A new critical chain project management based on social network and software maturity model

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Abstract. With the rise of the Internet and the booming development of information technology, more and more IT projects have been launched on the information infrastructure. However, due to the large uncertainty and specificity of IT projects, the project delays are very serious. Both the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) can no longer meet the management requirements. This paper has improved the Critical Chain Project Management (CCPM) to strengthen the progress and quality management of IT projects. According to the characteristics of IT projects, an improved Critical Chain Project Management (NS-CCPM) had been proposed, and which was based on social network and software maturity models. Then the application of NS-CCPM has been specifically elaborated in three aspects: critical chain identification, buffer design, and buffer dynamic management. Finally, a case was shown, which used the Monte Carlo simulation method to verify the availability of NS-CCPM.

1. Introduction
IT project management is an important discipline that has gradually developed in recent years. Due to the large uncertainty and specificity of the tasks in the implementation process of IT projects, it is common for project extension in reality, which seriously affects the quality and goals of project management. To this end, it is essential for the project to minimize the project implementation period and reduce the cost to obtain a competitive advantage by formulating a reasonable and feasible project implementation schedule and controlling the progress of the IT project. In this regard, the traditional classical CPM/PERT method has not met the request of actual IT project because CPM/PERT assumes that the tasks are opposite to each other, and there is no interference and correlation between the resource elements of the task. The Critical Chain management (CCPM) is a new method for project schedule management. It was first proposed by Dr. Gottlar in 1997[1]. Currently, it has a very wide range of applications in the optimization of IT project management. In the application process, some defects of the critical chain method are gradually revealed: The resource constraint in project is difficult to deal with in complex situation and the application of the “50%” method to set the buffer area is irrational [2]. To resolve the resource constraint problems in project, Jin Minli proposed a project scheduling method based on resource constraints under system engineering [3], but there were still many uncertainties in the calculation of resource constraints. Liu Shixin proposed a critical chain project schedule management that minimizes the project cycle as the optimization goal [4]. Heuristic method is used to solve the project, but it still cannot solve the resource conflict problem. Herroelen tried to use the branch-determining algorithm to calculate the project's critical chain [5], but it was only applicable to project management with few tasks and simple structure. For task buffer settings using the “50%” method, ASHTIANI [6] believe that there will be a huge waste. Some scholars have
proposed a method for limiting the design of multi-resource buffers, but they are only applicable to highly deterministic mission plans and do not conform to the characteristics of IT projects [7].

This paper introduces social network theory and software maturity model, and three key points of critical chain identification, buffer setting and buffer dynamic management according to IT project characteristics and the deficiencies of traditional project management methods and critical chain project management. Improvements have been made and the NS-CCPM has been proposed. Finally, the Monte Carlo simulation method was used in a typical case to demonstrate the application of the NS-CCPM model, and compared it with the traditional project schedule management method planning results to verify the effectiveness of the proposed NS-CCPM model.

Through introducing social network theory and software maturity model based on the critical chain project management, this paper proposed NS-CCPM to improve critical chain identification, buffer setting and buffer dynamic management. Finally, a typical case and the Monte Carlo simulation was used in this paper to demonstrate the application of the NS-CCPM model. This paper also compared with the traditional project schedule management method to verify the effectiveness of the NS-CCPM model.

2. Task relationship processing in NS-CCPM

Resources and progress in project schedule management are mutually restricted and inseparable. Currently, the critical chain method does not take differences in resource requirements in different tasks into account. This leads to the phenomenon of unreasonable resource allocation and long project planning. Therefore, social network method is introduced to determine the importance of the task nodes [8] in the project by comprehensively considering the three eigenvalues of the degree of the centrality of the task node, the value of the edge of the node and the centrality of the node. On the other hand, considering that the project planner will reserve more time for the important tasks. That means the importance of the task is proportional to the task safety time, so the task time should be added when determining the importance of the task node. In summary, to determine the importance of the tasks in NS-CCPM, the following model is used as a basis for selecting the order of the execution of tasks when resource constraints arise.

Task node importance is to \( K_i \), indicating the importance of task \( i \), task node number in project is set to \( n \). Mission planning time of task \( i \) set to \( t \), centrality of node degree is set to \( C_i \), the edge degree of node degree is set to \( E_i \), centrality degree inference of node degree is set to \( \delta_i \), The importance scale of the task node \( i \) is set to \( K_i \):

\[
K_i = t * f (C_i, E_i, \delta_i)
\]  

2.1 Centrality of node degree \( C_i \):

According to social network theory, node degree centrality:

\[
C_i = \frac{g_i}{n-1}
\]  

\( G_i = \sum_i a_{ij}, a_{ij}, a_{ij} \) is the representation of the degree of the task node in \( i \) row and \( j \) column in the network.

2.2 Edge degree of the node \( E_i \):

The Edge degree of the node \( E_i \) of each node is calculated by four-step decomposition principle:

\[
E_i = \frac{E_i}{m}
\]  

The number of performed executions is set to \( m \) during the decomposition algorithm.

2.3 Centrality degree inference of node:

According to the centrality of node inter-relationship, the number of all links from the source task point to the end task point to is set to \( O \). The center of the centrality degree inference value is set to \( v=0 \), the centrality degree inference parameter is set to \( \delta_i \), the center of the centrality degree inference
value is set to $v = 0$, when $V_i$ get a link, $v=v+1$. When $V_i$ get the critical link, let $v$ to be $v^*$, then search for each link:

$$
\delta_i = \begin{cases} 
\frac{v}{o} & v = v \\
2\frac{v}{o} & v = v^* 
\end{cases}
$$

(4)

In order to determine the importance of the node, this paper introduces the concept of network efficiency to determine the weight of each parameter. The author select the most commonly used IT projects and the informatization projects the author has participated in to conduct parameter deterministic tests. The final results are shown in Figure 1:

![Result of parameter deterministic tests](image)

Finally, when the task node schedule time is $t$, we can get the node important scale:

$$
K_i = t \times (C_i + E_i + \delta_i)
$$

(5)

3. Buffer set of NS-CCPM

Buffer design is the core of the critical chain project management. In the implementation of classical project schedule management, "Parkinson's Law", "Student Syndrome" and various task safety factors affect the project duration. In order to ensure the project executor completes the goal in the most efficient way during the project in the design of critical chain management, it is necessary to eliminate the safety time for each task arrangement in the planning stage and reduce the safety time for each task. Then collect the safety time and place it at the end of the link to form a time buffer. The buffer time can effectively guarantee the progress of the entire project. His paper aims at the characteristics of IT projects, comprehensively considers the importance and maturity of tasks node in project, establishes a task node maturity evaluation system based on the software maturity model (hereinafter referred to as CMM), which is estimated through questionnaires. The maturity evaluation system set the buffer size of different levels of task nodes and the buffer size of task nodes determine the entire project buffer size.

3.1. Buffer set of NS-CCPM

CMM is an evaluation system for software project development, management and software quality improvement capabilities. This paper proposed a maturity evaluation system that is more suitable for IT projects by using the software key-domain method of CMM. The task maturity level and key-domain status description form in the project is shown in Table 1:
Table 1. Maturity evaluation system.

| key-domain status description | Task maturity level |
|-------------------------------|---------------------|
|                               | Initial level       | Repeatable level | Defined level | Manageable level | Optimization level |
|                               |                     | Defined level     | Manageable level | Optimization level |
| Task execution ideas          | None                | Have little ideas | Have mature ideas | Can do this kind of work efficiently | Can do this kind of work efficiently |
|                               | bad                 | Have ability on some part of the project | Have experience in solving such problems | Have rich experience in solving such problems | Has extensive experience in solving such problems and can anticipate possible problems and solve such problems |
| Task execution capability     | None                | Lack of similar project management experience | Have some management experience | Very familiar with this kind of task, with a lot of project experience | Very familiar with this kind of task, with a lot of project experience |
|                               | shortage            | Not enough protection | Multiple guarantees | Adequate funding and sufficient support if additional funds are needed | Adequate funding and sufficient support if additional funds are needed |
| Management team's mission experience | None | Lack of similar project management experience | Have some management experience | Very familiar with this kind of task, with a lot of project experience | Very familiar with this kind of task, with a lot of project experience |
|                               | shortage            | Not enough protection | Multiple guarantees | Adequate funding and sufficient support if additional funds are needed | Adequate funding and sufficient support if additional funds are needed |

3.2. Task buffer setting

In order to reduce the risk of task delays that may occur after the elimination of the security time, a buffer calculation is required for each task node, and the total buffer is finally placed at the end of the task. According to the characteristics of different tasks in the CMM model, this paper selects the IT projects of the Beijing International Maritime Satellite Station and the four generations of satellite communication network construction projects completed in the past two years for a total of 54 major items, and 1836 sub-tasks obtained after the WBS task decomposition. The final questionnaire get 1521 sub-task feedback from the task executors. Assume the task time in the questionnaire is \( t_1 \), and the task plan time in the project details is \( t_2 \), \( r=1-t_1/t_2 \) is the time ratio of the safety time to the task time. The final results is as table 2:

Table 2. Maturity evaluation system.

| Task level maturity | Number of task planners’ view (week) | Task time of planners’ view (week) | Project detailed time (weeks) | Security time to mission time ratio |
|---------------------|--------------------------------------|-----------------------------------|------------------------------|----------------------------------|
| Initial level       | 18                                   | 135                               | 369                          | 63.5%                            |
| Repeatable level    | 45                                   | 99                                | 189                          | 53.3%                            |
| Defined level       | 261                                  | 530                               | 863                          | 38.5%                            |
Manageable level

Optimization level

The task executor can efficiently accomplish such tasks and be able to anticipate possible problems and have rich experience in solving such problems, the management team is very familiar with such tasks and have a lot of experience in dealing with such projects. Funds can guarantee the completion of project implementation according to the project plan. If needed Additional funding can also be given.

According to the experimental results, the buffer can be set to be simplified as the following calculation method:

\[
M_{it} \text{is the maturity level of task } i, P_t \text{ is the planned time of task } i, S_t \text{ is current planned time of task } i, B_t \text{ is the buffer time of task } i.
\]

\[
\begin{align*}
S_t &= 40\% \times P_t; D_t = 50\% \times (1 - 40\%) \times P_t & M_{it} &= 1 \\
S_t &= 50\% \times P_t; D_t = 50\% \times (1 - 50\%) \times P_t & M_{it} &= 2 \\
S_t &= 60\% \times P_t; D_t = 50\% \times (1 - 60\%) \times P_t & M_{it} &= 3 \\
S_t &= 70\% \times P_t; D_t = 50\% \times (1 - 70\%) \times P_t & M_{it} &= 4 \\
S_t &= 80\% \times P_t; D_t = 0 & M_{it} &= 5
\end{align*}
\]

Among them, \( M_{it}, t=\{1,2,3,4,5\} \) represents the task maturity level as initial level, repeatable level, defined level, manageable level, and optimization level.

4. Project management based on NS-CCPM

The critical chain method essentially eliminates the uncertainty of the project duration through buffer settings and redistribution. This method can effectively mobilize the potential of employees, and can also control the duration within the required range when deviations or uncertainties occur.

4.1. NS-CCPM Critical Chain Identification and buffer setting

The critical chain project management algorithm is to identify the task’s resource constraints, and then establish the critical chain, instead of using the critical path in the traditional project management as the project constraint. Therefore, after adjusting the order of the parallel tasks in the network diagram, the resource constraint problem of critical chain identification is solved, and then the critical chain identification scheduling algorithm needs to be established to complete the identification of the critical chain and the Maturity evaluation system need to be used to calculate the buffer. This paper uses the cycle scheduling to complete the identification of critical chains, the specific method is as follows:

Step 1: WBS task decomposition method is used to decompose all the tasks in the project, mark all the task nodes and use logic arrows to show the logical relationship between each node.

Step 2: Task planner estimate the planning time of each task and determine the buffer time setting according to the task maturity.

Step 3: Each task node configures its resource allocation in the project network.

Step 4: Node importance scale is calculated for all task nodes.

Step 5: Insert time value \( t \) to calculate \([t, t+1]\) step by step from \( t = 0 \) to see if the resource meets the demand of the resource within the time period, and judge whether the supply of the resource is greater than the resource demand. If step 6 is performed, if not, go to step 7.

Step 6: Select the task in the time period \([t, t+1]\) to see if there are concurrently executed tasks and resource conflicts between the tasks, sort the tasks according to the important scale of the node. If the task’s demand for resources exceeds this amount of time, the tasks that without enough resource to start will postpone to next time period.

Step 7: If \( t+1<T \) (total duration), go back to step 5, otherwise go to step 8.

Step 8: Reassign resources of each task node by comparing node importance scale of them.
4.2. NS-CCPM Buffer Monitoring

During the implementation of the project, the progress of the project can be traced through the monitoring of the consumption of resources in the buffer zone. This prompting the project managers to take appropriate actions to complete the supervision and management of the project and to complete the project on schedule. The traditional buffer monitoring method has a fixed alarm trigger point, which triggers a large number of invalid alarms. This paper proposes a dynamic buffer monitoring model based on the CMM model. It dynamically monitors the setting according to the actual situation during project execution, dynamically calculates the buffer size, and then dynamically adjusts the trigger points so that the alarms from the buffer monitoring can meet actual project progress.

4.2.1. Dynamic buffer adjustment

The size of the project buffer is a reflection of the uncertainty of the project. During project execution, the project uncertainty will decline. In this case, the progress of the project can be expressed in terms of the buffer time the project required and the size of the remaining buffer time. This article uses the shear method to calculate the dynamic buffer size.

Assume that there are a total of \( N \) activities in a CCPM project network. After critical chain identification, there are \( O \) task chains in the network. Set the buffer size of each task chain to \( B_0 \) and the number of tasks in the project to \( n_0 (o=1,2,\ldots,O) \), where \( o=1 \) represents the critical chain for the entire project. Then, \( \sum_{o=1}^{O} n_o = N \). \( V_i^o \) (\( 1 \leq i \leq n_o, 1 \leq o \leq O \)) indicates the number \( i \) task on the number \( O \) chain.

Let \( V_i^o \) be the mission planning time at time \( t \) as \( D_p(V_i^o) \), the mission actual time as \( D_A(V_i^o) \), the task completion ratio is \( P_i^o \), and the task has been executed as \( D_e(V_i^o) \), the remaining part of the task is \( D_o(V_i^o) \), and the task buffer time consumption is \( B_C_i^o \):

\[
B_C_i^o = D_e(V_i^o) * (1 - P_i^o)/P_i^o
\]

In formula (5) it is indicated that the task \( V_i^o \) estimates the actual duration at time \( t \) according to the proportion the task has been performed and the percentage completed.

\[
B_C_i^o = \sum_{k=1}^{i-1} D_A(V_{ik}^o) + \frac{D_e(V_{ik}^o)}{P_{ik}^o} - \sum_{k=1}^{i} D_p(V_{ik}^o)
\]

Equation (6) indicates that the task buffer time consumption at the time \( t \) is the difference between the actual completion time and the planned completion time of number \( i \) task.

The required buffer size of the remaining task nodes in the activity chain \( o \) at time \( t \) is \( B_R_i^o \):

\[
B_R_i^o = \frac{1}{2} (D_R(V_i^o) + \sum_{k=i+1}^{n_o} D_p(V_{ik}^o))
\]

4.2.2 Buffer monitoring point settings

The buffer monitoring point setting is the node that analyzes the project buffer during project execution. This article set up in the following situations as monitoring points: First, after each activity on each activity chain complete, a monitoring point is set up for monitoring. The second is to dynamically set up real-time task monitoring points. Monitor the implementation of the project regularly. Here we set the monitor value \( \mu \):

\[
\mu = \frac{\text{the buffer size required by the remaining tasks on the active chain}}{\text{the actual remaining buffer size on the active chain}}
\]

If \( \mu \leq 1 \), it means that the remaining buffering time is enough and there is no need to perform monitoring. If \( \mu > 1 \); indicates that the buffer time in the buffer may be insufficient for the remaining tasks. It is necessary to perform monitoring and take corresponding actions according to the monitoring execution. In this way, the progress of the project is monitored in real time by monitoring the value of \( \mu \).

This article design the dynamic monitoring trigger point according to the idea of dividing the maturity of the task in the CMM. First, according to the maturity evaluation system, set the task buffer as described in 3.2. The total buffer time of the project is the sum of the buffer time of each task planned on the link.
Let $V_i^a$ denote the number $i$ task on the number $a$ chain. After task $i$ is executed, perform a monitoring, or a monitoring in the execution of $i$.

Let parameter $\alpha$ be the remaining time in the buffer after executing task $i$, $\beta$ is the buffer time of the project, $\gamma$ is the actual project execution time after task $i$ is executed, $\delta$ is the planned time of task $i$, and the contact parameter is $\Omega$:

$$\Omega = \frac{\gamma}{\delta} \cdot \frac{\beta - \alpha}{\beta} \quad (11)$$

The first contact is $2/3 \Omega$; the second contact is $1/3 \Omega$. The value of the contact varies with the actual execution of each task. A yellow warning is issued when the first contact is triggered and a red warning is issued when the second contact is triggered.

5. Project management based on NS-CCPM

5.1. Basic conditions of the project

The project is the construction of an antenna radio frequency system for a satellite station. Decompose the task through WBS according to the project data. The specific project task table is shown in Table 3. The resource requirement in this case is human resources, where the same manufacturer team can only perform one job at a time. Using E in table3 represent engineer and M represent manufacturer.

| Task                        | Task numbers | Pre-task | Task planning time (weeks) | Resource requirement |
|-----------------------------|--------------|----------|----------------------------|----------------------|
| Environmental & Electromagnetic survey | A            | —        | 2                          | 2Es from M1          |
| Cabin construction          | B            | A        | 8                          | 10Es from M1         |
| Antenna-foundation bed      | C            | B        | 6                          | 10Es from M1         |
| construction                |              |          |                             |                      |
| Antenna construction        | D            | C        | 6                          | 8Es from M1          |
| RF equipment admission      | E            | B        | 2                          | 3Es from M2          |
| debugging                   |              |          |                             |                      |
| Antenna control equipment   | F            | B        | 1                          | 2Es from M1          |
| admission debugging         |              |          |                             |                      |
| Network & server            | G            | B        | 1                          | 2Es from M3          |
| equipment admission         |              |          |                             |                      |
| RF equipment installation   | H            | E        | 3                          | 3Es from M2          |
| & adjustment                |              |          |                             |                      |
| Antenna control equipment   | I            | F        | 1                          | 2Es from M1          |
| installation                |              |          |                             |                      |
| Antenna test                | J            | D,I      | 2                          | 3Es from M2          |
| Antenna, antenna control    | K            | J,H,G    | 8                          | 3Es from M2 & 2Es from M1 |
| equipment & radio           |              |          |                             |                      |
| frequency equipment joint   |              |          |                             |                      |
| debugging                   | L            | —        | 10                         | 4Es from M2          |
| Radio frequency, antenna    |              |          |                             |                      |
| system monitoring           | M            | L        | 6                          | 4Es from M2          |
| software development        |              |          |                             |                      |
| Radio frequency, antenna    |              |          |                             |                      |
| system monitoring           |              |          |                             |                      |
software testing, installation
RF antenna system and IF system joint test
Inmarsat network test
System test
Project Acceptance

Table 4. Critical chain identification and buffer setting table of 3 method.

| Task number | CPM | CPM | CCCM | CCCM | NS-CCPM | NS-CCPM |
|-------------|-----|-----|------|------|---------|---------|
| A           |     |     | 2    |     | 1       | 1.4     |
| B           | A   | 8   | A    | 4   | A       | 6.4     |
| C           | B   | 6   | B    | 3   | B       | 4.8     |
| D           | C   | 6   | C    | 3   | C       | 4.8     |
| E           | B   | 2   | B    | 2   | B       | 1.4     |
| F           | B   | 1   | D    | 0.5 | D       | 0.7     |
| G           | B   | 1   | B    | 0.5 | B       | 0.8     |
| H           | E   | 3   | J    | 1.5 | E       | 2.4     |
| I           | F   | 1   | F    | 0.5 | F       | 0.8     |
| J           | D,I | 2   | I    | 1   | I       | 1.6     |
| K           | J,H,G | 8 | FB2,J,FB3 | 4 | FB2,J,FB3 | 4.8 |
| L           |     | 10  | 5    |     | 7       |         |
| M           | L   | 6   | L    | 3   | L       | 4.2     |
| N           | K   | 6   | K    | 3   | K       | 4.2     |
| O           | K   | 2   | K    | 1   | K       | 1.2     |
| P           | O,M,N | 2 | O,FB1,FB4 | 1 | O,FB1,FB4 | 1.2 |
| Q           | P   | 1   | P    | 0.5 | P       | 0.8     |
| FB1         |     |     | M    | 4   | M       | 2.4     |
| FB2         |     |     | H    | 0.25| H       | 0.3     |
| FB3         |     |     | G    | 0.25| G       | 0       |
| FB4         |     |     | N    | 1.5 | N       | 0.9     |
| PB          | Q   | 10.5| Q    | 2.85|         |         |

5.2. Project planning results
According to the data of task decomposition in Table 2, critical method and task planning time of the traditional CPM method(CPM in table3), the classical critical chain management (CCCM) (using the traditional 50% method for buffer setting) and the improved critical chain management NS-CCPM are proposed in this paper as table 4.

According to the critical path or critical chain identified in Table 3, the critical path under the classical CPM method is A-B-C-D-J-K-O-P-Q, and the project duration is 37 weeks; the classical critical chain management is A-B-C-D-F-I-J-H-K-O-P-Q-P-B, and the project duration is 31.5 weeks;
under the NS-CCPM The critical chain is A-B-C-D-F-I-J-K-O-P-Q-P-B. The project duration is 31.35 weeks.

Considering that there will be a large number of uncertainties in the implementation of project management (assuming that the task duration meets the normal distribution function), the Monte Carlo simulation (simulated 1000 times) is needed to compare the duration of the classical CCPM and the NS-CCPM:

Based on the calculation results above, it can be concluded that: First, the final project plan period for the improved critical chain method and the classical critical chain method proposed in this paper is shorter than the CPM method. The average of the three methods is 31.33 weeks (NS-CCPM) and 31.41 weeks (traditional CCPM) and 37 weeks (CPM). Second, the improved critical chain method proposed in this paper is more stable than the classical critical chain method. In the coefficient of variation, the classical critical chain management is 0.10, which is higher than the improved critical chain method of 0.06; the longest and shortest simulation duration is 20.65 weeks and 41.24 weeks (traditional CCPM) which have a bigger fluctuation range than the improved critical chain method that have the number 23.81 weeks and 37.30 weeks (NS-CCPM).

6. Conclusion
This paper puts forward an improved critical chain project management method, determines the importance of the task through the social network theory method with it the order of the task execution can be determined when the resource constraints occur; the software maturity model is established through the CMM theory, it is used to determine the buffer settings for each type of task. The paper also establish a new dynamic buffer monitoring method to solve the ineffectively trigger warnings as the project progresses in traditional buffer management. Finally, an actual case analysis shows that the improved critical chain method proposed in this paper is more effective and reliable.

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