The Schedule Optimization and Control of Nuclear Power Construction Project Prophase Based on Petri Network

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Abstract. The work content of nuclear power plant project prophase covers a wide range, involves many kinds of professional, which cause the work coordination of the whole stage more difficult, have very strong complexity and uncertainty. On the basis of WBS decomposition in the initial feasibility study phase of nuclear power project, a model based on delay Petri network was established, the critical path of the network plan was found, the reachable marking graph(RMG) was formed, and the optimal state path was determined by calculating the arrival time of all states in the graph, thus project schedule optimization was achieved. The research results have contributed to the development of nuclear power plant project, by controlling the project schedule of the research phase, the level of China's nuclear power construction project managements have been improved, and the development of nuclear power project have been promoted.

Introduction

With the exploitation and usage more than 50 years, nuclear energy has become the kind of energy which is economical, reliable and clean in the world. The voice of global GHG emissions mitigation is heightening, requiring the path of electric power structure optimization adjustment to accelerate. Nuclear energy is the core of future global emission reduction low-carbon energy, and nuclear power will certainly play a bigger role [1]. The work in nuclear power construction pre-project concludes three aspects that project approval and administrative licensing, plant site project preparation, main work preparation [2].Among them, all the work contents involve national laws and regulations, various administrative provisions of relevant leading department of their trades at the central level and all kinds of resource under the management of local government, highly policed. Because of the long operative time of nuclear power, many external interface of every link and obvious logical relationship between links, the work has strong logical relation and effectiveness [3]. Besides, the work content of nuclear power preliminary work covers a wide range, involves many kinds of professional, which cause the work coordination of the whole stage more difficult, having very strong complexity and uncertainty.

In the condition of long cycle, project will meet unforeseen factors' influence in progress process, such as harsh climate, limited resources, delayed capital and managers' instability which also is uncertain factor affecting project normal progress, etc. [4]. These uncontrollable, unforeseen factors will enhance the difficulty of nuclear power project schedule control. Ineffective schedule control would bring proprietors various losses, far beyond interest, and electricity generation delay is even inestimable to national economic development [5]. So, at project prophase, large-scale nuclear power project need not only feasibility arguments about itself, but also scientific plan with its scheduling. On the basis of domestic and overseas correlational studies, this study achieves work schedule control during nuclear power construction period by applying WBS decomposition nuclear power construction project prophase work and using relevant schedule mathematical methods and models.

Petri network a mathematical expression to discrete parallel system. Considering Petri network nature and content feature in the paper comprehensively, the paper chooses Petri network to be study method. With great uncertainty of nuclear power construction project prophase time limit, we can only confirm upper limit and lower limit of work content time. Exactly, Petri network optimizes on the basis of different work content upper limit time and lower limit time. And Petri network has simple computational process relatively which fits to our nation's nuclear power construction project prophase schedule optimization and control.

The nuclear power construction pre-project time limit analysis based on WBS

In our country, nuclear construction project generally considers nuclear bottom pouring the first tank of concrete as the boundary to differentiate nuclear power construction project prophase and nuclear power construction project design building period. With so much study work content in the paper, we make the example with preliminary feasibility study to analyze in details.

Work content at preliminary feasibility study stage

According to time, nuclear power construction project prophase work can be divided into two stages, prophase preparation stage and construction preparation stage. According to present relevant management measures established by NDRC(National Development and Reform Commission), the demarcation point of prophase preparation stage and construction preparation stage is getting travel permit what means NDRC agree and reply the prophase work supporting document. The prophase preparation stage in nuclear power construction project mainly includes preliminary feasibility study and feasibility study. Preliminary feasibility study gets plant site appraisal advice, while feasibility study mainly gets project examination and approval advice.

Preliminary feasibility study is the base of feasibility study, and its work mainly includes nine aspects as following: ①studying electric power system of project; ②studying population distribution near the plant site; ③studying the environment surrounding plant site and external event overview; ④studying traffic status and heavy-cargo transportation condition; ⑤studying geologic and seismic condition; ⑥studying plant site engineering hydrology and water usage condition; ⑦studying meteorological condition, including brief extreme weather phenomena; ⑧studying engineering preliminary scheme; ⑨environmental impact assessment.

In pre-feasibility study stage, the goal is mainly compiling three reports, plant site general election report, pre-feasibility study report and project proposal. After reading literature, expert interviews and so on, we confirm the work content in nuclear power construction project preliminary feasibility study stage, the needed supporting documents shown as Tab.1. With the consideration of logical relation analysis of every work, we divide the work content in this stage into five small stages in time sequence and number them is shown in Table 1.

Tab.1 Supporting documents required for the feasibility study phase

Work number	required getting documents	approving and accepting administration
1-1	advice document that DRC of province or municipality agree carrying out nuclear power project prophase work	DRC of province or municipality
2-1	plant site general selection report	proprietors
3-1	review advice about plant site general selection report	committee of experts
3-2	intentional document that construction competent department of province or municipality agree plant location in principle	construction competent department of province or municipality
3-3	intentional document that territorial resources competent department of province or municipality agree using plant site land in principle	territorial resources competent department of province or municipality
3-4	intentional document that environmental protection agency of province or municipality agree carrying out nuclear power plant site prophase work in relevant area	environmental protection agency of province or municipality
3-5	document that military zone the site belongs to agree plant location	military zone the site belongs to
3-6	document that aviation authority in site area states overhead civil air line position and distance to plant plan range	aviation authority in site area
3-7	intentional document that provincial level(or above) grid company agrees nuclear power plant access system	provincial level(or above) grid company
3-8	intentional document that basin water competent administrative department agree nuclear power plant take water in principle	basin water competent administrative department
3-9	intentional document that provincial level ocean competent authority agree project use ocean in principle	provincial level ocean competent authority
3-10	supporting documents that provincial historical relic administrative department states the condition of involved historical relic protection site and covered ascertained historical relics	provincial historical relic administrative department
4-1	preliminary feasibility study report	proprietors
4-2	review comments about preliminary feasibility study report given by committee of experts	committee of experts
5-1	proposal for the project	proprietors

Labor-hour confirmation in pre-feasibility study stage

With different project location, the nuclear power project work content differs. Especially, the work gaining supporting documents relevant with plant sites differs much. As the condition in different plant site location is different, the administration for approval differs, too, such as geology seismic condition certification, no historic preservation certification, no minerals certification and so on. At the same time, with the development of time and policy, the work content in preliminary feasibility study stage in this paper will change.

Considering the factors above, it’s hard to make accurate prediction the time limit of project. During the study period, authors communicated with experts in this field. The authors wanted to confirm the labor-time in preliminary feasibility study stage with expert advice method, but experts said that it’s impossible to predict work labor-time in this stage, what could be predicted are time upper limit and time lower limit of every work. So, the paper establishes schedule optimization and control model of nuclear power construction project based Petri network. In initial modeling, symbols express time upper limit and time lower limit of work in every stage. Making the example of preliminary feasibility study stage, labor-time of every work is shown as Table 2.

Tab.2 Working hours of Preliminary feasibility study stage

work number	required getting documents	labor-time upper limit	labor-time lower limit
1-1	advice document that DRC of province or municipality agree carrying out nuclear power project prophase work	$T_{1\text{-}1s}$	$T_{1\text{-}1x}$
2-1	plant site general selection report	$T_{2\text{-}1s}$	$T_{2\text{-}1x}$
3-1	review advice about plant site general selection report	$T_{3\text{-}1s}$	$T_{3\text{-}1x}$
3-2	intentional document that construction competent department of province or municipality agree plant location in principle	$T_{3\text{-}2s}$	$T_{3\text{-}2x}$
3-3	intentional document that territorial resources competent department of province or municipality agree using plant site land in principle	$T_{3\text{-}3s}$	$T_{3\text{-}3x}$
3-4	intentional document that environmental protection agency of province or municipality agree carrying out nuclear power plant site prophase work in relevant area	$T_{3\text{-}4s}$	$T_{3\text{-}4x}$
3-5	document that military zone the site belongs to agree plant location	$T_{3\text{-}5s}$	$T_{3\text{-}5x}$
3-6	document that aviation authority in site area states overhead civil air line position and distance to plant plan range	$T_{3\text{-}6s}$	$T_{3\text{-}6x}$
3-7	intentional document that provincial level(or above) grid company agrees nuclear power plant access system	$T_{3\text{-}7s}$	$T_{3\text{-}7x}$
3-8	intentional document that basin water competent administrative department agree nuclear power plant take water in principle	$T_{3\text{-}8s}$	$T_{3\text{-}8x}$
3-9	intentional document that provincial level ocean competent authority agree project use ocean in principle	$T_{3\text{-}9s}$	$T_{3\text{-}9x}$
3-10	supporting documents that provincial historical relic administrative department states the condition of involved historical relic protection site and covered ascertained historical relics	$T_{3\text{-}10s}$	$T_{3\text{-}10x}$
4-1	preliminary feasibility study report	$T_{4\text{-}1s}$	$T_{4\text{-}1x}$
4-2	review comments about preliminary feasibility study report given by committee of experts	$T_{4\text{-}2s}$	$T_{4\text{-}2x}$
5-1	proposal for the project	$T_{5\text{-}1s}$	$T_{5\text{-}1x}$

Previous schedule optimization of nuclear power construction project

Schedule of pre-feasibility study phase

The paper uses the single code network diagram of the network planning technology in the beginning of the planning, the preparation processes are as follows: firstly, we should understand the work content of this paper fully, sort out the working relationship among the supporting documents, number and list for each job, so that determine the location of the each job in the network diagram; next, we can draw network diagram according to the node's position and the logical relationship between the nodes; finally, we also need to adjust network diagram according to the presented contents, such as giving workshop organization relationship, so as to make the schedule become compact and perfect. The schedule diagram of nuclear power construction project pre-stage pre-feasibility study phase is drawn by single code network drawing rules, which is shown in Figure 1.

Schedule optimization based on Petri net

We have made clear the activity time of each job in this paper, including the upper bound of time (α) and the lower bound of time(β). Meanwhile, the assumption that the real time of each job (t) is floating between the upper and lower bounds of the time, i.e. $\alpha \le t \le \beta$. Based on the logical relationship between the 1.1 in the analysis of the various work, we can start modeling [6].

Set $\sum = \{1-1, 2-1, 3-1, \ldots\ldots 5-1\}$ is a collection of work activities in this phase, $P_{Xxy}\left(x, y \in \sum\right)$represents control places which play a controlling role between activity x and active y, and for all control places, the upper and lower bounds of the time all is 0. After the start of the activity, only when $M(S_{xy}) \geq 1$, Sxy's Subsequent changes may occur at any time. In the model, in order to show the beginning and end of the work, the two parameters XS，Xf are introduced to represent the beginning and end of the activity respectively. In addition, when the identification of control place $M(S)=1$, the activity S is underway. From this, we can use the delay Petri net to build the initial model, which is shown in Figure 2.

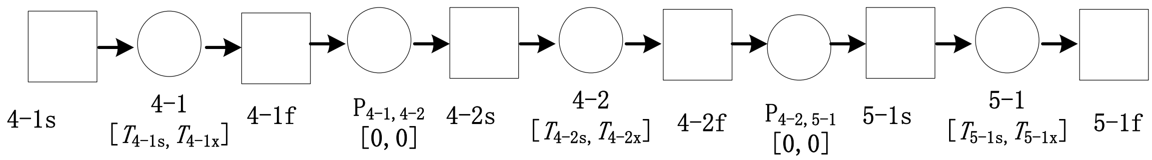


Fig.2(c) The Petri network model of Preliminary feasibility study stage

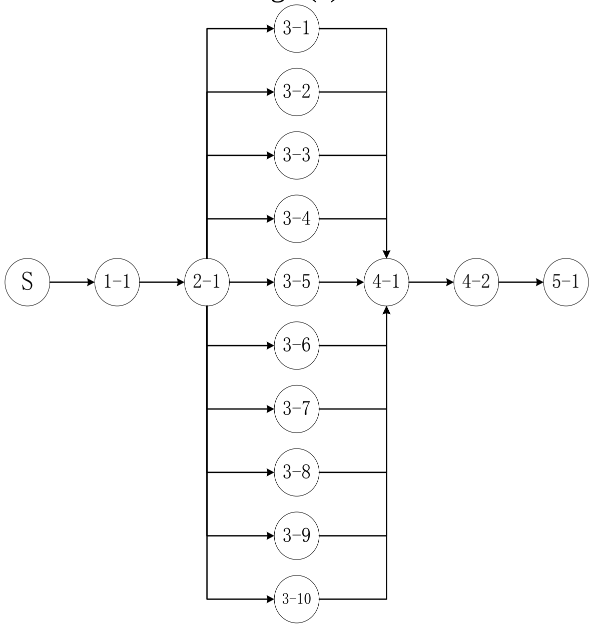
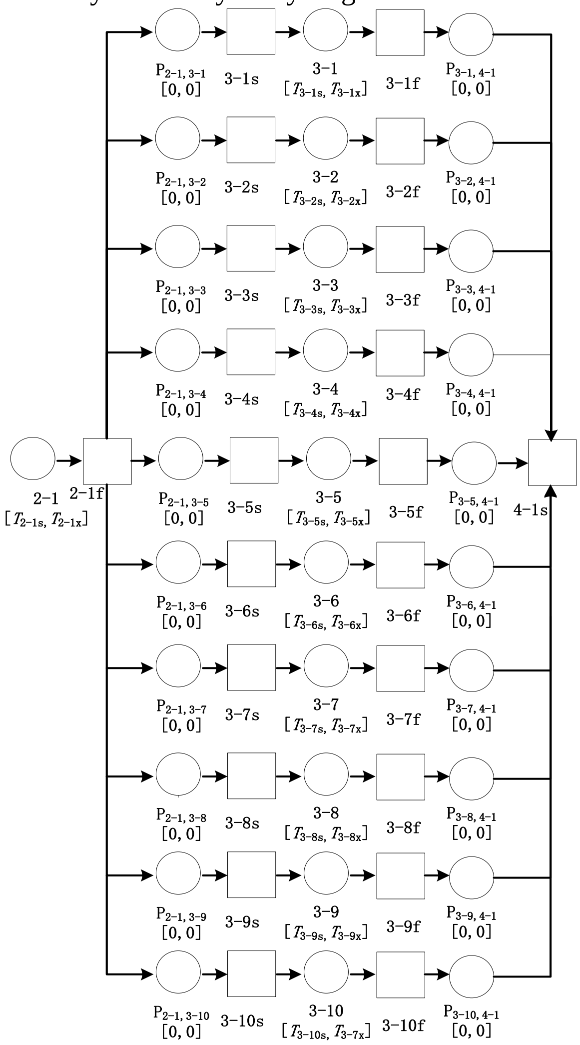


Fig.1 The schedule of Preliminary feasibility study stage



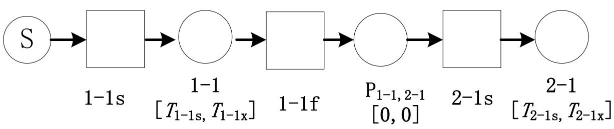


Fig.2(a) The Petri network model of Preliminary feasibility

Fig.2(b) The Petri network model of Preliminary feasibility study stage

Then, we elaborate the solving process of the key processes, and take the preliminary feasibility study stage for example [7].

Calculate the start time and end time of the work

$E_1(S)$ represents the earliest start time that is calculated by the upper bound of the time; $L_1(S)$ is the latest start time that is calculated by the upper bound of the time; $E_2(S)$ is the earliest start time that is calculated by the lower bound of the time; $L_2(S)$ is used to represent the latest start time that is calculated by the lower bound of the time. In the calculation process, we use So to represent the beginning of project, with Se to represent the end of the project [8]. The formulas for calculating the starting time and ending time are as follows. Specific applications can be based on the specific circumstances of the project, considering time, area, nuclear power plant type and other factors, the project expert team would estimate the upper and lower bounds of the time for all the work.

$$E_1(S)=\begin{cases} 0, & 当S=S_0 \\ \max\limits_{S'\in{}^\bullet T}\{E_1(S')+\alpha(S')\}, & 当{}^\bullet S=\{T\} \end{cases} \tag{1}$$

$$E_2(S)=\begin{cases} 0, & 当S=S_0 \\ \max\limits_{S'\in{}^\bullet T}\{E_2(S')+\beta(S')\}, & 当{}^\bullet S=\{T\} \end{cases} \tag{2}$$

$$L_1(S)=\begin{cases} E1(S), & 当S=S_e \\ \min\limits_{S'\in T^\bullet}\{L_1(S')\}-\alpha(S'), & 当S^\bullet=\{T\} \end{cases} \tag{3}$$

$$L_2(S)=\begin{cases} E_2(S), & 当S=S_e \\ \min\limits_{S'\in T^\bullet}\{L_2(S')\}-\beta(S'), & 当S^\bullet=\{T\} \end{cases} \tag{4}$$

(1) Find out the key process

The ideal main working procedure line is that each place is satisfied with $E_1(S)=L_1(S)$ in the directed path. It is the main working procedure line that reflects the time when the whole project tries to finish, and TE_1 is the total project time which is calculated according to the time lower limit. The sound main working procedure line is that each place is satisfied with $E_2(S)=L_2(S)$ in the directed path. It is the main working procedure line that reflects the time when the whole project must guarantee, and TE_2 is the total project time which is calculated according to the time upper limit [9].

Form the reachable marking graph(RMG) of Petri net

The RMG that don't contain the directed circuits of Petri net is called $RMG(\Sigma)$. In the graph, the node M can be used to represent the different states of the project in the deployment process. The RMG from Figure 2 can be obtained by computer program. In order to clearly display the RMG, the Petri model in Figure 2 is simplified, and the specific content simplifies the ten tasks in the third phase into two tasks, only including 3-1 and 3-2. After the simplification, the RMG is obtained, which is shown in Figure 3. In the RMG, the nodes in the shape of circle represent the different working conditions, which can be used to reflect the completion of different work contents. Because the different nodes represent the progress of all the work in the same stage, with the table of the node interpretation in the RMG, we can clearly know what work has been done and what work is still in progress [10]. Directed arrows in the graph represent the changes in the Petri model, specifically including the start and end of each job in the network plan. According to the RMG, a reasonable construction route can be designed.

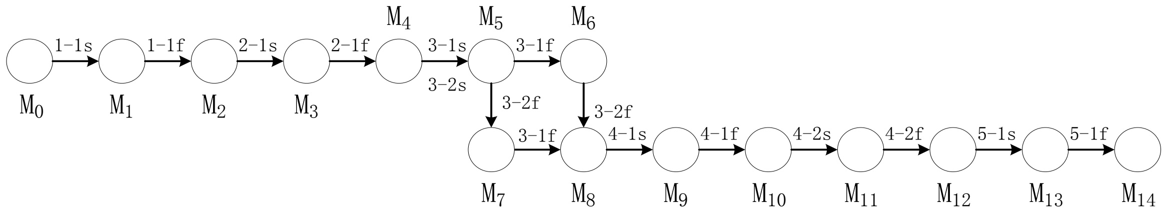


Fig.3 The RMG of Preliminary feasibility study stage

Among them, in the RMG of preliminary feasibility study phase, the represented states by each node M are shown in Table 3. For example, the state of the node M0 represents the work just beginning; the state of the node M1 represents the work 1-1 is underway; the state of the node M6 represents the work 3-1 has been completed, while the work 3-2 is still underway.

Tab.3 Node state of RMG

Node	State	Node	State
M_0	S_0	M_8	$P_{3\text{-}1,4\text{-}1}$,$P_{3\text{-}2,4\text{-}1}$
M_1	1-1	M_9	4-1
M_2	$P_{1\text{-}1,2\text{-}1}$	M_{10}	$P_{4\text{-}1,4\text{-}2}$
M_3	2-1	M_{11}	4-2
M_4	$P_{2\text{-}1,3\text{-}1}$,$P_{2\text{-}1,3\text{-}2}$	M_{12}	$P_{4\text{-}2,5\text{-}1}$
M_5	3-1, 3-2	M_{13}	5-1
M_6	$P_{3\text{-}1,4\text{-}1}$,3-2	M_{14}	S_e
M_7	3-1,$P_{3\text{-}2,4\text{-}1}$		

Calculate the arrival time of all the states in the RMG

$E_1(M)$ and $L_1(M)$ are used to represent the earliest arrival time and the latest arrival time of the state M that are calculated according to the time upper limit of each work, respectively. $E_2(M)$ and $L_2(M)$ are used to represent the earliest arrival time and the latest arrival time of the state M that are calculated according to the time lower limit of each work, respectively. The formula is as follows.

$$\begin{cases} E_1(M)=max\{E_1(S_i)|S_i\in M\} \\ E_2(M)=max\{E_2(S_i)|S_i\in M\} \\ L_1(M)=min\{L_1(S_i)+\alpha(S_i)|S_i\in M\} \\ L_2(M)=min\{L_2(S_i)+\beta(S_i)|S_i\in M\} \end{cases} \tag{5}$$

Obtain the optimal state path

In the key process of Petri net, each key step corresponds to multiple nodes in the $RMG(\Sigma)$, synthesize the RMG and four calculated values that obtained from the last step, selects node of $E(M)\le L(M)$, that is, the earliest time to reach the node is not greater than the latest time. Then according to the RMG and network plan, we can find out the nodes that palaces corresponds to the $RMG(\Sigma)$ in the key process， thus the key works can be concluded. On this, we can get a best path [11].

Conclusions

This paper mainly studies the preliminary optimization and control of nuclear power construction pre-project. By constructing the Petri model and the RMG, the key steps in the process planning of the stage are solved, and progress schedule is optimized. Because of the change of the nuclear power construction pre-project, the paper fails to predict the working hours of a specific project. For the research content of this paper, the expert forecast method is most suitable method, but the expert may have little knowledge about the project. We can study the working time budget in the future, and put forward a more suitable method for predicting the working hours of nuclear power construction projects.

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