues to execute according to the plan; When the buffer is in the middle third (yellow), there is an abnormal consumption of the buffer. At this time, project team members should conduct timely progress control analysis to identify the cause of excessive buffer consumption and provide corresponding solutions. At the same time, in the subsequent project development, project progress monitoring should be strengthened; When the buffer zone is in the last third (red), the buffer zone is about to be exhausted. If there is still a long time before the project is completed, it means that there have been serious problems with the project and the risk of project delay is high. The project team must promptly formulate preventive measures. If the project is nearing completion at this point, although the buffer zone will be depleted, it will not have a significant impact on the completion of the project. At this point, it is only necessary to continue to strengthen monitoring of the project. As shown in Fig 1, contact A and contact B are respectively three-point points, and Table 2 is a classification table of measures taken based on the three color monitoring method. By using the three color monitoring method to monitor and issue warning measures for project engineering accuracy, buffer zone warning and countermeasures are taken, forming an annual maintenance project network and risk assessment framework diagram as shown in Fig 2.

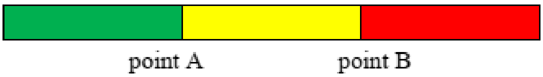

Fig. 2. Schematic diagram of three color monitoring method

Table 2. Classification of measures taken based on the three color monitoring method

Buffer consumption	Green area (the first third)	Yellow area (the middle third)	Red area (the last third
take steps	Buffer consumption is within normal range, no relevant measures need to be taken.	The consumption of the buffer zone has been abnormal. At this time, analyze the project: whether there is a resource conflict;	If there is still a long time before the completion of the project at this time, the project team should determine whether it can be completed on time and

		whether the procurement of equipment and spare parts is delayed; whether there are uncontrollable factors such as weather; Whether to expand the scope of the project and provide corresponding solutions.	whether additional resources are needed in exchange for progress. For project delays caused by uncontrollable fa ctors, the project team can negotiate with the user to increase the project cycle; At this point, the project is nearing completion and only needs to continue to strengthen monitoring.

In the example, the buffer zone is calculated, and the project engineering accuracy is monitored and early warning measures are taken through the three color monitoring method. After completing the buffer zone early warning and countermeasures, the annual maintenance project network and risk assessment framework are formed as shown in Fig. 3 below:

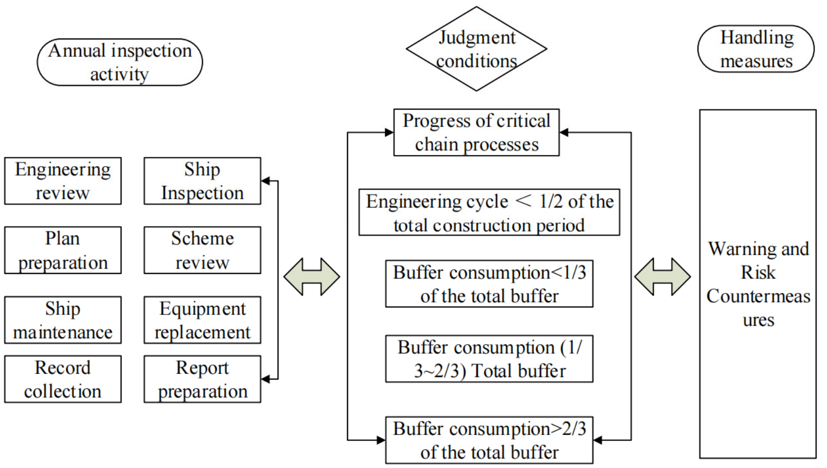

Fig. 3. Annual Maintenance Project Network and Risk Assessment Framework Diagram

4 Conclusion

This article addresses the difficulties in managing annual maintenance projects and the long maintenance periods. By introducing critical chain technology into annual maintenance projects, the following results have been achieved:

1) On the basis of critical chain technology theory, this article introduces uncertainty factor coefficients, process location coefficients, time elasticity coefficients, and resource utilization factors to obtain the calculation method of project buffer zones, and constructs an annual maintenance project schedule control model based on critical chain technology;

2) The setting of buffer zones has increased the project management's ability to control projects to a certain extent. Project management can judge the progress of projects by the consumption of buffer zones;

3) The critical chain technology has guiding significance in the management, control, and execution of annual maintenance engineering repairs, providing a new approach for project progress control.

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