Application Research of Critical Chain Technology in Project Portfolio Schedule Management

Juan Zhao*, Yao Xiao
School of Management, Shandong University of Technology, Zibo, Shandong, China
**Corresponding Author.*

Abstract: The study proposes a schedule optimization management framework for warehouse construction project clusters, driven by the goal of enhancing the efficiency and quality of the engineering delivery process. With the rapid expansion trend in modern enterprises' business activities, warehouse construction projects not only grow rapidly in scale but also increase in complexity, raising the requirements for accurate project management, especially in time planning precision. The cutting-edge project management tool, Critical Chain Method, has demonstrated significant advantages in managing uncertainty factors and resolving resource allocation conflicts in multi-project parallel processing. By implementing the Critical Chain Method in a warehouse construction project of an enterprise in Shandong Province, this study observed a significant reduction in the actual completion cycle compared to the scheduled plan. This not only improved the likelihood of completing the project on schedule but also effectively reduced both total time limit and cost. The results validate that the proposed schedule optimization strategy is scientifically sound and effective in practical project management.

Keywords: Project Management; Critical Chain; Project Buffering; Schedule Optimization Management; Schedule Control

1. Introduction

Engineering construction projects have a complex network structure and numerous tasks, involving resource allocation, construction planning, and supply chain management. It is crucial to optimize project progress and improve work efficiency through scientific and effective methods. The traditional method of project schedule management often proves ineffective in addressing these challenges; therefore, it is necessary to introduce new management thinking and tools to enhance project execution efficiency. Project schedule management technology based on the critical chain method applies the constraint principle to the project process while comprehensively considering logical relations and conditions. Current academic research focuses on optimizing each project schedule using the critical chain method: a management approach that identifies critical tasks and resources during project execution, maximizing overall progress by efficiently allocating resources and adjusting task order. However, with the continuous development of modern enterprises, single projects can no longer keep up with the enterprise growth pace; hence, the concept of project clusters emerges as widely used.

Li et al [1] introduced five indexes: risk control coefficient, resource impact coefficient, process complexity coefficient, process location coefficient, and environment coefficient. He utilized a buffer optimization model and dynamic monitoring mechanism to enhance the critical chain technology and applied the improved method to the construction schedule management of pumping station engineering. Du [2] adjusted and enhanced the critical chain method with the characteristics of modern prefabricated buildings, providing risk control measures such as buffer zones. Li et al [3] employed the critical chain method model to address key scheduling issues, systematically analyzed the actual project schedule situation, and achieved effective schedule control. In complex multi-project environments, the complexity of critical chain validation processes significantly increases. Li & Wang [4] utilized a design structure matrix for inter-project sequencing processing to handle coupling effects, and reduce process iteration frequency, and proposed a comprehensive DSM-CCM project schedule management model for the entire process. Ma & You [5] developed a critical chain schedule mathematical model for project clusters and introduced a genetic algorithm to solve it. Similarly, Liao & Zhang [6] designed a hybrid algorithm combining genetic algorithm and tabu search to solve the resource constraint problem in a multi-item environment. Gong et al [7] adopted a hybrid optimization algorithm to solve the multi-resource constraint and multi-project scheduling problems in the process of parallel ship construction. Bu et al [8], on the other hand, evaluates the importance of individual projects in a multi-project environment to identify key chains. Feng & Dong [9] focused on identifying the key chains in the multi-project system and built a schedule compression model to optimize the cost and schedule. These studies all demonstrate the application potential of intelligent algorithms in improving the efficiency of multi-project critical chain management. Tao et al. [10] conducted an in-depth study on the multi-project heuristic scheduling algorithm based on the critical chain. They determined the priority of processes by utilizing task coupling and delay penalty functions, thereby presenting a novel approach for resource allocation and schedule control in project management. The critical chain method has been widely used in the field of project schedule management.

As far as warehouse engineering is concerned, the project implementation cost, investment, safety and efficiency, and other factors are fully taken into account, and timely completion is an important goal in the project execution process, while the critical chain method can adjust the project schedule under the circumstances of limited resources to ensure that the project is completed on time. By introducing the basic idea and application process of the key chain method, and combining it with an example of a warehouse construction project, the author aims to explore the feasibility of extensive application of the key chain method in the schedule optimization management of the warehouse construction project.

2. Critical Chain Technology

2.1 Basic Idea

Under the framework of the critical chain method, comprehensive investigation is conducted on constraints such as environment and resources. This investigation yields a time sequence that takes into account the comprehensive influence of working time, logical relationship, and resource correlation. The critical chain method determines this time sequence by examining the constraints of resources under the influence of working time, logical relationship, and resource correlation. The longest method is identified as the critical chain, representing an important path for considering changes in resources.

The critical chain method emphasizes overall optimization and utilizes project buffering, input buffering, resource buffering, and other systems to mitigate the impact of unstable factors on project planning implementation. This ensures the quality of the critical chain and successful project plan implementation in a dynamic environment.

2.2 The Critical Chain Method Establishes the Steps of the Project Schedule

2.2.1 Adjust work duration estimates

On the basis of the Gantt chart formulation, the key chain's basic idea is utilized to estimate a 50% completion probability for work duration. The most optimistic time (Ta), most likely time (Tm), and most pessimistic time (Tb) for each task are determined. The three-point estimation method is then employed to calculate the duration of each task as follows:

$$F_i = \frac{T\mathrm{a} + 4T\mathrm{m} + T\mathrm{b}}{6} \quad (1)$$

This optimization technology utilizes the critical chain method to reduce unnecessary safety time, resulting in improved construction duration and implementation quality. This approach also enables operations managers to concentrate on construction activities. By considering the uncertainty associated with a 50% probability for each project, a buffer can be uniformly managed and implemented to mitigate risks.

2.2.2 Identify project critical chains

The key of the critical chain method is to first determine the key processes in important projects, and formulate the project promotion plan based on the interaction between project logic and technical constraints. In this way, the critical path of the project can be improved, the problem that the key work cannot be executed due to resource conflicts can be solved, and the resources required by the key processes can be guaranteed in a priority manner. The use of buffer Settings can also reduce the direct impact of project uncertainties on the schedule. This method not only balances the logical relationship between the processes and the contradiction of resources, but also reduces the direct impact of project uncertainties on the project schedule, and thus improves the project efficiency.

2.2.3 Set item buffer

In the early stage of construction, because the construction progress will be relatively positive, it is not very important to show the buffer zone setting. However, with the implementation of the project, after the project period reaches its peak, multiple potential problems will appear successively or in a concentrated way, and the current challenges and potential problems overlap, making the consumption of the buffer zone inevitable, and the consumption speed often exceeds the expectation. According to the central limit theorem, the greater the number of independent risk items, the more effective the overall risk management will be. Therefore, after the integrated management of project safety time, a buffer zone can effectively reduce the overall project risk level, which has been verified by many academic studies and practices.

The key chain method introduces three buffer Settings, which are item buffer, input buffer, and resource buffer. Project buffering is the provision of extra time at the end of the plan to deal with the uncertainty of the overall schedule; Input buffer is to set the time before the key process to deal with the impact of the delay or change of the previous task; Resource buffering is the time that is set for critical resources to resolve problems where a process cannot be completed on time due to resource constraints or conflicts. The length of the resource buffer is usually determined based on the actual conditions of the project, so I do not cover the setting of the resource buffer, only discuss the setting of the project buffer and the input buffer.

2.3 Application Process of Critical Chain Method in Program Schedule Optimization Management

The important idea of the critical chain method is to arrange the project timing by planning the project time margin and setting a buffer in the key interface during the reverse design of the project. At the same time, all remaining time is unified buffer preset management. The specific process is as follows:

2.3.1 Program building

By integrating related project management into a system, resources, technology, results, and benefits are taken into account, so as to coordinate the planning and implementation of various purposes within the project management cluster.

2.3.2 Determine item priority

It is used to deal with resource conflicts within the project, taking various factors into consideration to determine the priority of the project.

2.3.3 Break down project work

The most common project management method used at this stage is the work breakdown structure. By making the work breakdown structure diagram of individual projects, the project work is gradually subdivided into basic units.

2.3.4 Reproject the duration of work

On the basis of the original time planning method, in order to reduce the safety reserve of working time, use 50% of the work probability to replace the original 90% of the work probability, in order to reduce unnecessary safety time waste and jet lag.

2.3.5 Identify critical chain

By analyzing the constraints in the process of project execution, the limited resources are allocated according to the priority of the project, the parallel work is changed into serial work, and the key chain with the longest time is obtained.

2.3.6 Set buffer

You can consider the task completion date as the work time with a 50% probability, but given the uncertainty of the work time, you can give a safe date as the work buffer.

2.3.7 Management buffer

The buffer zone is controlled through the development of a management system to effectively manage and control the security time.

Through the above application process, the critical chain method can effectively optimize the project schedule management and improve the success rate and efficiency of the project execution.

3. Application of Key Chain Method in Warehouse Construction Project of an Enterprise

3.1 Project Background

With the rapid development of the business of an enterprise in Shandong Province, its product types and inventory are increasing. As the quantity of goods stored in the existing warehouse can no longer meet the market demand, the company decided to introduce a new warehouse to improve inventory efficiency and reduce inventory costs. To this end, the company plans to build three warehouses in different locations in the city. Among them, Project A (Warehouse 1) covers an area of 1500 square meters and a building area of 1000 square meters. The warehouse is planned to be built near the company's main production base to facilitate logistics transportation and cargo deployment, thereby reducing human, financial, and time costs. Project B (Warehouse 2) covers an area of 1000 square meters and a building area of 500 square meters. The warehouse is planned to be located closest to the end user to reduce the distance to provide the second leg to the customer and improve customer service levels. Project C (Warehouse 3) covers an area of 2000 square meters and a building area of 1500 square meters. The warehouse is planned to be built in a central location between end users and manufacturers and is designed to provide customers with inventory replenishment and consolidation services.

3.2 Project Work Breakdown

Based on the assumption that the macroscopic resources outside the project can meet the project needs, and according to the construction experience of the enterprise in previous projects, the work of three different types of warehouse construction projects with construction priorities A, B, and C is divided. Next, estimate the most optimistic time (Ta), most likely time (Tm), and most pessimistic time (Tb) required to complete each task, and record the estimates in Table 1.

Table 1. Work Breakdown of Warehouse Construction Project

Process code	Process name	Post-tightening operation	Ta/Day	Tm/Day	Tb/Day	Time limit for construction
A1	Support drainage and pile foundation engineering	A2、A3	28	40	49	40
A2	Earthmoving and underground structural works	A4、A6	35	60	85	60
A3	Main structure engineering	A4、A5、A6、A8	15	20	55	25
A4	Masonry work	A10	7	15	20	15
A5	Roofing equipment hoisting and lighting roof engineering	A10	12	20	30	20
A6	Installation of equipment pipeline and distribution box	A7	6	10	13	10
A7	Fire line installation	A9	10	18	38	20
A8	Curtain wall structure construction and surface material installation	A10	22	24	37	26
A9	Warehouse interior layout project	A10	9	15	21	15
A10	Acceptance work	—	29	40	51	40
B1	Support drainage and pile foundation engineering	B2、B3	23	37	40	35
B2	Earthmoving and underground structural works	B4、B6	30	58	70	55

B3	Main structure engineering	B4、B5、B6、B8	10	20	30	20
B4	Masonry work	B10	5	10	15	10
B5	Roofing equipment hoisting and lighting roof engineering	B10	10	18	28	18
B6	Installation of equipment pipeline and distribution box	B7	4	9	10	8
B7	Fire line installation	B9	6	15	18	14
B8	Curtain wall structure construction and surface material installation	B10	17	22	33	23
B9	Warehouse interior layout project	B10	6	10	15	10
B10	Acceptance work	—	20	31	35	30
C1	Support drainage and pile foundation engineering	C2、C3	40	59	85	60
C2	Earthmoving and underground structural works	C4、C6	51	77	92	75
C3	Main structure engineering	C4、C5、C6、C8	24	31	46	32
C4	Masonry work	C10	12	19	31	20
C5	Roofing equipment hoisting and lighting roof engineering	C10	14	22	35	23
C6	Installation of equipment pipeline and distribution box	C7	9	12	22	13
C7	Fire line installation	C9	10	13	31	23
C8	Curtain wall structure construction and surface material installation	C10	20	31	42	31
C9	Warehouse interior layout project	C10	8	19	24	18
C10	Acceptance work	—	30	46	56	45

According to the logical order and time of the work, the Gantt chart of the time plan for A, B, and C in the project can be prepared. The specific drawing process is shown in Figure 1. As can be seen from the figure below, the original planned completion date of Project A is July 16, 2024, the original completion date of Project B is May 9, 2024, and the original completion date of Project C is October 21, 2024.

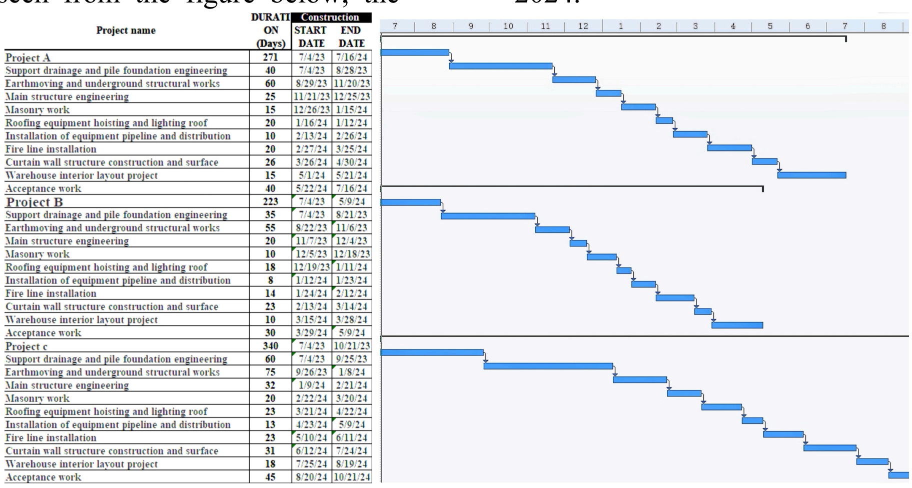

Figure 1. Gantt Chart of Project A, B and C Schedule Plan

3.3 Re-estimate Working Hours

Reduce project staff, student syndrome, and Parkinson's law in the execution of project management, so that employees can effectively engage in work before the project starts. In order to enhance the accuracy of task time prediction, the author selects the most likely completion time of 50% probability as the task time prediction. When the project schedule or implementation time is reduced, projects A, B, and C remain interdependent.

3.4 Identify and Optimize Critical Chains

When the key chain is determined after the combination of goals A, B, and C, considering the fact that A has priority over B and B has priority over C in the target group, we choose the most priority target resource for project A, then project B and finally, project C. Resource conflicts occur when A, B, and C in a task group are executed together. Therefore, the task priorities need to be adjusted according to the task priorities. Therefore, it is generally recommended to first adjust the execution of task C to the start of task B, and then adjust the execution of task B to the start of task A, so as to achieve the balance of resource conflicts among tasks. From this, it can be concluded that the critical path sequence of project A is: A1-A2-A6-A7-A9-A10; The critical path sequence of project B is B1-B2-B6-B7-B9-B10. The sequence of critical paths for item C is C1-C2-C6-C7-C9-C10, as shown in Figure 2.

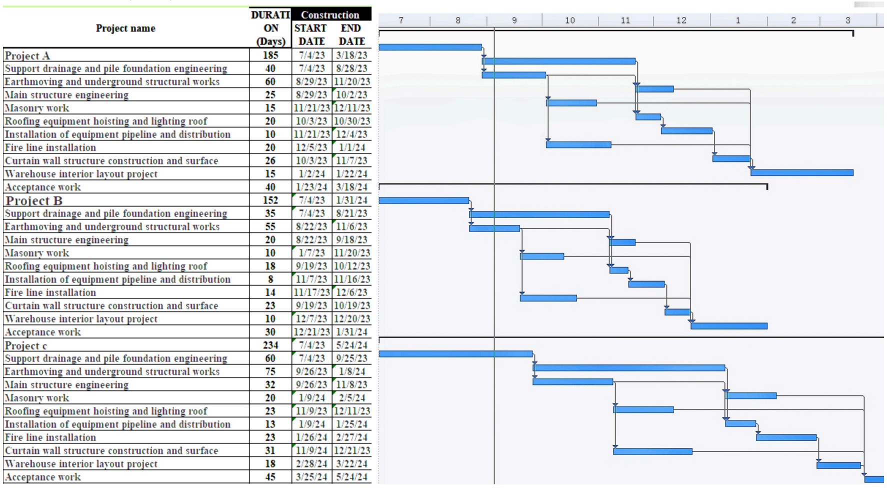

Figure 2. Gantt Chart of Project A, B and C Schedule for Key Chain Optimization

3.5 Set up and Manage Buffers

Depending on the size of the variance of each task's execution time, the buffer is allocated to both critical and non-critical tasks to deal with potential delays. According to the results of variance analysis, the sizes of the project buffer and non-critical path buffer are calculated to balance resource conflicts and improve project stability. By using the root variance method, buffers can be adjusted more accurately to deal with uncertainties and risks in task execution time. The root variance is calculated as follows:

$$PB/FB=\sqrt{\sum_{r\in R}(\sigma_{\mathrm{r}}-a_{r})^{2}} \tag{2}$$

In the formula, PB and FB represent the project buffer and input buffer respectively; R is the sum of all processes on the critical chain and non-critical chain and represents the running time of the process σ_{r} estimated by the traditional method. α_{r} represents the running time of process r estimated by the critical chain method. The author calculates the output buffer and incoming buffer of each schedule by the root variance method, so as to adjust the buffer position of the target group plan on the time graph appropriately. See Table 2 for specific cache configurations. Through the configuration of the cache in the project, the buffer is imported after the corresponding progress of the target is reached, and the buffer is added to the non-critical path, so as to realize resource scheduling. Finally, the conclusion shown in Figure 3 can be drawn.

Table 2. Project Buffer Settings

Process name	Buffer code	Item buffer/d	Input buffer/d	Buffer position
Project A	PB - A	48	—	End of item
Project B	PB - B	41	—	End of item
Project C	PB - C	62	—	End of item

	FB - A3	—	13	Progress after A3
	FB - A4	—	8	Progress after A4
	FB - A5	—	13	Progress after A5
	FB - A8	—	18	Progress after A8
	FB - B3	—	10	Progress after B3
	FB - B4	—	5	Progress after B4
	FB - B5	—	13	Progress after B5
	FB - B8	—	15	Progress after B5
	FB - C3	—	16	Progress after C3
	FB - C4	—	10	Progress after C4
	FB - C5	—	20	Progress after C5
	FB - C8	—	22	Progress after C8

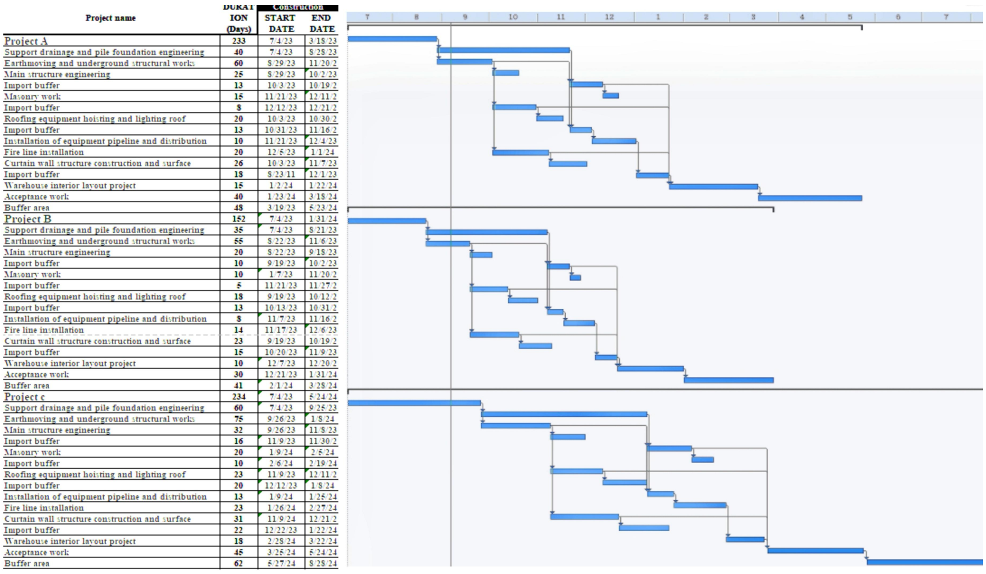

Figure 3. Gantt Chart of the Schedule for Projects A, B, and C with Buffering Added

As can be seen from the figure, Project A was completed on May 23, 2024, Project B was completed on March 28, 2024, and Project C was completed on August 20, 2024. By comparing with Figure 1, it is found that the key chain method can make the project schedule of the enterprise 38 days earlier than the original calculation period, 30 days earlier than the original calculation period of the project B plan, 44 days earlier than the original calculation period, optimize the resource allocation of the project and effectively reduce the project construction cost.

4. Conclusions

Based on the key chain method, a schedule optimization management method focusing on the warehouse construction project group is proposed. By optimizing the critical path, the delivery efficiency and quality of the project are successfully improved. However, the author is only limited to the application of the key chain method at the theoretical level, and has not discussed the resource constraints in the key chain method in depth, so further empirical research and verification are still needed in practical application. Future research could further explore the application of the critical chain method in different types of projects and further study its comparison and combination with other schedule management methods. In particular, the resource constraint in the critical chain method is carefully considered, and its effect and feasibility in practical projects are evaluated with the help of empirical research. Such research is helpful to further promote the application of the critical chain method in program management, and provide more practical management guidance and decision support.

References

[1] Liu Yongqiang, Sun Haocong, Zhu Bin, Yang Zhi-shuai. The application of

improved critical chain technique in the progress control of pump station construction. China Rural Water and Hydropower, 2024, 1-12.

[2] Du Jianfeng. Application of key chain technology in production schedule management of prefabricated building components. Dwelling, 2020(34):35-36.

[3] Li Min, Yao Zekun, Liu Renjing,Xu Qingchuan. Review of Multi-project Management Based on Critical Chain Technology. Science and Technology Management Research, 2019, 39(01):205-210.

[4] Li Jianguo, Wang Tao. The application of an improved critical chain method in programme schedule management. Project Management Technology, 2023, 21(05):153-159.

[5] Ma Guofeng, You jianxin. Quantitative Analysis of Critical Chain Multiple Project Scheduling Management. Systems Engineering-Theory & Practice.2007,(09)：64-60.

[6] Liao Liang-cai, Zhang Qi. Multi-resource and Multi-project Schedule Optimization Based on a Hybrid Genetic Algorithm and Critical Chain Method. Science Technology and Engineering.2014,14(06)：190-195.

[7] Gong Jun, Hu Tao, Liu Shengxue. Schedule management method of warships multi-project parallel construction based on critical chain and hybrid optimization algorithm. Systems Engineering and Electronics.2020, 42(08):1784-1793.

[8] Bu Zhuzhen, Liang Xiaobei, Meng Hu. Improved Method and Application of Critical Chain ldentification Based on Multi-Project lmportant Degree. Industrial Engineering and Management.2021, 26(5):187-194.

[9] Feng Jing-chun, Dong Ling-li. Construction Period-Cost Optimization of Program Based on Critical Chain Method under Multi-Resource Constraints. Chinese Journal of Management Science. 2022, 30(04):132-143.

[10] Tao Liyan, Du Haowei, Zhao Pengfei. Research on the Multi-project Schedule Management of the Key-chain Subway. Science and Technology Management Research, 2019, 39 (17):199-204.

