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Research on the Management of Delays in a Construction Plan

By

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Acknowledgements

Eleven months ago, I arrived in Rotterdam to start my master study in MEL. It is an excellent experience because I really enjoy the friendly atmosphere for learning, discussing and thinking about important problems not only in the field of maritime economy but also in life.

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Abstract

Dutch shipbuilding once dominated the market during the Golden Age. Nowadays, it is still famous all around the world because of the sound quality control. Similar to other manufacturing industries, the shipbuilding process requires much scheduling and planning to avoid or eliminate the possible delays in ship building process.

On the other hand, advanced planning tools such as PERT network and critical path method developed during the application to manufacturing industries. Different approaches towards almost every aspect of the scheduling tools increased the popularity in real industries,

To manage the possible delays by applying practical scheduling tools is the main topic in this research. In an effort to solve the problem of possible delays, three steps including critical path identification, activity time estimates and scheduling strategy application are conducted. The results of the case study prove the effectiveness of the new developed split and advance strategy.

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Chapter 1 Introduction

After hundreds of years of sound development, the complete concept and structure of international shipbuilding industry has been established. Similar to other manufacturing industry, advanced techniques have been applied to the process of constructing a ship. However, the shipbuilding process is so complicated that each stage of the construction needs specific planning. The delays in the final completion time of a project are shipbuilders' major concern. This research will be aiming at combing the theory of delay management with the real construction process of a shipbuilding project.

1.1 Research Background

Shipbuilding is such a professional process that every associated step will be designed carefully during the whole production. In general, each ship is different from the other even if they belong to the same category. Therefore, unique technique is required from the negotiation stage to the final delivery of the ship. This research aims at reducing the risks of shipbuilding by controlling and monitoring the scheduling the whole project. Here, the risks refer to the possibility that the ship builder is not able to deliver the ship in time. Due to the fact that every ship is special in designing as well as in production, no single method is perfect for all stages. To manage the possible delays in certain stages of a production plan, several scheduling methods will be used.

1.2 Problem Definition

To manage the possible delays in a shipbuilding process attracts attention from the planner of the shipbuilding process. However, the structures for building ships differ from ship to ship, no single method is applicable to all kinds of delays. Therefore, a few different strategies need to be developed according to the real situation. To be more specific, the research is more about combining the concepts behind the advanced methods with real practice.

However, the production plan of building a ship is so complicated that scheduling is required for the whole project as well as for each single stage. Due to the time limitation, the scope of the research will be limited to the production plan in general.

1.3 Research Questions

The research question of this research is how to manage the delays in a construction plan. To answer this question deeply, several corresponding sub-questions will be raised up.

a) What is the construction process in shipbuilding industry nowadays?

b) How to describe a construction plan in shipbuilding process?

c) What will be the possible delays in a construction plan?

d) How to measure the delays in a construction plan?

e) What will be the strategy for managing the delays in a construction plan?

f) How does the new strategy perform when applied to a real practice in shipbuilding industry?

1.4 Research Methodology

Firstly, abundant literatures are reviewed to find out the possible answers for the research questions. Generally speaking, the author employs the classical scheduling methods such as PERT network and Critical Path Method in this research. However, those methods have been developing for about 60 years during the application to various production processes in different industries. With regard to the features of shipbuilding industry, only a few concepts behind those methods are suitable for solving the problems that shipbuilding companies are faced up with.

Furthermore, the case to be used in this thesis is complex owing to that the different modules of the ships will be built in different places. When identifying the potential risks for this project, logistics side of the construction plan will be significant in determining the duration of the whole project. Therefore, the author will make a few assumptions to simplify the problem.

Finally, the newly developed scheduling method associated within the whole production network is concluded to provide some alternatives for the similar problems occurring in other industries.

1.5 Structure of the Study

The thesis is structured into five chapters. The brief introductions of each chapter are listed as below.

In Chapter 1, a general Introduction is conducted to give some background information about the research. After that, the main research question and corresponding sub-questions are raised up to give the general objectives of this research. Finally, the methodology to be used in the research will be presented briefly.

In Chapter 2, literatures with the topics of scheduling network, PERT network and critical path method are reviewed. Because of the importance of these methods in this research, detailed researches focusing on the specific area of those methods will be preferred. Those articles provide excellent references for making assumptions, choosing the appropriate algorithm and analyzing the outcomes of such methods.

In Chapter 3, five steps in the research are described at the beginning of the chapter. Then the major research methodology is presented in detail.

In Chapter 4, the complete structure of scheduling a whole production project is demonstrated. To be more specific, the fourth chapter starts with the assumptions to design a simple network. Then the basic principles and methods for solving the delays are described. This chapter ends up with the results after using those methods in a simple network created by the author. Furthermore, the sub question d) how to measure the delays in a construction plan and e) what will be the strategy for managing the delays in a construction plan would be answered in this chapter.

In Chapter 5, a real case in ship building industry is introduced. This chapter starts with the introduction of the shipbuilding company and the project to be deeply researched into. With regard to the complexity of the problem, a few assumptions are made to make it simplified. After that, the applications of the methods developed in chapter 4 are revealed. The results of applying the methods will be shown at the end of this chapter. The sub-questions of a), b), c) and f) are answered in this chapter.

In Chapter 6, the performance of the carefully designed methods is concluded. Furthermore, there is a prediction about the further application of the methods. Lastly, the recommendations for further research are made.

Chapter 2 Literature Review

2.1 Introduction

The research aims at providing a better scheduling strategy for certain production process. To achieve this result, firstly, it is necessary to construct a complete PERT network. An estimate of activity duration, as well as the variance of certain activity is following up to complete the network. Combining the structure with the expected duration of each activity, the critical path is diagnosed. Next, according to the assumptions of the PERT network at first, possible solutions for rescheduling the project are designed. The whole research is ended up with the improvements in the total project duration.

According to the logic of the research, several topics to be discussed about, including general scheduling tool, PERT network, Critical Path Method and rescheduling methods are included in the research. Therefore, relevant books, journals articles and papers are reviewed and summarized. The following graph illustrates the inherent relations and logic of elements to be discussed in this paper.

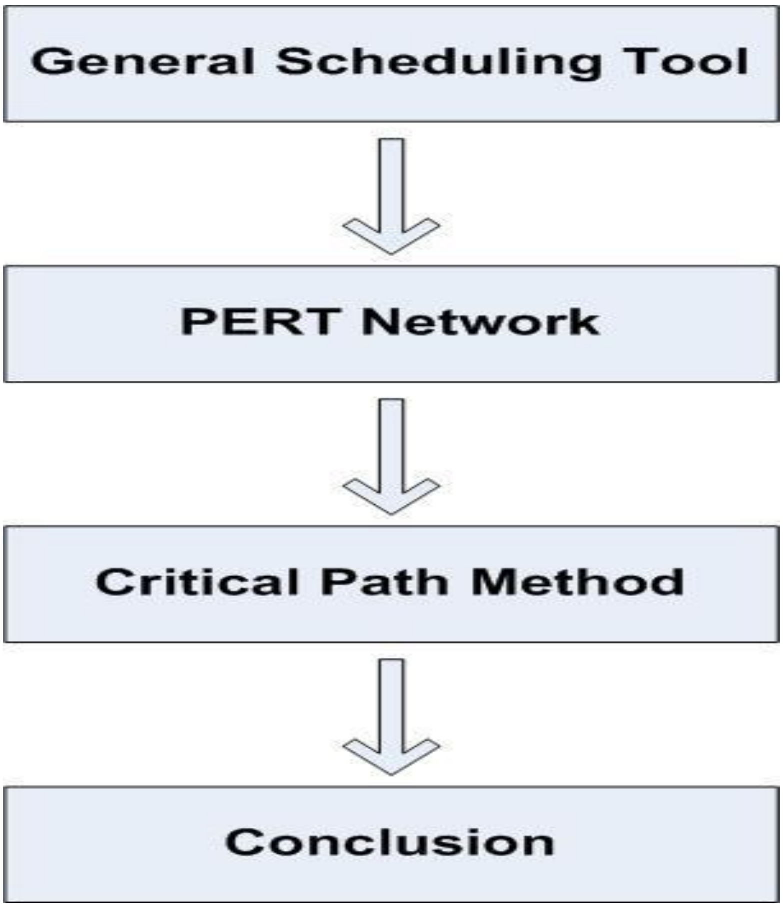


Figure 2-1 Inherent Relations and Logic
Source: compiled by author

2.2 Project Scheduling Network

2.2.1 General Research

"In 2004, project scheduling/rescheduling method such as PERT Network and Critical Path Method had been developing for more than 50 years since 1950s. These traditional techniques made contributions to planning and managing the duration of certain projects. However, during the applications of these methods, planners found the shortages or necessity of improvements of these methods" (Ahuja & Thiruvengadam, 2004). Therefore, a lot of new methods rooted from these traditional concepts had been developing rapidly. Ahuja and Thiruvengadam (2004) studied various journals, published and unpublished research papers. Finally, they made a summary of the current research status of the subject of project scheduling and monitoring (Ahuja & Thiruvengadam, 2004).

The summary provided a practical reference list including relevant literatures from 1950s till 2004 for this research.

2.2.2 Delay Analysis Methods

"There are several methods to assess the impacts of the delays in a construction project. However, no one can be used universally or replace another when conducting different kinds of delay analysis" (Arditi & Pattanakitchamroon, 2006). To provide a suggestion to select the most appropriate method, Arditi & Pattanakitchamroon (2006) reviewed the results of previous 20 researches. Finally, the authors came up with a summary that the selection of the delay analysis method depended largely on the availability of data (Arditi & Pattanakitchamroon, 2006).

Yang and Kao (2012) argued that none of the existing delay analysis methods was perfect in assessing the schedule delay's impacts on total schedule duration. *"However, they identified that one of the window-based delay analysis method, known as the effect-based delay analysis method (the EDAM method), was efficient in delay analysis and effective in soling concurrent delays and determining schedule shortened"* (Yang & Kao, 2012).

In this research, the ideas for selecting the best delay analysis method are included.

2.2.3 Delay Management in Other Industries

Hamzah, et al., defined delay as *"a situation when the actual progress of a construction project is slower than the planned schedule or late completion of the projects"* (Hamzah, et al., 2011).

The definition in this article gives a new thought of understanding delays in a construction plan.

Bubshait and Cunningham (2004) dealt with the concurrent delays in a construction plan. The problems are a little bit complicated because there are two or more delays occurring in a construction project. In this article, they reviewed a few previous articles and discussed about an example of concurrent delay assessment (Bubshait & Cunningham, 2004).The ideas to deal with concurrent delays give an approach to manage complex delays occurring in a construction plan.

Alkass, et al. (1996) reviewed a few delay analysis techniques and mainly introduced one of them, which is called Isolated Delay Type (IDT). *“The IDT technique can be used as a standalone module or incorporated within a computer system for construction delay analysis”*(Alkass, et al., 1996). The delay analysis techniques introduced in this article is a good reference for looking for ideal delay tools for delay analysis.

2.3 PERT Network

2.3.1 Definition and History

Malcolm, et al.(1959) firstly introduced PERT netwoek, which was set up to develop, test, and implement a methodology for providing management with integrated and quantitative evaluation. *“In that research, PERT network was used to solve R and D programs, which were characterized as a network of interrelated events to be achieved in proper ordered sequence”* (Malcolm, et al., 1959).The method applied in this research is often referred to as classical PERT network.

In the first part of the work by Sergio Lerda-Olberg (1966), he listed all the English literature appeared in journals or periodicals during the time period of 1962 to 1965. The period is regarded as the beginning of the development of PERT network. Therefore, this bibliography is a good reference for finding out the basic concepts during the development of PERT network (Lerda-Olberg, 1966).

Roman introduced the origin PERT network in 1962.

“PERT is developed jointly by the Navy Special-Projects office and Booz-Allen-Hamilton, in conjunction with the Fleet Ballistic Missile Program, has had its major impetus and success in association with the Polaris missile” (D. Roman, 1962).

“PERT helps managers put their focus on the key development parts which could disrupt the whole program goals, and it is different from other methods in setting the denominator to evaluate the accomplishment of the whole program” (D. Roman, 1962).

Burgher (1964) defined PERT network as follows.

"PERT (the initial stand for Program Evaluation and Review Technique) is a remarkably effective method of project scheduling and coordination based on an integrated logic network. Originally developed by the U.S. Navy in 1958 to plan and control the famous Polaris missile project, it is applicable to any complex "project"-type activity consisting of a number of sub-activities or tasks, including those which depend upon the completion of (or are otherwise related to) other sub-activities and those which are entirely independent of others and may be carried on simultaneously" (Burgher, 1964).

International Business Machines Corporation described the PERT network as follows.

"PERT/PEP is a management control tool to define and integrate what must be done to accomplish program objectives on time. It is a statistical technique-diagnostic and prognostic-for quantifying knowledge about the uncertainties involved in completing the intellectual and physical activities essential for timely achievement of program deadlines. It is a technique for focusing management's attention on danger signals that require remedial decisions, and on areas of effort that require trade-offs in time, resources, or technical performance to improve the capacity to meet major deadlines" (International Business Machines Corporation, 1961).

Different authors provide different views of thinking when referring to the definition of PERT network. Various definitions, together with the history of the network give the whole picture of this network, which helps a lot when analyzing a specific system by this method.

2.3.2 Algorithms to Build PERT Network

As with the development in PERT network during the past 60 years, several authors came up with new methods to solve the PERT network.

Kamburowski (1985) described a simple method for obtaining lower and upper bounds for the expected project completion time. *"The method is based on the assumption that the durations of the activities in a PERT network are independent and normally distributed"* (Kamburowski, 1985). *"However, the result of applying the same method to the situation that the durations are non-normally distributed was also discussed"* (Kamburowski, 1985).

Littlefield and Randolph provided a different approach to restrict the variance of β

-distribution and to approximate the mean (Littlefield & Randolph, 1987). Gallagher concluded the two approaches to make assumptions about the duration of each activity (Gallagher, 1987).

Badiru (1991) introduced a specialized shareware for PERT network simulation, STARC 2.0. One of the advantages of the STARC was that it took time and resource constraints into consideration when modeling the specific PERT network. Furthermore, an illustrative example was presented to show the simulation run by STARC 2.0 (BADIRU, 1991).

It was Aghaie and Mokhtari (2009) that firstly applied Colony Optimization (ACO) metaheuristic, together with the Monte Carlo (MC) simulation technique for the stochastic project crashing problem (SPCP). Finally, it turned out that the project completion probability was improved from a risky value to a desirable predefined amount (Aghaie & Mokhtari, 2009). The research provided a new approach for stochastic project crashing problem (Aghaie & Mokhtari, 2009).

Baradaran et al. (2012) solved the problem of multi-mode PERT network with resource constraints. *"In this research, each combination of resource requirements of the activity and its duration is represented by an execution mode. Each activity can be accomplished in one of the several execution modes. The aim of the research is to achieve an optimal schedule with the shortest duration of the whole project. In addition, the author tried to minimize the resources allocated to each activity in the whole network. This study provided a good example for dealing with PERT network with multiple objectives"* (Baradaran, et al., 2012).

The researches on simulating the PERT networks give the front edge of the development in PERT network. The results from those articles are used to build the PERT network in this research.

2.3.3 Different Approaches

A. Koonce et al. (1994) argued the traditional planning networks such as PERT and CPM is not suitable in dealing with long-duration, low-volume manufacturing typical in aerospace industry. Therefore, they present a network representation based on the artificial intelligence knowledge representation technique of semantic networks (A. KOONCE, et al., 1994).

Soroush (1993) studied the risk taking behaviors of project managers in stochastic PERT network, namely RISKPERT. *"Due to the difficulty in solving general RISKPERT, the author based his research on two assumptions: firstly, activity durations are statistically independent; moreover, disutility functions are linear, exponential, quadratic, or linear-exponential. The results of the research showed that RISKPERT are more realistic than classical PERT network since it captured managers' risk taking* *behaviors"* (Soroush, 1993).

2.4 Critical Path Method

2.4.1 Definition and History

Critical Path Method (CPM) is a mathematically based algorithm for scheduling a set of project activities. It was firstly developed in the 1950s by the US Navy. In 1961, the professor from Stanford University, John Fondal, (2009) published the paper "A non-computer approach to the critical path method for the construction industry", which was regarded as the first application of CPM to construction industry (Santiago & Magallon, 2009)**.**

2.4.2 Assumptions about the Task Time

To estimate the task time is the most difficult part at the beginning of designing a PERT network. In addition, there exists the problem of translating the forecasts by "experts" into the model in the network (Lau & Somarajan, 1995). To solve these problems, Hon-Shiang Lau and C. Somarajan (1995) proposed and justified a practical and more logical procedure. But it is also pointed out that real-world random variables could not fit into any of the known mathematical distribution functions (Lau & Somarajan, 1995).

The results from this research give the idea of how to estimate the task time according to the opinions from experts.

2.4.3 Algorithms to Find the Critical Path

The algorithm developed by F. Guerriero and L. Talarico (2010) took three kinds of time constraints into consideration, that is, time-window constraint, time-schedule constraint and time-switch constraint. In addition, this method can be used to find the critical path in any practical situation (Guerriero & Talarico, 2010)**.**

To calculate the probability that certain activity is on the critical path of a network, Fatemi and Teimouri (2002) defined the critical path index (CPI) to represent the probability that the duration of certain path is longer than or equal to any other paths. In addition they developed a formula to compute the CPI and activity critical index (ACI) for the PERT network with any structure (Fatemi & Teimouri, 2002).

Abbasi and Mukattash (2001) developed a mathematic program to reduce the project time based on the pessimistic estimation in a PERT network. By investing money in certain activities along the critical path, the pessimistic duration of the whole project is reduces, so does the variation of the duration (Abbasi & Mukattash, 2001).

Robbillard and Trahan (1976) developed a new method to obtain a new lower bound (optimistic estimation) of the whole duration of the project after studying the previous research on the estimation of the duration. In addition, the consideration about its evaluation is presented at the end of the research (Robillard & Trahan, 1976).

Fulkerson (1962) developed a method to obtain a fairly good lower approximation to the expected duration time of a project. More importantly, it is proven the estimate by using the method is usually better, and never worse, than replacing the each random job time by expected value (Fulkerson, 1962).

The literature reviews above show the traditional and newly developed algorithms to solve the critical path problems. In the step to find out the critical paths in a PERT network and in a real ship building process, these methods are used.

2.4.4 Different Approaches

Besides the aforesaid algorithms to solve the critical path problem, there are several researches focusing on the some methods rooted from classical CPM.

H. M. Soroush (1994) defined and formulated “most critical problem in a PERT network”, which means the probability of completing its activities by a given time is less than that of every other path (SoroushSource, 1994).

A new rule for slack allocation of PERT network is defined and formulated in the paper written by J. Castro et al in 2007. “The rule allows a schedule to be made during every stage of a project” (Castro, et al., 2007).

N.E. Mouhoub et al (2011) proposed a new method for constructing a PERT network to have dummy arcs as little as possible. To be more specific, the authors focused on the existence of transitive arcs (Mouhoub, et al., 2011).

In real practice, the word “critical path” stands for different paths in different networks. The different approaches in the above researches provide some ideas about how to combine the critical path in real industry with that in theoretical research.

2.5 Conclusion

As indicated aforesaid, the research into classical scheduling method such as PERT network and CPM started in 1950s, boomed in 1960s. There were abundant researches on those subjects during the second half of 20th century. Thanks to the worldwide popularity of those classical planning methods, in recent years, different approaches have been developed during the application in more and more practical situations.

When comparing PERT and CPM, the author find that the two methods have the same general purpose and utilize much of the same terminology. However, the major difference between them is that PERT was developed to handle uncertain activity times. CPM was developed primarily for industrial projects for which activity times were known (Anderson, et al., 2012).

After reviewing all those literatures, I had a profound impression that none of those methods are applicable to every real situation. To solve the problems in real industrial production process, we need to combine the basic concepts of these methods with the reality we are faced up with. One of the common examples is the neglecting of possible delay in the activities along uncritical path. Classical PERT network method ignored the possibility that delay in the activities along the non-critical path may change the position of certain activities in the whole network. But it is not always true, and the ideal assumption may lead to faults in the calculation of the duration of certain projects. For instance, X is the activity appearing along an uncritical path, if we use classical PERT network or CPM, X will never appear in the longest path, which is known as the critical path, of the whole network. However, if X delays too much, longer than the difference between the longest path including X and the critical path, the critical path will be changed to the longest path including X. Moreover, the total duration of the project will be extended.

With regard to the characteristics of shipbuilding industry, to finish the construction without any delay is the main object of the whole production plan. In other words, the biggest concern of shipbuilding industry is the constraints in time, rather than that in costs. Furthermore, the construction plan depends largely on the performance of suppliers in providing all the equipments and materials in time. Failures in accurately estimating the expected time of supplying certain equipments may lead to a delay in the whole production plan. Therefore, the research will be focusing on finding certain solutions for delays. By reviewing the relevant literatures mentioned in this chapter, a practical method for estimating, scheduling and rescheduling the production plan will be founded to mitigate the impacts of possible delays in certain activities.

Chapter 3 Research Design and Methodology

3.1 Introduction

The research aims at looking for possible solutions to reduce the risks in the production process of ship building. In this chapter, the structure of the research as well as the methodology used in this paper will be described. To erase the effects of possible delay in a PERT network, the author designs a strategy to reschedule all the tasks.

3.2 Research Design

In general, the research consists of six steps.

Step1: Literature reviewing and summary. The author will read books, journals articles and papers related to rescheduling in PERT networks, as well as the risk management in ship building industries to find out the ideas for erasing the effects of possible delay in the whole production process in manufacturing industry.

Step 2: Problem statement. In this part, I will describe the problems I intend to solve in my thesis. To be more specific, the problem statement will include the scope of my research, the main research question and the corresponding sub-questions.

Step 3: Methodology introduction. Combined with the results of research in aforesaid two steps, Careful designed method applicable to the practical problem will be introduced in detail. The description started with a few assumptions to simplify the problem. After that, the advanced method in PERT network will be discussed. This step will end up with the application of the method to a simple case built by the author.

Step 4: Case study. Firstly, a real case abstracted from the production process of a shipbuilding company will be described. Then the method mentioned in step 3 will be applied to the case. Finally, the improvement in the performance of the production process will be discussed to examine the results of this method. Different from other parts of the research, major methodologies in this study are the interviewing of the project planners in the shipbuilding companies.

Step 5: Conclusion and recommendation for further research. This is the final step of my research. The method used in the research as well as the performance of the method in a real case will be concluded. Furthermore, the restrictions in this research will be discussed. Recommendation for further research will be made at the end of the research.

3.3 Classical PERT Network Method

As is introduced in the literature review in chapter 2, *"PERT, the initials of which stand for Program Evaluation and Review Technique, is a remarkably effective method of project scheduling and coordination based on an integrated logic network"* (Burgher, 1964) *"It is a management control tool to define and integrate what must be done to accomplish program objectives on time"* (International Business Machines Corporation, 1961).

The research about the classical PERT network is based on a few assumptions.

1) Since the time estimates for some activities are highly uncertain, it is impossible to give the accurate time duration of those activities. However, it is possible to give three kinds of estimations. That is, optimistic time estimate, most probable time estimate and pessimistic time estimate.

2) The activities are independent from each other. The time duration of each activity follows normal distribution.

As is mentioned in the conclusion of literature review, the PERT network is developed for dealing with project with uncertain activity time. To incorporate the uncertain activity time into the network, three time estimates of each activity must be obtained in the first place.

$$\text{Optimistic time a} = \text{the minimum activity time if everything progresses ideally}$$
$$\text{Most probable time m} = \text{the most probable activity time under normal conditions}$$
$$\text{Pessimistic time b} = \text{the maximum activity time if significant delays are encountered}$$

If the activity could be repeated a large number of times, the average time for the activity is as follows.

$$t_i = \frac{a + 4m + b}{6}$$

The variance, which is used to describe the variation in the activity time values, is calculated by the following formula.

$$\sigma_i^2 = \left(\frac{b - a}{6}\right)^2$$

By applying these two formulas, the project with uncertain completion activity time is transferred to a project with certain activity time. Therefore, CPM becomes applicable after this transfer. The expected completion time of the whole project and the corresponding variance are calculated by the following two equations.

$$E(T_n) = \sum t_i \qquad \sigma_n{}^2 = \sum \sigma_i{}^2$$

In addition, it is assumed that the completion time of the whole project follows normal distribution. The possibility that an uncritical path becomes critical is ignored (Malcolm, et al., 1959).

During the application PERT network in real industry, some problems have been put forward. In general, the problems mainly relates to the assumptions. To be more specific, the two major doubts are on the following two assumptions.

1) The completion time of each activity follows Normal Distribution

   Some researchers argued that the completion time of each activity was a random variable. It might follow other random distributions, such as Gamma Distribution and Triangular Distribution. However, either Gamma Distribution or Triangular Distribution can be obtained just by changing the parameters in Normal Distribution. In other words, both Gamma Distribution and Triangular Distribution are just special examples of Normal Distribution.

2) It is impossible that an uncritical path becomes critical.

   In real situation, when the duration of certain activity varies in a large range, the critical path may be changed. The assumption to ignore the possibility sometimes causes false evaluation of the completion time of the project.

3.4 Methods to Calculate PERT Network

To solve the aforesaid problems in classical PERT network, several methods have been developed to calculate. All the methods can be classified into three categories. That is, MC (Monte Carlo) Method, Fuzzy Network Program and other approximate calculation methods based on classical PERT network.

3.4.1 MC method

The attempt to apply MC method to PERT network problems started in 1960's. It is a computational algorithm that relies on repeated random sampling to obtain numerical results. (Wikipedia, 2013) When applying MC method to a PERT network, the duration of each activity is assigned by a sample value drawn from its proper distribution. (van Slyke, 1963). The experiments are conducted for several times to get the expected completion time and variance. In the next step, the results from the experiments are illustrated by a bar chart demonstrating the possibility to finish the project within certain period. Based on the bar chart, a probability density curve is created by using the following equations.

$$T_{min} = \min\{T_k\}, \qquad k \in (1, \cdots, N)$$

$$T_{max} = \max\{T_k\}, \qquad k \in (1, \cdots, N)$$

$$T_g = \frac{T_{msx} - T_{min}}{l}$$

Therefore, $T_1 = T_{min} + T_g$, $T_2 = T_1 + T_g$, $\cdots$, $T_m = T_{m-1} + T_g$.

In the aforesaid equations, T_{min} is the minimum completion time of the whole project in N times' experiments. T_{max} is the maximum completion time of the whole project in N times' experiments. l is the number of groups and T_g is the length of each group.

When comparing MC method to classical PERT network, they have one thing in common: both of the methods base the calculation on the assumption that the duration of each activity is a random number. As to the differences between them, MC method can be used to evaluate the project completion time no matter what kind of distributions the activity time follows; while PERT network is based on the assumption that all the activity time follows Normal Distribution.

3.4.2 Fuzzy Network Program

Considering the fact that the completion time of each activity in a PERT network is affected by many reasons, it is hard to give estimates about the duration of each activity. But experienced people working in certain industry for many years are relatively good at estimating the duration of each activity. In the application of fuzzy network program Dubois and Prade, experts are asked to give estimates of the duration of activity (i, j) (Dobois & Prade, 1987), which are recorded as:

$$[t_1^-, t_1^+]_{ij}, [t_2^-, t_2^+]_{ij}, \cdots, [t_m^-, t_m^+]_{ij}$$

Therefore, the range of the duration of activity (i, j) is $(\min t_i^-, \max t_j^+)$.To simplify, it is recorded as $\mu_T(t(i, j))$. According to the explanation by Dubois and Prade, with regard to the definition of L-R fuzzy number, the fuzzy set of activity time parameters is the fuzzy number of L-R, And relation between them can be explained as follows.

$$\mu_T(t(i,j)) = \begin{cases} L\left(\dfrac{m(i,j) - t(i,j)}{\alpha(i,j)}\right), t(i,j) \le m(i,j), \alpha(i,j) > 0 \\ R\left(\dfrac{t(i,j) - m(i,j)}{\beta(i,j)}\right), t(i,j) \ge m(i,j), \beta(i,j) > 0 \end{cases}$$

In which L, R are parameter functions. By using the above equation, the fuzzy set of activity time parameters $\mu_T(t(i, j))$ can be quickly calculated by any combination of two fuzzy numbers L-R (Dubois & Prade, 1979).

In addition, Dubois and Prade (1979) calculated the activity time $\mu_T(t(i,j))$ by using L-R triangular function.

$$\mu_T(t(i,j)) = \begin{cases} \max\left\{0, 1 - \dfrac{t(i,j) - m(i,j)}{\beta(i,j)}\right\}, t(i,j) \geq m(i,j), \beta(i,j) \geq 0 \\ \max\left\{0, 1 - \dfrac{m(i,j) - j(i,j)}{\alpha(i,j)}\right\}, t(i,j) \leq m(i,j), \alpha(i,j) \geq 0 \end{cases}$$

To apply the fuzzy network program, estimates of the activity time of all the procedures are required from experienced experts. Therefore, it is difficult to apply this method in real practice.

3.4.3 Other Approximate Calculation Methods

To estimate the duration of a PERT network, some researches come up with a few approaches.

Elmaghraby described a method in 1967. The necessary data for the method is three estimates of the activity time as usual. However, he defined the network with certain time nodes (Elmaghraby, 1967). Then he calculated the longest path toward the nodes. The calculation towards the last node in the network is the completion time of the project. Compared with the classical PERT network, this results by using this method is more close to the reality.

Weiss determined the critical path among the several paths going towards node j $(2 < j \leq n)$ by the following function:

$$P(Z_j^l \geq Z_j^k) > P(Z_j^l \leq Z_j^k)$$

In the above function, Z_j^l means the duration of the number l path towards node j; similarly, Z_j^k stands for the duration of the number k path towards node j. (Weiss, 1986) Comparing with the classical PERT network, there is some improvements in the algorithm developed by Weiss. However, the influence of uncritical paths was not taken into consideration.

In this research, the author focuses on the MC method.

3.5 Conclusion

Steps of this research are introduced in the beginning of this chapter. After that, the common management tool of classical PERT network is introduced. Because of the increasing complexity in the planning work in real industry, there are more and more problems during the application of the classical PERT network. New methods such as Monte Carlo Method and Fuzzy network program are developed to calculate the PERT network. The introduction of the advanced delays management tools in this chapter is the foundation of the following research.

Chapter 4 Modeling and Simulation

Before applying the methods to the reality in shipbuilding industry, it is necessary to set some basic principles for dealing with possible delays during the whole construction project. In addition, to evaluate the performance of the methods in dealing with a relatively simple situation helps to make adjustments when they are not effective enough. Based on the aforesaid considerations, the methodology to be used in this research will be described in detail in this chapter before being applied to a case abstracted form real industry practice.

The research questions answered in this chapter are as follows.

a) What are the possible management tools for delays?
b) How to estimate the delays at the planning stage of a project?

4.1 Introduction

In general, the author will employ PERT network and CPM method to reschedule the whole project. When compared with other manufacturing industries, shipbuilding is a specific area especially in manufacturing technology. For instance, ships under construction will be staying in a particular shipyard, rather than moving along the production line, which is common in car manufacturing.

Generally speaking, there are five steps in dealing with possible delays in a construction project.

In the first place, it is necessary to recognize the critical path (the longest path in a complete construction plan) in the whole network. Secondly, the cut off value (X) of the total project duration have to be determined. It is a number to determine the acceptance range of the delays in the project. Thirdly, judgment upon the location of the delay is to be defined. To be more specific, when a delay occurs, the planner has to make sure whether it is on the critical path: if yes, the delay in the whole project will be the same as that in the specific procedure. In this case, the planner needs to make further judgment on whether the delay in the whole project is acceptable. If yes, there come the acceptance of the delay; if no, another rescheduling awaits to be done. In another situation when the delay occurs in the critical path but is beyond the acceptance range, rescheduling will be necessary. On the other side, the delay occurs somewhere out of the critical path, the planner has to examine whether the delay is longer than the difference between the longest path including the procedure with delay and the critical path. if the answer is no, accept the delay. If the delay is longer than the difference, the planner needs to redo the whole judgment for a second time. The flow chart below shows the procedures to make decisions for planners. The chart below demonstrates the basic principles for dealing with delays. It is significant to mention that in the chart, CP stands for critical path, D means the delay in certain procedure, T_c demonstrates the duration of the critical path and T_0 describes the duration of the longest path which includes the procedure with delay.

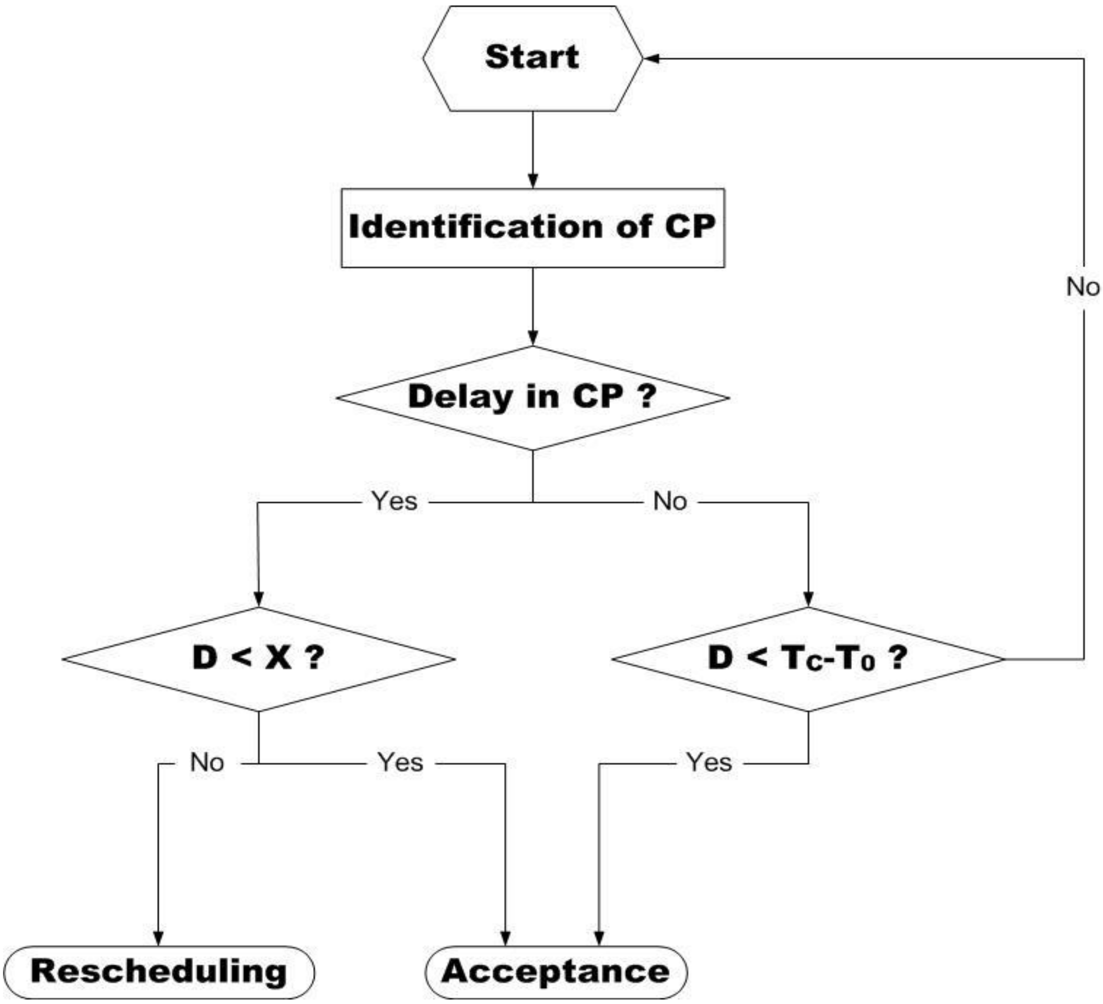


Figure 4-1 Flow Chart of Dealing with Delays
Source: compiled by author

In the fourth place, when it is determined to reschedule the whole project, methodology to be developed afterwards will be applied. The whole process is ended up with the evaluation of the performance of the new strategy.

To simplify the problem, some basic assumptions need to be made. Firstly, critical path is defined as the longest path in the whole network. Secondly, the acceptance range of the delay is defined as 5% of the total duration of the production plan. Finally, for easily describing the problem, some characters are defined as below.

X – Cut off value of measuring the delays
D – Delay in certain procedure
T – Duration of certain path

4.2 Basic Principles

In this section, the basic principles to manage the delays are provided. In general, there are two kinds of methods to deal with the possible delays. One is to finish some procedures in parallel instead of in certain sequence. The other one is to add some workers or other resource to improve the productivity. They are explained in detail in the following text.

4.2.1 Parallel Operations

However complicated the network seemed, it is made up of several kinds of basic routes. To build the whole structure of the methods dealing with delays, it is necessary to firstly find possible solutions for delays in a common route as below.

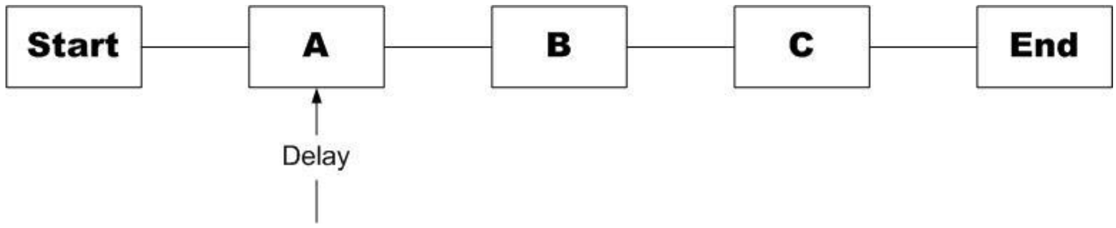


Figure 4-2 Common Route 1
Source: compiled by author

As is illustrated in the graph, A, B and C are three steps in a common route. Now we assume that the duration for each process is a, b and c separately. Therefore, $\mathrm{T} = \mathrm{a} + \mathrm{b} + \mathrm{c}$. According to the assumption that the acceptance range of delay is 5% of the total duration, In this case, the cut off value or the acceptable delay is $\mathrm{X} = 5\% * (\mathrm{a} + \mathrm{b} + \mathrm{c})$. To give an example, we set a = 30 days, b = 20 days and c = 50 days. Therefore, the acceptance range of delay equals $5\% * (30 + 20 + 50) = 5$ days. When the delay in A is smaller than 5 days, it will be accepted. Otherwise, the planner has to make rescheduling for the route.

Here, we design the route to be doing B and C in parallel. The new route is demonstrated as below.

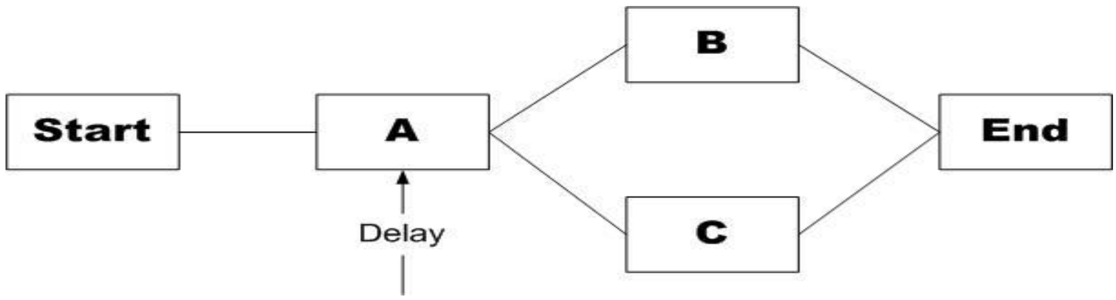


Figure 4-3 Rescheduling Strategy 1 – Make Parallel
Source: compiled by author

In this new route, without considering the delay, the total duration of the project is $\mathrm{T} = \mathrm{a} + \max(\mathrm{b}, \mathrm{c}) = 80$ days. So when use the new strategy, the new acceptance of delays is $5 + (100 - 80) = 25$ days.

However, in real practice, to simply apply this method is not practical. Certain steps can be taken only when all the previous steps are finished. For example, the ship builder will not start the construction without the supply of steel. That is to say, under no circumstance will the procurement of steel and the cutting of the steel be in parallel. The author draws two conclusions based on the above facts. Firstly, it is significant to build the PERT network with the explanations on the unchangeable sequences of certain procedures. In the second place, dividing the specific procedure into several sub-procedures and then do the sub-procedures with unchangeable sequence one after another, but finish the sub-procedures once belonging to the same procedure in parallel.

Take the case mentioned above for example, it is assumed that procedure a can be divided into three sub-procedures, which consuming 15 days, 10 days and 5 days separately. Procedure b is divided into three parts as well. The duration of each sub-procedure is 5 days, 5 days and 10 days. The division of procedure c is 20 days, 20 days and 10 days. However, the basic principle is to start sub-procedure b1 after a1, to start c1 after b1 and so on. Moreover, procedure a2 can only start when procedure a1 finishes. The start of procedure a3 is based on the accomplishment of procedure a2. The new strategy with the division of the procedure is illustrated as follows.

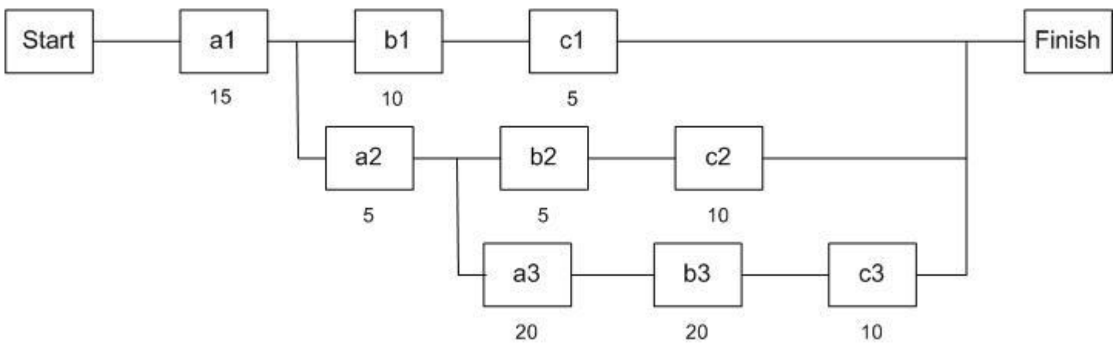


Figure 4-4 Rescheduling Strategy 2 – Split & Advance
Source: compiled by author

As is shown on the graph above, the new duration of the network is 70 days. $[15 + 5 + \max\ (10 + 5, 5 + 10, 20 + 20 + 10)]$ So the new acceptance of delay is 35 days. $(100 - 70 + 5)$ This case gives a clear explanation on the advantages of applying this rescheduling strategy.

4.2.2 Adding Capacity

In the common practice in real industry, it is not always possible to divide the tasks or to do the project in a different order. Therefore, to give other options to deal with the delays are necessary.

One of the options to eliminate the delays is to put more capacity to the network. Take the logistics aspect as an example, adding capacity refers to changing the common transportation by sea to transportation by air. In a real production plan, employing more workers and pay extra money for labor shifts are common practice.

From this respective, adding capacity seems more practical and easier to conduct. However, the larger capacity costs extra money. When applying this strategy, it is always a balancing to choose between time and costs.

4.3 Critical Path Identification

To examine the outcomes of using the methods mentioned above, the author cited the Western-Hill Shopping Center Project as the example. (Loucks, 2000) The case is explained by the following table.

Table 4-1 Description of Western-Hill Shopping Center Project

Activity	Description	Immediate Procedure	Activity Time (days)
A	Prepare archit. Drawing	-	50
B	Identify new tenants	-	60
C	Develop prospects	A	40
D	Select contractor	A	30
E	Prepare building permits	A	10
F	Obtain approval build permit	E	40
G	Perform construction	D,F	140
H	Finalize contracts w tenants	B,C	120
I	Tenants move in	G,H	20

Source: Slides by John Loucks

According to the description of the project in the table, the project can be illustrated by the graph below.

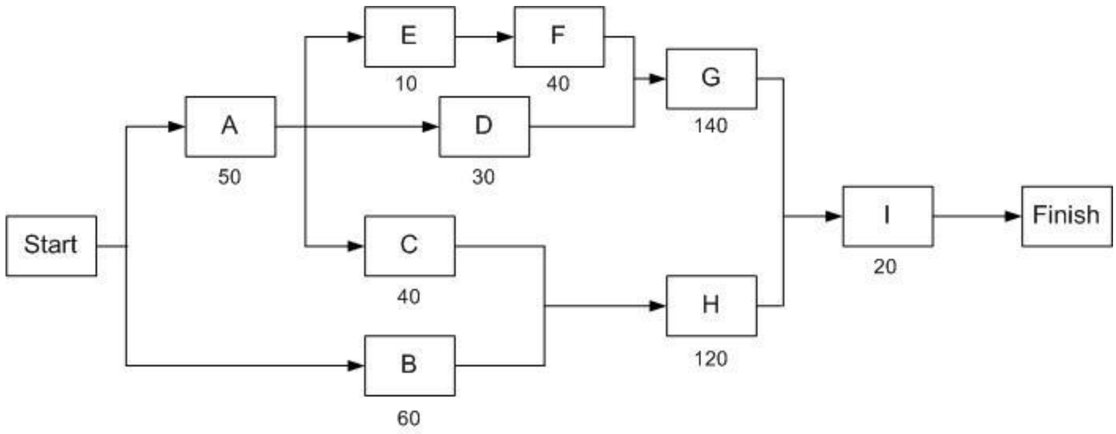


Figure 4-5 Western-Hill Shopping Center Project
Source: compiled by author

In general, critical path determines the duration of the whole project. In other words, critical path means the longest path in a certain network. To find out the critical path in the Western-Hill Shopping Center Project, the author calculates the earliest start time (ES), earliest finish time (EF), latest start time (LS) and latest finish time (LF) for each procedure. The results are listed below.

Table 4-2 Calculation Results about the Western-Hill Shopping Center Project

Activity	Duration	ES	EF	LS	LF	Slack	Critical
A	50	0	50	0	50	0	√
B	60	0	60	60	120	60	×
C	40	50	90	80	120	30	×
D	30	50	80	70	100	20	×
E	10	50	60	50	60	0	√
F	40	60	100	60	100	0	√
G	140	100	240	100	240	0	√
H	120	90	210	120	240	30	×
I	20	240	260	240	260	0	√

Source: compiled by author

According to the results above, the critical path in the given project is as follows.

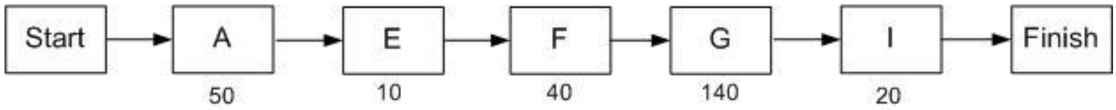


Figure 4-6 Critical Path in the Western-Hill Shopping Center Project
Source: compiled by author

Critical path is significant in the whole construction plan because it determines the duration of the whole plan. There is no slack along the critical path. In other words, if a delay occurs in the critical path, the whole project will be put off without effective methods to eliminate the delays.

4.4 Assumptions about the Durations of Certain Activities

However, during the stage of planning a project in real practice, the activity time is usually uncertain. Therefore, one necessary step before managing the delays is to assume the duration of the delays. However, to simply assume that the completion time of each activity follows normal distribution may cause inaccurate of the estimates. To eliminate the impacts of the inaccurate estimates, the author makes assumptions that the duration of each activity follows normal distribution and triangular distribution separately. The results of each assumption are described as follows.

4.4.1 Normal Distribution

The normal distribution function is as follows.

$$P(t \leq T_s) = \int_{0}^{T_s} \frac{1}{\sigma_n \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-T_s}{\sigma_n^2}\right)^2} dt$$

The Normal Distributed numbers are generated by the following function.

$$f_i = E_i + \sigma_i \sum_{i=1}^{12} (r_i - 6)$$

In the function above, f_i is the generated random duration of an activity. E_i is the expected duration of certain activity. σ_i is the variance of the activity. r_i is a pseudo random number within the range of (0,1).

4.4.2 Triangular Distribution

The triangular distribution density function is:

$$f(x) = \begin{cases} \frac{2(x-a)}{(m-a)(b-a)}, & x \in [a,m] \\ \frac{2(b-x)}{(b-a)(b-m)}, & x \in [m,b] \\ 0, & \text{other value} \end{cases}$$

The Normal Distributed numbers are generated by the following function.

$$f_i = \begin{cases} a + \sqrt{r_i(m-a)(b-a)} & r_i \le (m-a)/(b-a) \\ b - \sqrt{(1-r_i)(b-m)(b-a)} & r_i > (m-a)/(b-a) \end{cases}$$

In the equation above, f_i is the generated random duration of an activity. a, b and m are the optimistic estimate, most probable estimate and pessimistic estimate separately. r_i is a pseudo random number within the range of (0,1).

4.5 Modeling and Simulation

In this section, the durations of certain activities are simulated three times by using different kinds of the distributions. The major algorithm used in this part is standard theory of PERT network and Monte Carlo Method. To start with, the estimates of optimistic time, most probable time and pessimistic time are given in the following table.

Table 4-3 Estimates of the Activities' Durations in Western-Hill Shopping Center Project

Activity	Immediate Procedure	Optimistic Time (days)	Most Probable Time (days)	Pessimistic Time (days)
A	-	40	50	55
B	-	50	60	70
C	A	37	40	45
D	A	28	30	32
E	A	7	10	12
F	E	30	40	52
G	D,F	110	140	150
H	B,C	100	120	130
I	G,H	16	20	22

Source: compiled by author

To simplify the problem for the research, it is assumed that however the duration of each activity changes, the critical path of the project does not change.

4.5.1 Results of the Simulation of the Activity Time

Based on the estimates of the activities' durations, the author generates several project completion times to evaluate the performances of each distribution pattern.

1) Simulation results 1: activity time follows normal distribution

   To simulate the whole project duration with Monte Carlo Method, the author generates 1000 random numbers that follows normal distribution for each activity time. With the assumption that the critical path does not change when the duration of each activity changes, the author obtains 1000 new project completion time. With the results from the 1000 experiments, Monte Carlo Method is conducted to give an overview of the probability distribution of the project completion time. The results are described in detail by table 4-5 and figure 4-7.

Table 4-4 Simulation Results with the Activity Time Following Normal Distribution

Group	Range		Frequency	Probability	Cumulative Probability
1	150	170	3	0.003	0.003
2	170	190	19	0.019	0.022
3	190	210	69	0.069	0.091
4	210	230	165	0.165	0.256
5	230	250	267	0.267	0.523
6	250,	270	257	0.257	0.78
7	270	290	156	0.156	0.936
8	290	310	45	0.045	0.981
9	310	320	14	0.014	0.995
10	330	339	5	0.005	1

Source: compiled by author

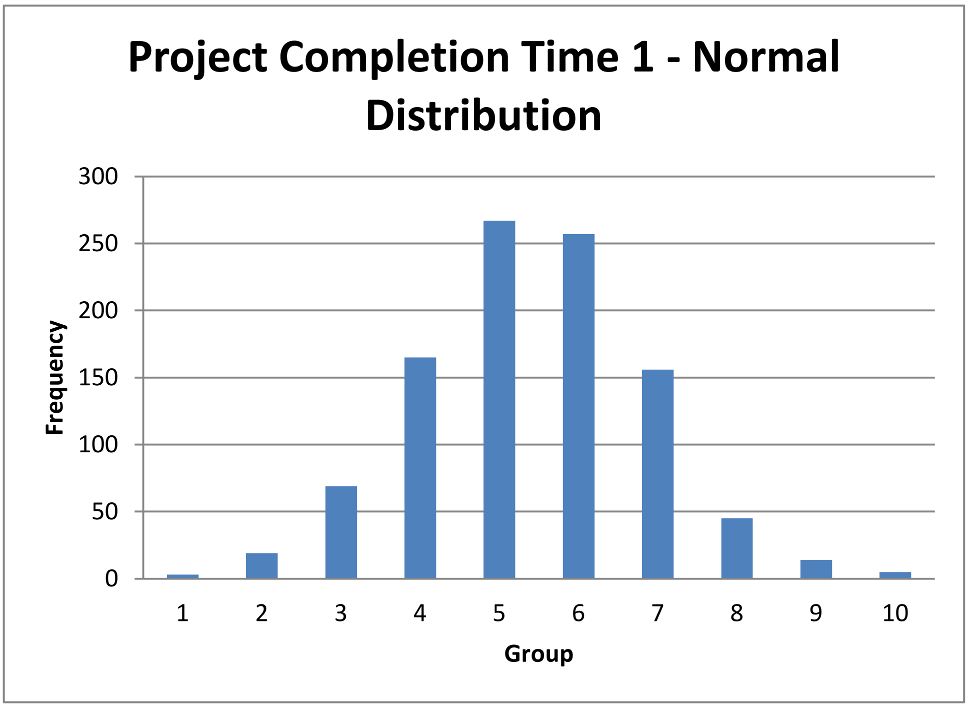


Figure 4-7 Project Completion Time with Activity Time follows Normal Distribution
Source: compiled by author

2) Simulation results 2: activity time follows triangular distribution

Similar to the steps in the normal distribution simulation, the second simulation is conducted with the assumption that activity time follows triangular distribution. The detailed results are illustrated by the following table 4-6 and figure 4-8.

Table 4-5 Simulation Results with the Activity Time Following Triangular Distribution

Group	Range		Frequency	Probability	Cumulative Probability
1	204.45	212.95	27	0.027	0.027
2	212.95	221.45	42	0.042	0.069
3	221.45	229.95	66	0.066	0.135
4	229.95	238.45	112	0.112	0.247
5	238.45	246.95	139	0.139	0.386
6	246.95	255.45	181	0.181	0.567
7	255.45	263.95	158	0.158	0.725
8	263.95	272.45	130	0.13	0.855
9	272.45	280.95	99	0.099	0.954
10	280.95	289.45	46	0.046	1

Source: compiled by author

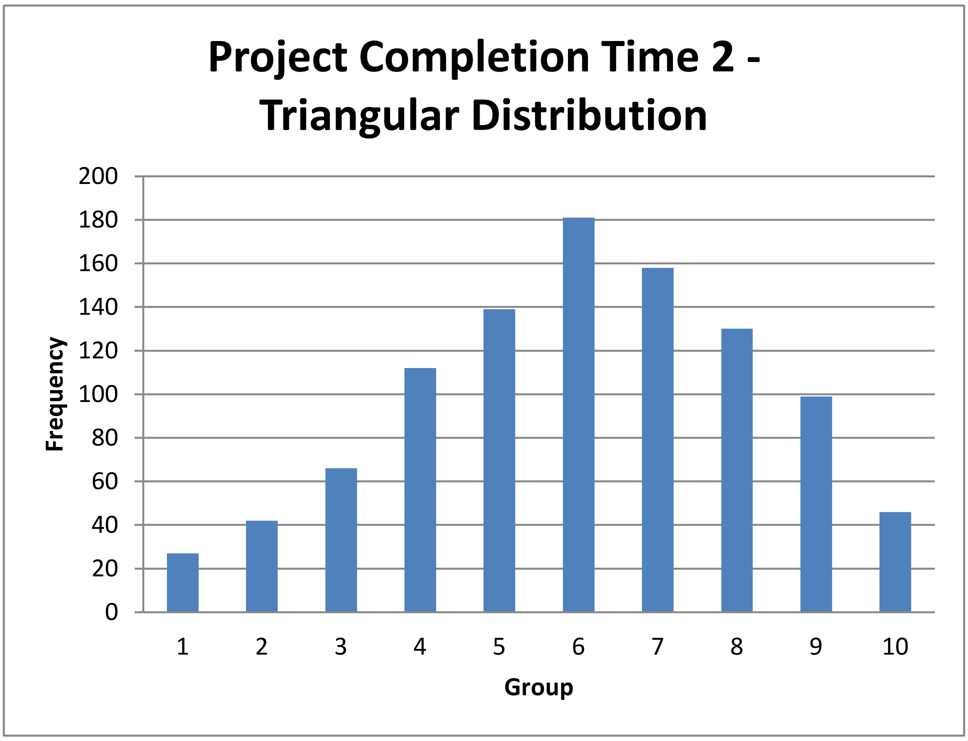


Figure 4-8 Project Completion Time with Activity Time follows Triangular distribution
Source: compiled by author

4.5.2 Analysis towards the results of the simulation

In this section, the simulation results based on different assumptions about the activity time are analyzed in detail. The purpose of the analysis is to find the best activity time distribution assumption for a real case study in chapter 5. To evaluate the performances of different assumptions, the author set three expected completion time of the whole project. The probabilities to complete the project on time are firstly calculated with the mean and the variance. Finally, the conclusion is achieved by comparing between the probabilities with different assumptions.

Firstly, the maximum values, minimum values, means and standard deviations of the whole project completion time are shown on the following table.

Table 4-6 Analysis towards the Characteristic Values of the Project Completion Time

Distribution of Activity Time	Max	Min	Mean	Standard Deviation
Normal Distribution	351.49	149.59	248.44	28.98
Triangular Distribution	289.07	204.46	251.52	18.51

Source: compiled by author

With regard to the maximum and minimum completion time indicated in table 4-7, the three expected project durations are set as 260 days, 275 days and 285 days. The calculation of the expectation to complete the project in 260 days is described as follows.

1) Completion Probability under normal distribution

$$Z = \frac{T_S - T_c}{\sigma} = \frac{260 - 248.44}{28.98} = 0.3989 \approx 0.40$$

By looking it up in the standard normal distribution table, the probability to complete the project in 260 is 65.54%.

2) Completion Probability under triangular distribution

$$Z = \frac{T_S - T_c}{\sigma} = \frac{260 - 251.52}{18.52} = 0.4579 \approx 0.46$$

By looking it up in the standard normal distribution table, the probability to complete the project in 260 is 67.72%.

In the next step, the expected completion time of the project is set to 275 days and 285 days separately. The probabilities to finish the project on time are listed in table 4-7.

Table 4-7 Completion Probability with Different Distributed Activity Time

Distribution of Activity Time	Mean	Standard Deviation	260 days	275 days	285 days
Normal Distribution	248.44	28.98	65.54%	82.12%	89.62%
Triangular Distribution	251.52	18.51	67.72%	89.80%	96.48%

Source: compiled by author

As is demonstrated on table 4-8, when the assumption is that activity time follows normal distribution, the completion probabilities are relatively higher than that with triangular distribution. In other words, the completion time is more likely to be overvalued with the triangular distribution than that with normal distribution. During the stage of project planning, estimates of the duration of the whole project determine the due date of the whole project. The risk to put off the due date is what builders are making efforts to avoid. Based on the above considerations, to choose a planning method with higher risk evaluation is better. The conclusion of this analysis is: to assume that activity time follows normal distribution reduces the risk of an underestimate in the completion time of a project. In the real case study in chapter 5, the normal distribution is conducted to estimate the activity time.

4.6 Conclusion

This chapter starts with the introduction of the principals for delay management in this research. Basically there are two strategies for managing the delays: doing some work in parallel and adding capacity.

For the first strategy to do some work in parallel, there are two different approaches. The first one is to scheduling the following two steps in parallel when there is a delay in certain procedure. The other strategy is called split and advance, which means splitting the procedures with long duration into small procedures. So the completion time of each sub procedure is reduced. After that, the following procedure gets started earlier. In this way will the constructor be able to finish the project ahead than planned. Actually it is a strategy to manage the delays by using the time saved from the application of the split and advance strategy.

For the second approach to manage the delays by adding capacity, in a construction plan, it refers to employing more workers or transferring to more sufficient method. Comparing to the first strategy of parallel working, adding capacity is easier to conduct. But the disadvantage is the application of this strategy gives rise to the associated costs.

As an important part of delay management, to estimate the activity time is a significant step to quantify the performance of the management strategy. In the next section, a real case of Western-Hill Shopping Center Project is used to examine the assumptions about the durations of certain procedure during the planning stage of a project. In this case study, the activity time of each procedure is assumed to follow normal distribution and triangular distribution separately. After comparing the results based on different assumptions, the conclusion is to assume that single activity time follows normal distribution works better in reducing the risks of overvaluing the probability to finish a project within certain time period. The conclusions from this chapter are used in the case study in chapter 5.

Chapter 5 Case Study in Ship Building Industry

The main research question of this chapter is how to manage the delays in a construction plan. The four key words in this question are manage, delays, construction and plan. With regard to the logic between the four words, the author develops the structure into four parts. The sub topic of each part is: Shipbuilding Process (Construction), Plan, Delays and Manage.

The author begins the description of shipbuilding process with the introduction of DAMEN Schelde Naval Shipbuilding (DSNS), which is the name of the company that is as example for case study. Secondly, the shipbuilding process in DSNS is explained in general. In this part, the author wants to answer the following sub questions.

a) What is the shipbuilding process in DSNS?
b) What are the elements in the process?
c) How is modular shipbuilding different from previous technologies?

In the second part of this chapter, we describe the plan for shipbuilding process in detail. To be more concrete, this part focuses on the so-called PKR project in DSNS. After the description, the critical path of the plan is defined and discovered. At last, the author researches into the possible consequences if there is any change in this plan. Furthermore, delays are defined in the third part of this chapter. After that, there is an analysis of possible delays and corresponding consequences.

As the only verb among four key words, “manage” decide the logic and procedure of this case study. In general, there are six steps in the process of managing.

1) Observe the process supposed to manage
2) Classify the observations into problems or non-problems
3) For those problems, sort them into the problems can solve themselves and problems can and have to be solved
4) Rank the problems that have to be solved according to importance and urgency
5) Divide problems into sub-problems
6) Decide the sequence of solving the problems

Based on the research above, the first three steps are conducted in the beginning of this chapter. The last part of this chapter is about to finish the final three steps. For those problems can and have to be solved, we select delays, one of the common but difficult problems in a construction plan, to research into. In this research, delays are classified into four categories according to their durations and locations. The ones occurring in the critical path with long duration are the focus of management. Therefore, efficient methods are applied to those delays to observe the outcomes. Finally, there is a evaluation of the performance of the split and advance method.

5.1 Shipbuilding Process

5.1.1 Introduction of DSNS

DSNS is the initials of Damen Schelde Naval Shipbuilding which is located in Vlissingen in the Netherlands. The history of naval shipbuilding in Vlissingen can be dated back to the middle of 19th century. More than 135 years ago, quality naval and commercial shipbuilding in Royal Schelde shipyard made it known to the world (DAMEN Schelde Naval Shipbuilding, 2011).

"In 2000, Royal Schelde became a member of the DAMEN Shipyards Group. The group consists of more than 30 major shipyards and operating companies around the world, has built more than 4,000 commercial and military vessels, currently employees nearly 8,500 skilled workers and has nearly EUR1.5 billion in annual turnover. Over the past years DSNS has made great strides in efficiency, subcontracting a significant amount of work and now building more ships than before. Flexibility, Performance and Perfection has become our trade mark" (DAMEN Schelde Naval Shipbuilding, 2013).

"As the supplier of naval surface combatants and auxiliaries to the Royal Netherlands Navy, the yard has carried out over 50 years of continuous frigate and auxiliary vessel development which resulted in seven generations of frigates and four generation of auxiliary vessels" (DAMEN Schelde Naval Shipbuilding, 2013).

5.1.2 Introduction of the Shipbuilding Process in DSNS

In DSNS, there are three levels of management in conducting the shipbuilding process. Firstly, there is project management which controls the whole project in general. In the second place, the planning and logistics department is responsible for the detailed scheduling and planning for the shipbuilding process. The operations are located at the third level of the structure. The three levels of management towards shipbuilding process are shown on the picture below.

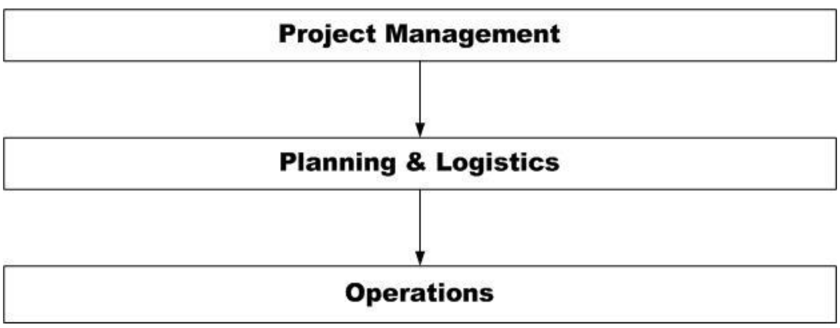


Figure 5-1 Management Structure of PKR 1 Project
Source: compiled by author

As to the third level of operations, it is about the real shipbuilding process in DSNS. To be more specific, there are six steps in a shipbuilding process, which include engineering, procurement, working preparation, production, setting to work and final acceptance. The following graph illustrates the process well in detail.

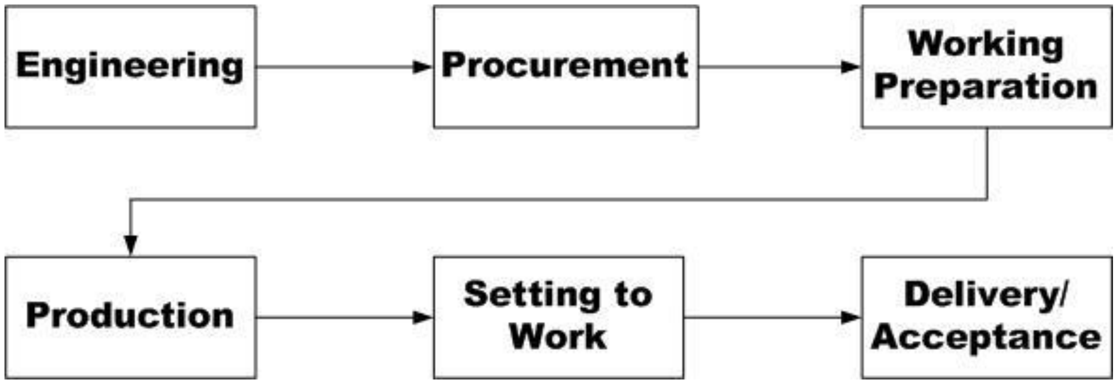


Figure 5-2 Shipbuilding Process in DSNS
Source: compiled by author

However, each of the steps is associated with the one before it and the one following up. There is little flexibility in changing the sequence, which also leads to the long duration of a shipbuilding process. To solve these problems, the more efficient concept of modular shipbuilding is introduced to the shipbuilding industry. In a modular shipbuilding process, the structure of the whole ship is divided into several parts. Each part is built separately. When all the parts are finished, they are assembled to a whole ship. Because this method provides the possibility to build different parts of the ship in parallel instead of in certain sequence, total project duration is shortened. Based on the assumptions that the ship is divided into 3 modules, the modular building concept n general is illustrated below.

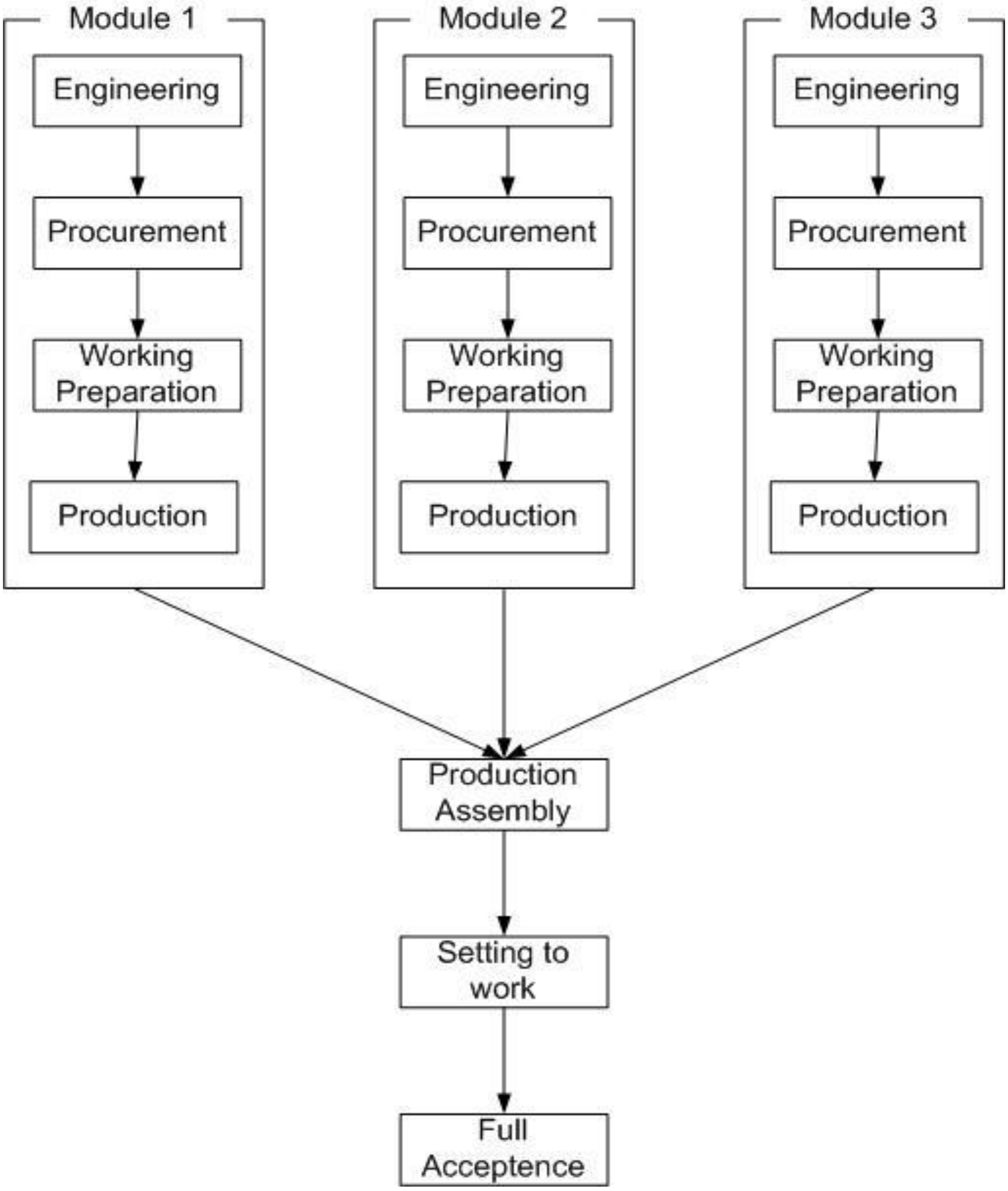


Figure 5-3 Modular Building
Source: compiled by author

Since 2001, 20 ships have been built in Vlissingen. (DAMEN Schelde Naval Shipbuildling, 2013) The practice of using this method has been proven effective with regard to the decrease in delivery time.

5.2 Plan of Shipbuilding Process

5.2.1 Introduction

Based on the experience of more than 50 years in building naval ships for Royal Netherlands Navy, DSNS now offers navies worldwide a broad range of naval and patrol vessels.

Recently, the Indonesia government orders two guided missile frigates (PKR) from DSNS. According to the requirements of the customers, there need to be a Transfer of Technology Program (ToT Program). Therefore, DSNS has committed itself to design and built these ships together with PT-PAL Surabaya. To be more specific, the ToT Program comprises that DSNS will apply her knowledge to instruct, train and educate personnel of PT-PAL in order to realize a mutual production of the PKR vessels in Surabaya at the PT-PAL premises. The key aspect in this ToT Program is sharing knowledge related to the project and "training on the job" by experienced DSNS trainers and managers, both during the design stage, embedded in the organization in Vlissingen as well during the hull assembly, outfitting and commissioning phase in Surabaya where the PT-PAL personnel will be supported by an experienced building team from DSNS in Surabaya embedded in the JOA. This final building stage will be leaded by a Yard manager from PT-PAL and a Yard manager from DSNS. Compared to the vessels built in Vlissingen, this new requirement will lead to a longer duration of the construction mainly due to the longer transportation time and the lower productivity in Indonesia.

To simplify the problem, only the construction plan for PKR 1 is discussed in this thesis. To be more specific, the building location of the construction is illustrated as by the following picture.

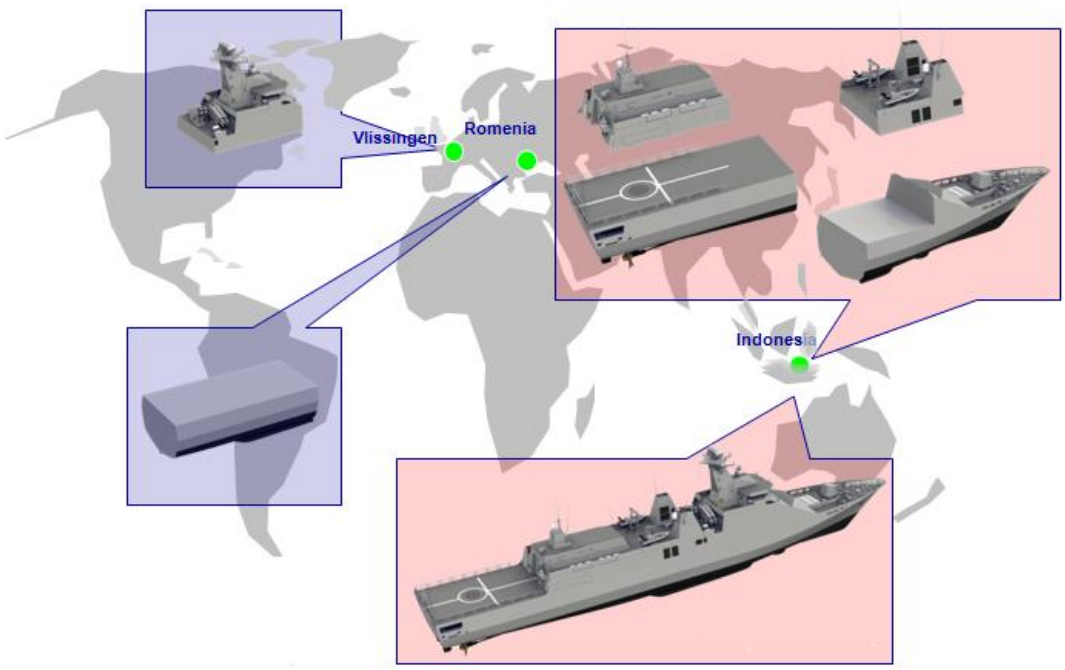


Figure 5-4 Building Locations
Source: DSNS

According to the illustration on figure 5-2, module 1, 2, 4, 6 will be built in Surabaya in Indonesia; module 5, which is the control tower of the ship, will be built in Vlissingen in the Netherlands. Module 3, which is also called power plant, will be built in Galati in Romania. The hull assembling, outfitting, testing and deliveries are to be done in Surabaya in Indonesia.

To be more specific, the whole logistics chain can be demonstrated by the following graph.

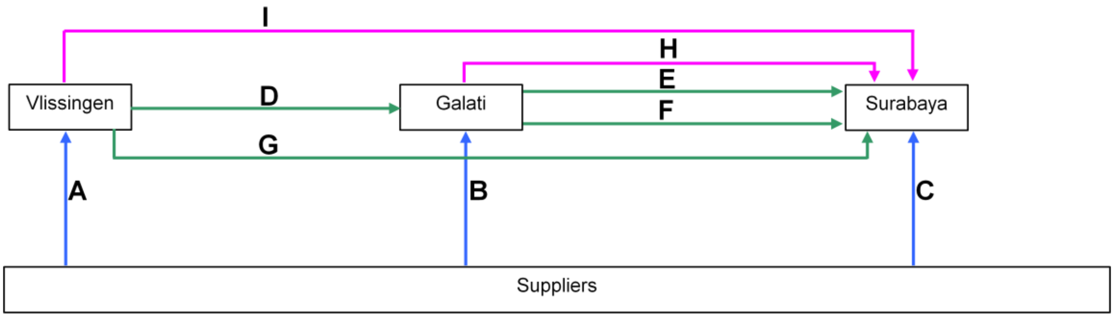


Figure 5-5 Logistics Chain of PKR Project
Source: DSNS

On the chart above, there are 9 materials flows in total. The explanation of each flow is shown on the table below.

Table 5-1 Explanation of the Materials Flows

Stream	From	To	Content	Duration
A	Suppliers	Vlissingen	Steel for module 5 / equipment for module 5	0-2 weeks
B	Suppliers	Galati	Selection of equipment / non ferro and stainless steel piping materials	2 weeks
C	Suppliers	Surabaya	Selection of equipment / non ferro and stainless steel piping materials	12 weeks
D	Vlissingen	Galati	Selection of equipment / non ferro and stainless steel piping materials	1 week
E	Galati	Surabaya	Selection of equipment	9 weeks
F	Galati	Surabaya	Selection of equipment	
G	Vlissingen	Surabaya	Hull steel	13 weeks
H	Galati	Surabaya	Complete module 3	7 weeks
I	Vlissingen	Surabaya	Complete module 5	

Sources: DSNS

5.2.2 Planning Concept

In practical, once the contract for building is signed, the ship builder will make a construction plan according to the due date mentioned in the contract. Overall speaking, there are three steps to make the detailed construction planning. The following graph shows the names and the sequences of the steps clearly.

Figure 5-6 Steps in Planning
Source: compiled by author

In the first step, the due date means the date that the full acceptance of the ship needs to be realized. This date is confirmed in the contract by both the seller and the buyer. According to that date, the ship builder then makes a master plan of the whole construction. In fact, the master plan is more or less the time schedule of the whole project. Because of the complexity of the shipbuilding process, the whole project will be divided into several sub projects, the due date of each sub project will be set in the master plan. To be more accurate, they are named as milestones in the master plan by DSNS. The whole process will be reviewed at each milestone to make sure that DSNS can finish building on time. After the master planning, ship builder makes an operational plan, which includes all the detailed steps in the construction. In this research, the author focuses on managing the delays in the master plan.

5.2.3 Master Plan

As is introduced above, the most important element in the master plan is the specific milestones for checking the process of the project. In the specific PKR 1 project, there are six main milestones in total.

Table 5-2 Milestones in the Master Plan

Milestone	Date	Activity name
1	Dec 27th, 2012	EDC
2	May 30th, 2013	Main ships construction plan review
3	Dec 30th, 2013	Start cutting
4	Dec 10th, 2015	Launching/Floating
5	Sep 20th, 2016	Completion of HAT
6	Jan 24th, 2017	Final acceptance

Source: DSNS

With regard to the aforesaid shipbuilding process, each milestone implies the end of certain step or the beginning of the next step. To be more specific, each milestone is explained below.

1) The milestone EDC means the Effective Date of the Contract. Referring to the shipbuilding process of PKR 1, this date is the beginning of the engineering process.

2) The second milestone means the end of engineering. Once the construction plan is agreed by both parties in the contract, the ship builder, which is DSNS in this case, starts the starts the procurement.

3) The third milestone, start cutting, means cutting steel plates into the parts that will form the hull and deck sections of the ship. It is often regarded as the starting point of production.

4) Launching or floating refers to filling the dock with water to float the ship. It is the next stage when all the blocks are mounted and jointed. (Shipipedia, 2013) According to the explanation, the launching is the end of production and the beginning of the setting to work.

5) Completion of Harbor Acceptance Test (HAT). As an important part of setting to work, the completion of HAT implies the success in the setting to work process. Combined with the six steps in shipbuilding, to reach this milestone means the end of the fifth step.

6) Full acceptance is also the last step of the construction plan. Therefore, the last milestone means the end of the construction plan, as well as the whole project.

5.2.4 Operational Plan

To make an operational plan according to the milestones described above, there are four steps. First, the planner makes hull assembling plans for all modules according to the master plan. In the second place, it is a backwards planning from hull assembly plan to hull constructions plan. Thirdly, engineering planning and purchasing planning are made according to the engineering delivery milestones. Last step is to match the purchasing, platform and combat planning. For the time being, the production plan is in progress, hull assembly planning and hull construction planning still need to be finalized with building yards, and outfitting planning is still to be created.

For the time being, the production plan is in progress, hull assembly planning and hull construction planning still need to be finalized with building yards, and outfitting planning is still to be created. The specific operational plan is shown in appendix 1.

5.2.5 Critical Path

In this research, the author defines the critical path as the process and activities without any slack in the whole construction plan. Generally speaking, there are three critical paths in the PKR 1 construction plan.

1) The first critical path is named as cable pulling. This path consists of four steps in total. This accomplishment of this path is marked with the well functioning of electrical systems in the whole ship.

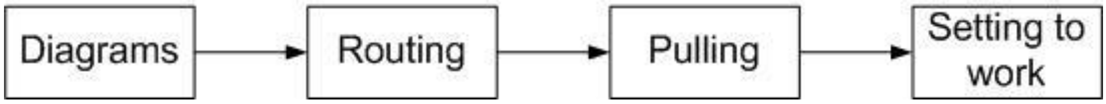


Figure 5-7 Cable Pulling
Source: DSNS

2) The second critical path is the shaft alignment. In other words, this step is all about constructing the propulsion system of the ship. The construction takes four steps.

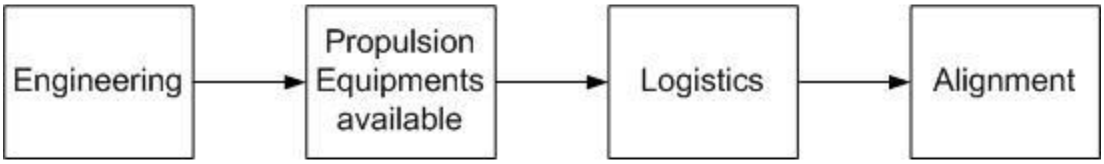


Figure 5-8 Shaft Alignment
Source: DSNS

3) The last critical path is combat system integration. The most significant feature of naval ships is their combat systems. Before being assembled to a ship, this system is tested independently. The third critical path includes five steps. In the third step, the initials FAT stands for factory acceptance test.

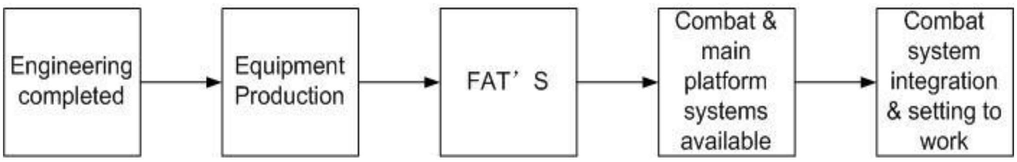


Figure 5-9 Combat System Integration
Source: DSNS

With regard to the definition of critical path in this construction plan, there is little room for adjustments in those three critical paths. In other words, once there is a delay in any of the three paths, the final acceptance is definitely to be put off. Therefore, they are the most crucial parts in the whole project. Any change in those associated procedures will bring risk to the whole project. To manage the delays in the construction plan is a problem that a manager has to solve, while to manage the delays in the critical paths is more important and urgent.

5.3 Delays in PKR 1 Project

This part starts with the definitions of delays. After that, analysis towards the reasons and corresponding consequences are discussed.

5.3.1 Definition of Delays

The English word “delay” may have different meanings according to the situation in which this word is used. In this case study, It is regarded as the object of the study. So it is vital to make the meaning of delay clear in the beginning of the study.

According to the explanations in Merriam-Webster leaner’s dictionary, the delay in defined as follows. “Delay is a situation in which something happens later than it should” (Merriam-Webster Leaner's Dictionary, 2013).

Combining the definition of delay and the real shipbuilding project, the word delay in this research is defined as follows. Delay is a situation in which the accomplishment of certain procedure happens later than planned. Based on the definition above, the author analyzes the shipbuilding process carefully in order to find out possible reasons of delays.

5.3.2 Reasons of Delays in PKR 1

As is indicated in section 5.1, the shipbuilding process takes six steps in general. However, one of the biggest challenges of the PKR 1 project is the transportation of materials, equipments and finished modules between Asia and Europe. Therefore, in the analysis of possible delays, the logistics part of the project needs to be taken into consideration. In addition, the last step of the construction is the full acceptance of the ship, which only represents a time point instead of a certain time period. In the analysis about the possible reasons for delays, the last step is skipped. In the analysis following up, reasons for delays in different stages will be concluded. The possible reasons are concluded by author based on an interview with a planner in PKR 1 project.

1) Delays in Engineering

   With regard to the fact that it is the first time that DSNS fully applies modular building concepts in a shipbuilding project, different modules are firstly built in different places and then being transported to a specific shipyard to have the final assembling. It is true that modular building saves time for production because the modules are built in parallel instead of following certain sequence. However, extra time for engineering the final assembling procedure is required. Therefore, in the stage of engineering, the delays are mainly owing to the extra work such as final assembling.

2) Delays in Procurement

It is important to point out that in the PKR 1 project, most of the building process will be finished in Asia, but all the suppliers for equipments and materials are mainly sourced in Europe. To be more accurate, before being transported to Indonesia, most equipment needs to be examined by DSNS in Vlissingen to make sure that they are in good quality. The same examination applies to some materials as well. For the rest such as stainless steel piping materials, they are sent directly from the suppliers in Europe to the shipyard in Surabaya.

According to the estimation by DSNS, the transportation of building materials package will take from 7 to 13 weeks depending on the transport mode. While long distance transportation is not so reliable. The duration of the shipment depends largely on the weather conditions on the sea, which is not always predictable. In addition, the time for customer clearance can fluctuate due to Indonesian regulations .

On the other side, there exists procurement between suppliers and the ship yard in Vlissingen or between suppliers and the shipyard in Galati. The prediction about the procurement within Europe is more dependable. There are two reasons for this accuracy. One reason is that the transport distance is relatively shorter than that between Europe and Asia. In general, the shorter the distance, the lower the transportation risk. Another reason is that the buyers are much more familiar with the procurement within Europe. The predictions by experienced people are usually more liable.

In conclusion, the possible delays in procurement mainly due to the uncertainty upon the transportation leg of the project. To be more accurate, it is the transportation between Europe and Asia adds the possibility of delays

3) Delays in Working Preparation

Working preparation mainly refers to the FAT's on the arrived equipments. The possible delays in this procedure are probably due to the failure appearing in the tests. If the equipment doesn't well during the test after arrival, possible solutions are requiring suppliers to repair the equipment or replace it by a new one. In this situation, extra time for dealing with the bad operation is required. In other words, failures in FATs are the reasons of possible delays.

4) Delays in Production

The production in the PKR 1 project takes place in three locations simultaneously. But it is the first time that DSNS conducts the ToT program, which indicates DSNS will instruct, train and educate personnel of PT-PAL to realize a mutual production of the PKR vessels in Surabaya. This big difference from previous projects extends the project duration not only because of the extra tasks to educate the workers in Surabaya but also the lower productivity in Indonesia when compared to that in Europe.

However, similar production processes in Vlissingen and Galati have been practiced for many times. The estimation towards the durations of the productions in these two places are much more accurate.

In conclusion, the possible delays in production in the PKR project owing largely to the training and lower work productivity in Surabaya.

5) Delays in setting to work

With regards to the application of modular building in the PKR 1 project, the step of setting to work consists of two parts.

One is the setting to work of each module. Take module 5 for an example. This module is built in Vlissingen After the completion of this module, it will be tested with electric supply but without the existence of other modules. This test is necessary before being delivered because it helps to make sure that the module is functioning well before the shipment to Indonesia. This kind of quality guarantee reduces the possibility of the failure occurring after the final assembly to the greatest extent.

The other kind of setting to work is the tests on the whole ship. After the arrivals of module 3 and module 5, the two parts are assembled on to the whole ship, which is mainly built in Indonesia.

Although there are two kinds of the step of setting to work, the reasons for delays in this step are the same. That is, the failure in the test when any module or the whole ship is set to work.

To conclude, the reasons of possible delays are listed in the table as below.

Table 5-3 Possible Reasons for Delays in Different Stages

Stage	Main reason for delays
Engineering	Extra engineering work
Procurement	Transportation of materials between Europe and Asia
Working Preparation	Failures in FATs
Production	Extra training and low productivity in Surabaya
Setting to work	Failure in testing

Source: compiled by author

5.3.3 Consequences of the Delays

The consequences of the delays depend largely on the locations and durations of them. According to this fact, the author classified the delays into four categories. That is, long delays along the critical path, short delays along the critical path, long delays outside of the critical path and short delays outside of the critical path.

For the long delays along the critical paths, they are ranked in the first place. Firstly, they appear in the critical paths. Since there is little room for adjustment in the three critical paths Delays occurring on any of the three paths lead to the shipbuilder's failure in final delivery. The conclusion based on the analysis above if possible these delays must be solved firstly since they will lead to the final delay of the whole project to a large extent.

For the short delays outside the critical paths, they are ranked lastly. They don't appear on the critical path, so there are still slack for adjustment on the paths includes the procedures with delays. Additionally, the delays are short, so the new duration of the path containing certain procedures will not be longer than that of the critical path. In this research, short delays appear outside the critical path are not discussed in detail.

It is a little bit difficult to choose between short delays along critical path and long delays outside the critical path to be ranked at the second place. The main principle for making the choice is to select the one that will affect the duration of the whole project furthest.

Long delays located outside the critical path may change the duration of the whole project as well. When they are long enough, all the slacks within the certain path may be used up. In other words, when the delays outside the critical path are too long, then a new critical path will be defined. From this perspective, the long delays outside the critical path may affect the total duration of the project as well. As to the short delays along the critical path, they will definitely put off the accomplishment of the whole project, but to little extent. To simplify the problem, the author takes the concepts in classical PERT network method and CPM that a non-critical path will not be changed to a critical path. Based on that assumption, short delays within critical path ranked secondly among the four kinds of delays.

In general, delays put off the accomplishment of the whole project. But different delays impacts the duration of the project to different extent. Long delays occurring along the critical paths surely directly lead to a big delay in the construction plan. They need to be solved in the first place. Short delays along the critical paths certainly cause small delays in the accomplishment of the whole project. They are labeled with the second importance among all the possible delays. According to the assumptions in last paragraph, the delays outside the critical path will not be discussed in this research.

5.4 Manage of Delays in PKR 1 Project

Based on the analysis on possible delays in the construction plan, the last step of this study will be managing the delays according to the reasons and consequences.

5.4.1 Problem Identification

According to the analysis on the construction plan and possible delays, the management of the delays focuses on the delays along the critical paths. The whole network to be researched into is shown on the next page. The description is based on the general introduction of PKR 1 project provided by DSNS.

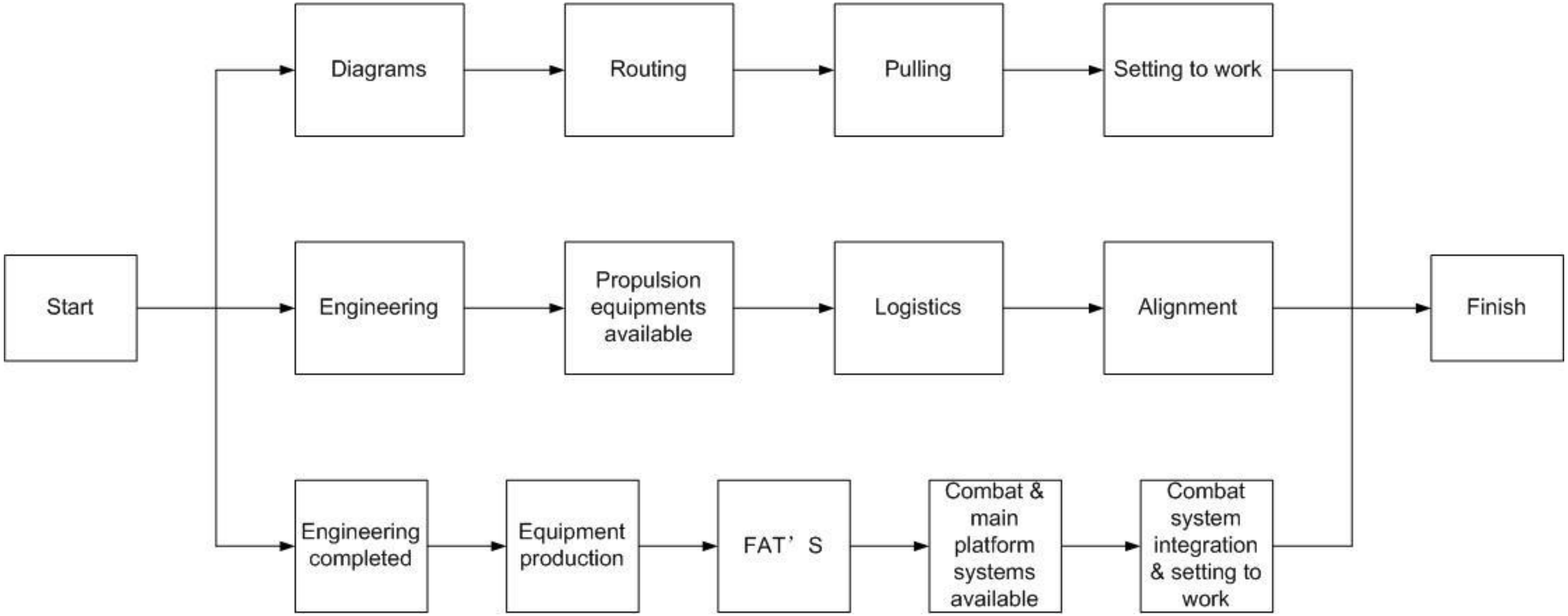


Figure 5-10 Constructions Plan with Critical Paths
Source: DSNS

To simplify the description of the project, the author abstracts the construction plan as follows.

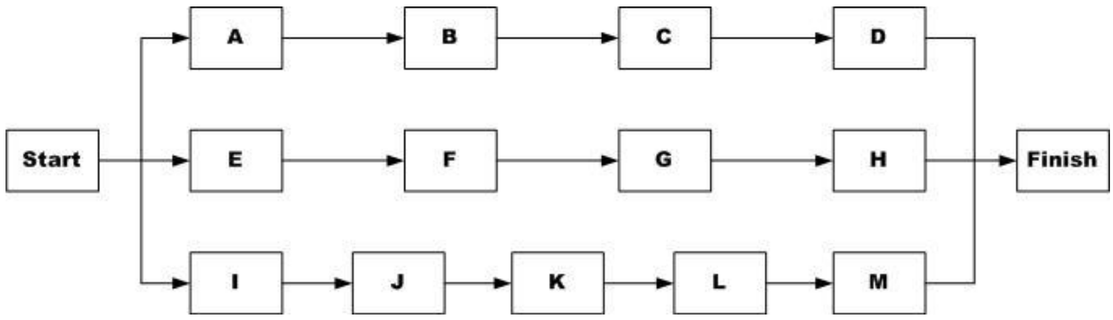


Figure 5-11 Abstraction of the Construction Plan
Source: compiled by author

As the key part in the construction plan, the three critical paths have the same duration. Besides, there is little slack for each of the 13 procedures associated within the construction plan. The detailed information about the 13 procedures is listed in the following table.

Table 5-4 Procedures along Critical Paths

Critical Path	Procedure	Name	Stage	Possible delays
Cable Pulling	A	Diagrams	Engineering	Extra engineering work
	B	Routing	Engineering	Extra engineering work
	C	Pulling	Production	Extra training and low productivity
	D	Setting to work	Setting to work	Failure in the tests
Shaft Alignment	E	Engineering	Engineering	Extra engineering work
	F	Propulsion Equipments Available	Working Preparation	Failure in FAT'S
	G	Logistics		
	H	Alignment	Production	Extra training and low productivity
Combat System Integration	I	Engineering completed	Engineering	Extra engineering work
	J	Equipment Production	Working Preparation	Failure in FAT'S
	K	FAT'S		
	L	Assembling	Production	Extra training and low productivity
	M	Setting to work	Setting to work	Failure in the tests

Source: compiled by author

5.4.2 Analysis of the Delays

Based on the analysis above, delays along the critical paths are managed according to specific reasons. In addition, the two possible methods to manage the delays that introduced in chapter 4 are used. In this section, the study is all about managing the 13 procedures along the critical paths. For the delay management of each procedure, the following three questions need to be answered.

a) What are the specific reasons of these delays?
b) How to make estimates of durations of certain activities?
c) What will be the possible methods to reduce the risks of having delays?

In the next step, delays in the 13 procedures within the three critical paths are analyzed based on an interview with an engineer in DSNS.

1) Delays in Procedure A (Diagrams of Cable Pulling)

   Procedure A is the designing for cable pulling structure. To be more specific, it is more about the detailed design of the cable pulling system, such as the way to make two different cables connected. In this stage of cable pulling, the designs have to be confirmed with the customer. It normally takes two weeks. One week is for customers to check all the details and another is for them to reply. However, when the customers are unsatisfied with the designs, another half month is necessary to be planned.

   Referring to the real operational plan of the PKR project, the drawing of the diagrams takes 20 weeks. Based on the reason analysis of the delays in procedure A, it is reasonable to make a pessimistic estimate that it will take another 4 weeks for finishing all the diagrams for cable pulling. However, in the planning stage, there are some slacks planned into the project to reduce the risk of delays. That is to say, if everything goes smoothly just as planned, it is also possible that the procedure A is finished 2 weeks earlier than planned.

   Procedure A is the beginning of the critical path of cable pulling, since the most uncertain part of the delays comes from the corporation with customers, it is not easy to speed up the process by putting more resources into it. The most practical solution is to reschedule the following procedures to avoid the possible delays in the whole project.

2) Delays in Procedure B (Routing of Cables)

   Different from designing the diagrams for cable pulling, routing of cables is more about how to fit the cables into a ship. As is mentioned in the introduction of the PKR 1 project, module 3 and module 5 are built in Europe. Before being sent for final assembling in Surabaya in Indonesia, the two modules are set to work independently. Therefore, special routing is also needed for the sea trials of module 3 and module 5. In addition, it is the first time that DSNS applies the concept of fully modular building. Ships are built in different modules firstly and then be assembled to the whole ship. This big difference brings extra work for the procedure of routing because the designer has to be careful in deciding the sequence of assembling cables.

Lastly, the design of routing has to be agreed with the customers

In the real operational plan of PKR 1 project, routing takes 20 weeks. On one hand, with regard to the reasons aforesaid, the author makes the pessimistic estimate of the delay in procedure B to be 6 weeks. On the other hand, the optimistic estimate is to finish the procedure B in 18 weeks.

Routing is a part of the engineering process. If there is a delay in this procedure, adding resources such as employing more designers can be a solution. But adding more resources increases the cost. In addition, split and advance is another approach. For example, the routing process consists of two parts: routing of different modules and routing of the whole ship. Routing of different modules is urgent because it have to be ready before the building of the modules. But routing of the whole ship can be put off since it is required before the final assembling.

3) Delays in Procedure C (Pulling of Cables)

Pulling of the cables is classified into the stage of production. Due to the fact that the final assembling of the ship is finished in Surabaya, the production process will go slower because of the lower productivity in local area. However, there have never been experiences in building naval ships in Indonesia, so it is hard to estimate the duration of the pulling process. In addition, as an important part of PKR 1 project, DSNS will instruct, train and educate personnel of PT-PAL. The training also takes a lot of time. The real duration depends on the corporation with local shipyard.

It is estimated in the operational plan that the pulling of cables takes 52 weeks. However, the reasons for delays are in fact reasons for uncertainty in the duration of cable pulling. For example, the local productivity may be higher or lower than expected, so the duration of procedure C can be bigger or smaller than estimated. From this perspective, the pessimistic estimate is that it costs 58 weeks to finish procedure C, and in an optimistic situation, procedure C takes 48 weeks.

If there is a delay in procedure C, possible solution 1 is to add capacity, mainly refers to increasing the number of workers and adding labor shifts. When compared with the labor cost in Europe, it is much cheaper to hire an extra worker in Indonesia. Therefore, the best choice to manage the delays in pulling the cables is to add capacity. Moreover, it is also practical to manage the delays just by splitting and advancing the step.

4) Delays in Procedure D (Setting to work)

The last step in the critical path of cable pulling is setting to work, namely procedure D. Since it is the setting to work procedure of cable pulling, which starts after the final assemble, it is regarded as the setting to work procedure of the whole ship. Therefore, procedure D consists of many tests of the completed ship. The biggest issue that may cause delays in setting to work procedure is the failure in the tests.

In the detailed operational plan, procedure D takes 34 weeks. Based on the reason analysis of the delays and previous experience, in the most pessimistic situation, the procedure takes 50 weeks; while in an optimistic estimate, it takes 32 weeks.

If the failure in the tests appears, there is little possibility that the delays are eliminated by adding more capacity. Because the checking after the tests is time consuming and adding capacity, for example, add workers to the tests, helps little in improving the productivity. Moreover, it is the last step in the critical path of cable pulling, so there is little room for adjustment in the following steps. In conclusion, there is no efficient method to manage the delays in setting to work procedure; the more practical solution is to plan more slacks for this procedure.

5) Delays in Procedure E (Engineering)

Procedure E, namely the engineering of shaft alignment, is the beginning of the second critical path. This procedure is classified into the engineering stage of the whole project plan. Generally speaking, the main reason for the delays in the engineering stage in PKR 1 project is the extra engineering work due to the different locations for building the ship. However, in procedure E, the main reason for delays is the communication between ship builder and customers.

It is estimated procedure E takes 10 weeks in the operational plan. Due to the uncertainty in the communication between builders and customers, it is assumed it takes 12 weeks at most, 8 weeks at least.

Since procedure E is the first step in the critical path of shaft alignment, possible management tools of the delays in this procedure is to split this step, and split and advance the steps following up. In addition, by increasing the number of engineers to speed up procedure E is also a practical solution, but extra costs must be taken into consideration.

6) Delays in Procedure F (Propulsion equipment available)

Procedure F is a combination of different activities within the working preparation of shaft alignment. To be more specific, this procedure consists of ordering the equipments from suppliers, production of the equipments and the factory acceptance tests, which is conducted in the factories of the suppliers. Therefore, to analyze the reasons for delays, all the sub procedures need to be checked in the first place. In general, delays often happen in the production of the equipments and FAT'S afterwards. For example, the suppliers may fail in finishing the main engine because of the shortage in steel. Furthermore, failure in FAT'S seldom happens. But once it appears, it would take up to extra 1.5 months.

In fact, 92 weeks are planned for the availability of propulsion equipments in the operational plan. Considering the above reasons for delays, it is reasonable to make a pessimistic estimate that procedure E takes 108 weeks. If everything go smoothly, to finish this step in 104 weeks can be expected.

As to the possible management strategy for the delays in procedure E, asking suppliers to add workers for producing the equipments is practical, but it costs extra money. Since propulsion equipments include engine, shaft and propeller in general, another possible solution is to split this procedure and to advance some activities.

7) Delays in Procedure G (Logistics)

When all the propulsion equipments pass the FAT'S, they are ready for transportation from Europe to Asia. With regard to the fact that most of the equipments are heavy and large, to transport them by sea is an ideal choice. But the duration of the sea transportation depends largely on the weather conditions on the sea. The uncertainty of weather leads to the difficulty in estimating the duration of procedure G. In addition, it is transportation between different countries. The uncertainty in customer clearance also needs to be taken into consideration.

If it is assumed logistics part of shaft alignment takes shorter than expected, the sea transportation takes about 8 weeks. In general, it takes 9 weeks. However, when there are problems in sea transportation as well as in customer clearance, the duration of up to 12 weeks is also possible.

As to the possible solutions for the delays in procedure G, use faster transportation such as to transport some small equipments by air is acceptable. In that case, extra transportation costs must be considered.

8) Delays in Procedure H (Alignment)

As the last step in the critical path of shaft alignment, alignment starts with the arrival of all the equipments in Surabaya, and ends with the floating. Since it is classified into the production stage of the whole project, general reasons for the delay in procedure H is extra training provided by DSNS and lower productivities in Surabaya.

According to the operational plan for PKR 1 project, the alignment of the shaft takes 15 weeks. If the training is more effective than expected or the productivity in Surabaya improved a little bit, procedure H can be shorten to 13 weeks. However, if the productivity is lower or the training takes longer than expected, the duration of procedure H can be up to 19 weeks.

In general, the production process is speeded up by adding more workers, which is also applicable in procedure H. Besides that, to split the procedure in to several activities and advance some of the activities also helps to reduce the duration of the second critical path.

9) Delays in Procedure I (Engineering)

Combat system includes of many weapons, which are located in different places of the ship. However, most of them are equipped to the superstructure of the ship, which is named module 5 in PKR 1 project. To simplify the problem, the research into the combat system of PKR 1 is focusing on the building of module 5 in Vlissingen.

Procedure I or the engineering of the combat system is the first step in the combat system integration. It is classified into the engineering stage of the whole project. Therefore, the main reason for the delay in procedure I can be the failure in a timely agreement with the customers about the designs. In addition, the engineering work must be checked by the classification association. If there are some problems in the designs of the combat system, engineers have to make some changes. The extra designs take time.

Based on the operational plan of PKR 1 project, the engineering of the combat system takes 85 weeks. In an optimistic situation, it is assumed the engineering of the combat system takes 81 weeks. However, when there is a disagreement between shipbuilder and customers or classification association rejects the designs, up to 91 weeks is necessary to finish the engineering of the combat system.

To manage the possible delays in procedure I, adding engineers to the project is reasonable. With regard to the building process of module 5, building of the modules starts with section building. In other words, the chain of engineering and building different sections can be conducted in parallel.

10) Delays in Procedure J (Equipment production)

To be more specific, the procedure J also involves the ordering of the equipments. The main reasons for the delays in the equipment production are the suppliers' failure in supplying the equipment in time.

As is described in the production plan of PKR 1 project, the equipment production of the combat system takes 5 weeks. In a pessimistic situation, procedure J takes 6 weeks. The suppliers may also be good enough in producing those equipments in 4.5 weeks.

Possible strategy to manage the delays in the equipment production of combat system is to add more workers. In addition,

11) Delays in Procedure K (FAT'S)

After the production, all the equipments for combat system have to be examined in the factory of the suppliers. The possible reasons for the delays in produce K is the failure in the tests.

6 weeks are planned for the procedure K in the third critical path. However, it happens that the failure in FAT'S takes 4 weeks. Therefore, it is assumed pessimistically procedure K takes 10 weeks. If all the equipments are proven to be effective in the first round of the tests, the procedure takes only 4 weeks.

Unfortunately, there are few solutions to speed up this procedure since it really depends on the performances of the equipments during the tests. However, to split the following procedures and advance some of them would be a choice.

12) Delays in Procedure L (Combat & main platform systems available)

As the start of the production of module 5, procedure L is classified into the section building of the combat system integration. Different from the production of other critical paths in the project, the building of the combat system is conducted in Vlissingen in the Netherlands. So there are no issues such as extra training or lower productivity in procedure L. However, the completed module 5 need to be tested before the transportation to Surabaya, extra production for the tests may cause delays in procedure L. In addition, the lack of available workers is another reason of the delays.

It is estimated in the operational plan that procedure L takes 17 weeks. Due to the fact that the estimate of the producing module 5 is relatively dependable, the optimistic estimate of procedure L is 16 weeks, and the pessimistic estimate of the procedure is 19 weeks.

To manage the delays in the production of combat system, employing extra workers or running the production for longer hours are practical. In addition, the production of the combat system can be split up and advanced to speed up the production process.

13) Delays in procedure M (Combat system integration & setting to work)

Procedure K is the final step before module 5 is transported to Surabaya. The main reason for the delays in this procedure is the possible failures in the tests

According to the production plan, procedure K takes 11 weeks. If the results of the tests are better than expected, the duration can be shortened to 13 weeks. However, if a failure happens, the final step takes up to 18 weeks.

To manage the delays in procedure K, employing extra workers for the integration process is a choice. Besides that, advancing some parts of the integration is more effective. But the split and advance strategy can only be applied with the change in procedure J.

5.4.3 Modeling and Simulation

To simplify the problem for the research, the modeling and simulation will be based on the following assumptions.

a) The durations of the activities follow normal distribution
b) The acceptance range of delays is 5% of the total duration of the master planning
c) The total duration of the master planning is set with 98% confidence level
d) The duration of certain critical path is set with 98% confidence level

Naval shipbuilding industry is different from other shipbuilding industries because they consider the time limitation of the project in the first place. In this research, we will just focus on the time control of the PKR 1 project and neglect the cost perspective. According to the four assumptions, the new critical path is identified. The completion time with certain confidence level is recalculated to evaluate the effects of the split and advance strategy.

1) Simulation before the Application of the Strategy

To simplify the problem for the research, the duration of each procedure is measured in weeks. Based on the aforesaid analysis of the delays, the optimistic estimate, the most probable estimate and the pessimistic estimate of the duration of each activity is listed in the following table.

Table 5-5 Estimates of the Activities' Durations in PKR 1 Project

Critical path	Activity	Estimates (weeks)		
		Optimistic (a)	Most probable (m)	Pessimistic (b)
Cable Pulling	A	18	20	24
	B	18	20	24
	C	48	52	58
	D	32	34	50
Shaft Alignment	E	8	10	12
	F	88	92	108
	G	8	9	12
	H	13	15	19
Combat System Integration	I	81	85	91
	J	4.5	5	6
	K	4	6	10
	L	16	17	19
	M	11	13	18

Source: compiled by author based on an interview with a planner in DSNS

As is indicated in chapter 4, to assume that activity time follows normal distribution reduces the risk of an underestimate in the completion time of a project. Therefore, the author simulates the model of PKR 1 project based on the assumption that activity time follows normal distribution.

Similar to the simulation of Western-Hill Shipping Center Project using Monte Carlo Method in chapter 4, we firstly calculate the mean value (t_i) and variance (σ^2) of different activities' durations using the following formulas.

$$t_i = \frac{a+4m+b}{6}\ ,\ \sigma^2 = \left(\frac{b-a}{6}\right)^2$$

The results of the calculations are listed in the following table.

Table 5-6 Mean Value and Variance of Activities in PKR 1 Project

Critical path	Activity	t_i	σ^2
Cable Pulling	A	20.33	1.00
	B	20.33	1.00
	C	52.33	2.78
	D	36.33	9.00
Shaft Alignment	E	10.00	0.44
	F	94.00	11.11
	G	9.33	0.44
	H	15.33	1.00
Combat System Integration	I	85.33	2.78
	J	5.08	0.06
	K	6.33	1.00
	L	17.17	0.25
	M	13.50	1.36

Source: compiled by author

Combining the results in table 5-6 and the assumption that all the activity time follows normal distribution, we generate 1000 groups of durations of all the activities to get the distribution of the project completion time of the whole project. However, comparing with the simulation for Western-Hill Shipping Center Project, one of the biggest differences is that the model for PKR 1 project consists of three critical paths, the durations of which are the same. Therefore, during the simulation of the project, one important step is to re-identify the critical path and then calculate the whole project duration. The results of the simulation are demonstrated by table 5-7 and figure 5-12.

Table 5-7 Simulation Results with the Activity Time Following Normal Distribution

Group	Range		Frequency	Probability	Cumulative Probability
1	124.00	126.00	16	0.016	0.016
2	126.00	128.00	71	0.071	0.087
3	128.00	130.00	210	0.21	0.297
4	130.00	132.00	300	0.3	0.597
5	132.00	134.00	216	0.216	0.813
6	134.00	136.00	115	0.115	0.928
7	136.00	138.00	53	0.053	0.981
8	138.00	140.00	13	0.013	0.994
9	140.00	142.00	5	0.005	0.999
10	142.00	144.00	1	0.001	1

Source: compiled by author

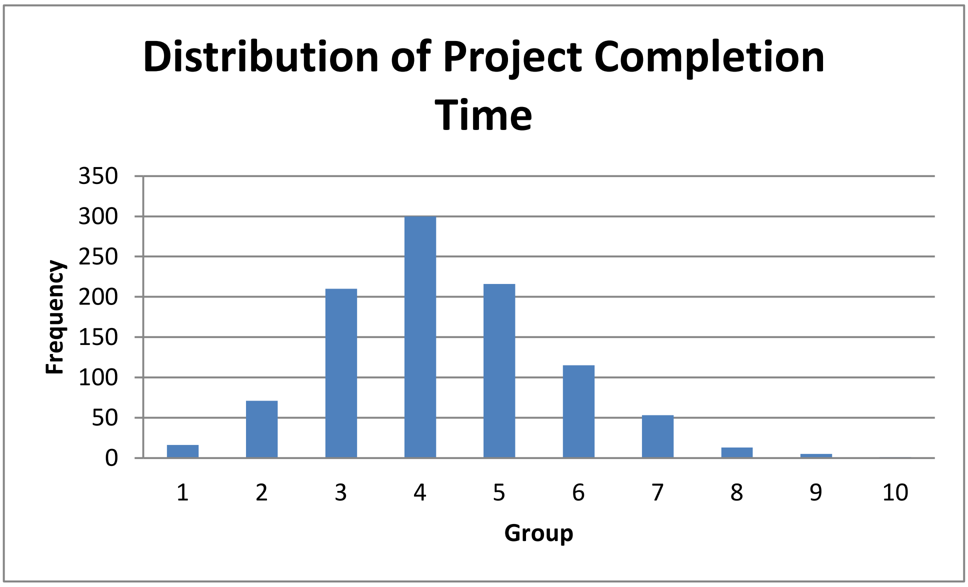


Figure 5-12 Simulation Results with the Activity Time Following Normal Distribution

Source: compiled by author

However, the thought behind the simulation is to replace the actual distribution of the project completion time by the 1000 groups' simulation results. An important step before using the simulation results is to check if the replacement is reasonable. In other words, it is necessary to know to which extend is the estimation reliable to reflect the facts. According to the theory of statistical inference, the confidence level of the estimates can be examined by interval estimators. The procedure of interval estimate\ors is as below.

a) Determine the n samples for research
b) Calculate the mean (x) and standard deviation (σ) of the samples
c) Calculate the 95% confidence interval ($x - \sigma * 1.96/\sqrt{n},\ x + \sigma * 1.96/\sqrt{n}$).
d) Check if the mean value of 1000 times simulations located in the 95% confidence interval.
e) If yes, the estimates are reliable; if not, run the simulation again.

Now we select 900 numbers out of 1000, and then group them into 9 groups. In the next step, calculate the mean value of the numbers in the same group and use them as samples. So there are nine samples in this case. The results of the calculations are listed in table 5-8.

Table 5-8 Calculation Results of the Confidence Interval - Project Completion Time

mean	standard deviation	95% confidence interval	
		lower	upper
131.5918	0.278631331	131.4098	131.7738

Source: compiled by author

And the mean value of the 1000 times' simulation is 131.6022 weeks, which is located within the 95% confidence interval. Therefore, the estimations of the project completion time are reliable.

As we can see from fihure 5-12, the frequency to finish the project within the time range between group 2 and group 5 is high. That is to say, the project is more likely to be completed between 125 and 145 weeks. According to a theorem about normal distribution, if variances follow normal distribution, then the sum of them follows normal distribution as well (Keller, 2010). Therefore, we may calculate the confidence level to complete the project within certain period of time by the formula as below. During the evaluation, the results from 1000 times' simulation are used to calculate the mean (μ) and variance (σ) of the total project duration. X is the certain requirements for the duration of the project.

$$Z = \frac{X - \mu}{\sigma}$$

$$\mathbf{P(X \leq T) = P(Z \leq \frac{X - \mu}{\sigma})}$$

In the equations above, Z follows standard normal distribution, so the probability that $Z \leq \frac{X-\mu}{\sigma}$ can be figured out by referring to the standard normal distribution table. The specific results are illustrated by table 5-9 and figure 5-13.

Table 5-9 Cumulative Probability of the Completion Time

Durations(weeks)	133	134	135	136	137	138
Confidence level	68.93%	80.15%	88.50%	93.99%	97.17%	98.81%

Source: compiled by author

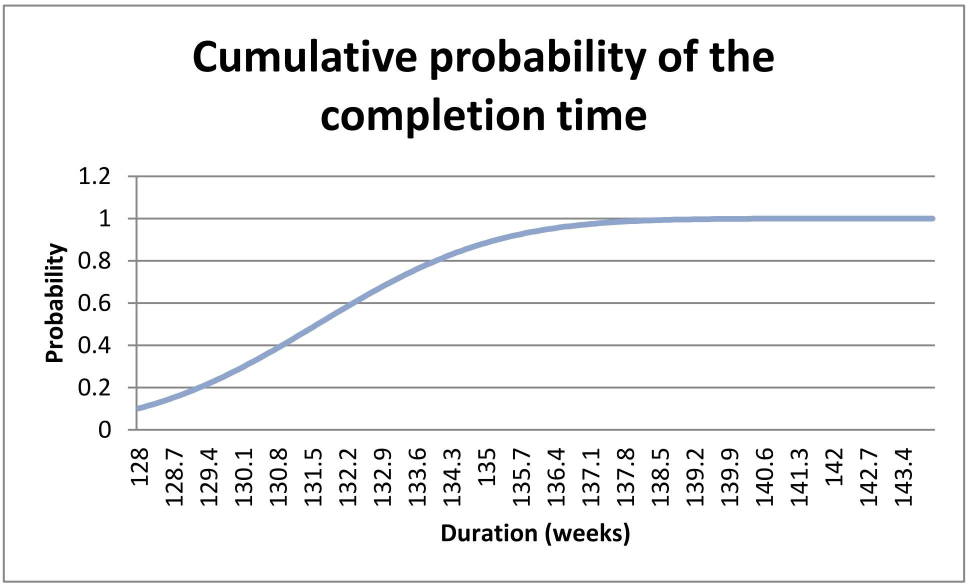


Figure 5-13 Cumulative Probability of the Completion Time
Source: compiled by author

As is indicated in table 5-9 and figure 5-13, the project is supposed to be completed in 138 weeks with 98% certainty. To simplify the analysis later on, we use the project duration with 98% confidence level for calculation, and the acceptance range of delays is 5% of the whole duration. Therefore, in this case, the delay acceptance range is 7 weeks. In the following study, we would just focus on the management strategies when there is a delay in each single critical path. This research mainly focuses on the time management of projects when there is a delay occurring. According to the assumptions before the simulation, the split and advance strategy does not add extra costs in this project. In simulating the management strategy, we would just examine the results from applying split and advance strategy.

2) Simulation of Managing Delays in Cable Pulling

When there is a delay in the first critical path of cable pulling, we firstly check if it is smaller than the acceptance range of delays, which is 7 weeks in this case. If yes, we just accept it. If the delays exceed 7 weeks, we would apply the split and advance strategy in the critical path of cable pulling. However, according to the introduction of every activity within the whole project, this strategy is only suitable for some specific steps in this path. To be more specific, only activities of diagrams, routings and cable pulling are suitable to be split. Therefore, the new activities in this path become as follow.

Table 5-10 Descriptions of Activities in New Critical Path of Cable Pulling

Original Critical Path	Activity	Description
Cable pulling	A1	Diagrams of module 1,2,4 and 6
	A2	Diagrams of module 3 & 5
	B1	Routing of module 1,2,4 and 6
	B2	Routing of module 3 & 5
	C1	Cable pulling of modules
	C2	Cable pulling of the whole ship
	D	Setting to work

Source: compiled by author

The new cable pulling process is illustrated by figure 5-14.

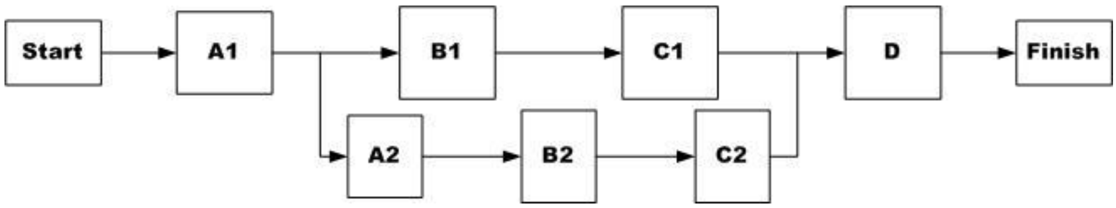


Figure 5-14 New Cable Pulling Process
Source: compiled by author

After applying the split and advance strategy in the critical path of cable pulling, the corresponding new estimates of the activity durations in the new project are made as shown on the table below.

Table 5-11 Estimates of the Activities Durations in New Cable Pulling Process

Activity	Estimates (weeks)		
	Optimistic (a)	Most probable (m)	Pessimistic (b)
A1	7	8	12
A2	11	12	16
B1	9	10	14
B2	9	8	12
C1	20	22	24
C2	28	30	34
D	32	34	50

Source: compiled by author based on an interview

Based on the estimates in table 5-11, we calculate the mean value (t_i) and variance (σ^2) of different activities' durations using the following formulas.

$$t_i = \frac{a+4m+b}{6}\ ,\ \sigma^2 = \left(\frac{b-a}{6}\right)^2$$

The results of the calculations are listed in the following table.

Table 5-12 Mean Value and Variance of Activities in New Cable Pulling Process

Activity	t_i	σ^2
A1	8.5	0.69
A2	12.5	0.69
B1	10.5	0.69
B2	8.83	0.25
C1	22	0.44
C2	30.33	1
D	36.33	9

Source: compiled by author

Based on the results from table 5-12, we generate 1000 groups of durations to get the distribution of completion time of cable pulling. The results of the simulation are shown on table 5-13 and figure 5-15.

Table 5-13 Simulation Results of New Cable Pulling Process

Group	Range		Frequency	Probability	Cumulative Probability
1	92.00	95.00	2	0.002	0.002
2	95.00	98.00	4	0.004	0.006
3	98.00	101.00	53	0.053	0.059
4	101.00	104.00	203	0.203	0.262
5	104.00	107.00	359	0.359	0.621
6	107.00	110.00	258	0.258	0.879
7	110.00	113.00	97	0.097	0.976
8	113.00	116.00	20	0.02	0.996
9	116.00	119.00	4	0.004	1

Source: compiled by author

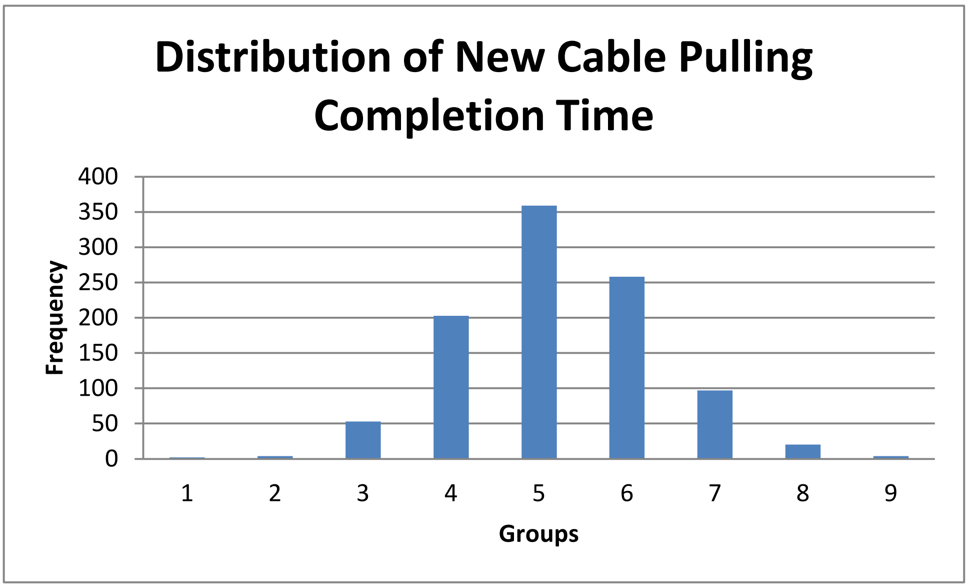


Figure 5-15 Simulation Results of New Cable Pulling Process
Source: compiled by author

Similarly, the next step is to check if the estimates are reliable. The calculation results are listed in the table 5-14.

Table 5-14 Calculation Results of the Confidence Interval – Cable Pulling

mean	standard deviation	95% confidence interval	
		lower	upper
106.0818	0.277117	105.9007	106.2628

Source: compiled by author

And the mean value of the 1000 times' simulation is 106.103 weeks, which is located within the 95% confidence interval. Therefore, the estimations of the project completion time are reliable.

In the next step, we use the following formulas to calculate the cumulative probability of new cable pulling completion time.

$$Z = \frac{X - \mu}{\sigma}$$

$$\mathbf{P}(\mathbf{X} \leq \mathbf{T}) = \mathbf{P}(\mathbf{Z} \leq \frac{\mathbf{X} - \boldsymbol{\mu}}{\boldsymbol{\sigma}})$$

In the equations above, Z follows standard normal distribution, so the probability that $Z \leq \frac{X-\mu}{\sigma}$ can be figured out by referring to the standard normal distribution table. The specific results are illustrated by table 5-15 and figure 5-16.

Table 5-15: Cumulative Probability of the New Cable Pulling Completion Time

Durations(weeks)	110	111	112	113	114	115
Confidence level	83.70%	92.83%	96.10%	98.03%	99.09%	99.61%

Source: compiled by author

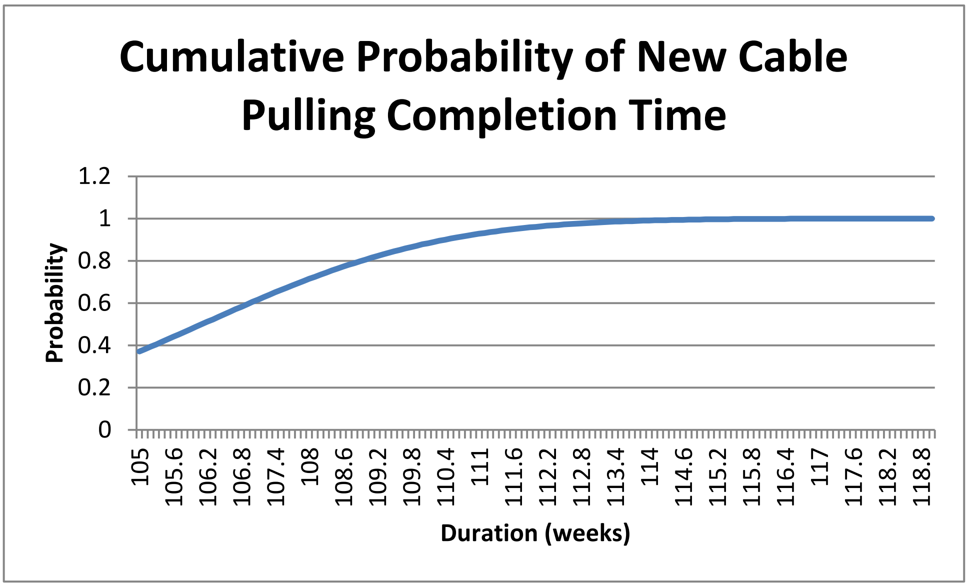


Figure 5-16 Cumulative Probability of New Cable Pulling Completion Time
Source: compiled by author

As is indicated in table 5-15, with the application of split and advance strategy in the first critical path, the new cable pulling process would take only 113 weeks with 98% confidence level. In the original master planning, the total duration of the project is 138 weeks, and the corresponding acceptance range of delays is 7 weeks. After the application of the strategy in cable pulling, the cable pulling process is shortened to 113 weeks. So the new acceptance range of delays would be 7 weeks plus the difference between the original project duration and the new cable pulling completion time. In this case, a delay of 32 weeks is acceptable. So after the application of split and advance strategy, the acceptable delay in the critical path of cable pulling is extended by 25 weeks.

3) Management of Delays in Shaft Alignment

Similar to the management strategy of the delays in cable pulling, when a delay occurs in the second critical path of shaft alignment, the first step is to check if it is within the acceptance range of delays, which equals 7 weeks in this case. If yes, we would accept it. If the delay is larger than 7 weeks, we would apply the split and advance strategy to the critical path of shaft alignment. However, the specific strategy is only suitable for two procedures in this path. To be more specific, only activities of engineering and making propulsion equipments available are suitable to be split. Therefore, the new activities in this path are as follow.

Table 5-16 Descriptions of Activities in New Critical Path of Shaft Alignment

Original Critical Path	Activity	Description
Shaft alignment	E1	Engineering of modules
	E2	Diagrams of the whole ship
	F1	Routing of modules
	F2	Routing of the whole ship
	G	Logistics
	H	Alignment

Source: compiled by author

The new shaft alignment process is illustrated by figure 5-17.

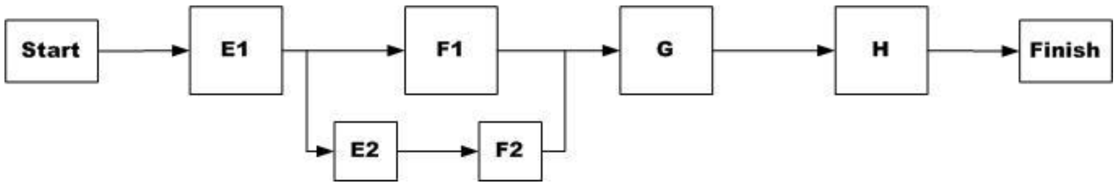


Figure 5-17 New Shaft Alignment Process
Source: compiled by author

After applying the split and advance strategy in the critical path of shaft alignment, the corresponding new estimates of the activity durations in the new possible critical path are made as shown on the table below.

Table 5-17 Estimates of the Activities Durations in New Shaft Alignment Process

Activity	Estimates (weeks)		
	Optimistic (a)	Most probable (m)	Pessimistic (b)
E1	5	6	10
E2	3.5	4	8
F1	67	70	80
F2	18	22	30
G	8	9	12
H	13	15	19

Source: compiled by author based on an interview

Based on the estimates in table 5-17, we calculate the mean value (t_i) and variance (σ^2) of different activities' durations using the following formulas.

$$t_i = \frac{a+4m+b}{6}, \ \sigma^2 = (\frac{b-a}{6})^2$$

The results of the calculations are listed in the following table.

Table 5-18 Mean Value and Variance of Activities in New Shaft Alignment Process

Activity	t_i	σ^2
E1	6.5	0.69
E2	4.58	0.56
F1	71.17	4.69
F2	22.67	4
G	9.33	0.44
H	15.33	1

Source: compiled by author

Based on the results from table 5-18, we generate 1000 groups of durations to get the distribution of completion time of shaft alignment. The results of the simulation are shown on table 5-19 and figure 5-18.

Table 5-19 Simulation Results of New Shaft Alignment Process

Group	Range		Frequency	Probability	Cumulative Probability
1	98	100	8	0.008	0.008
2	100	102	33	0.033	0.041
3	102	104	103	0.103	0.144
4	104	106	236	0.236	0.38
5	106	108	264	0.264	0.644
6	108	110	216	0.216	0.86
7	110	112	113	0.113	0.973
8	112	114	23	0.023	0.996
9	114	116	4	0.004	1

Source: compiled by author

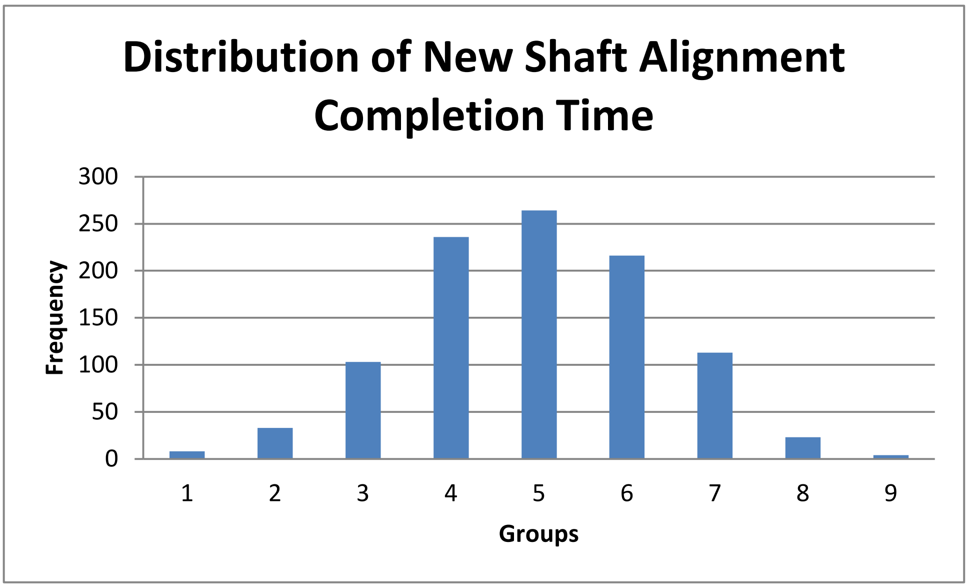


Figure 5-18 Simulation Results of New Shaft Alignment Process
Source: compiled by author

Similarly, the next step is to check if the estimates are reliable. The calculation results are listed in the table 5-20.

Table 5-20 Calculation Results of the Confidence Interval – Shaft Alignment

mean	standard deviation	95% confidence interval	
		lower	upper
106.9253	0.252832	106.7601	107.0905

Source: compiled by author

And the mean value of the 1000 times' simulation is 106.9131 weeks, which is located within the 95% confidence interval. Therefore, the estimations of the project completion time are reliable.

In the next step, we use the following formulas to calculate the cumulative probability of new cable pulling completion time.

$$Z = \frac{X - \mu}{\sigma}$$

$$\mathbf{P(X \leq T) = P(Z \leq \frac{X - \mu}{\sigma})}$$

In the equations above, Z follows standard normal distribution, so the probability that $Z \leq \frac{X-\mu}{\sigma}$ can be figured out by referring to the standard normal distribution table. The specific results are illustrated by table 5-21 and figure 5-19.

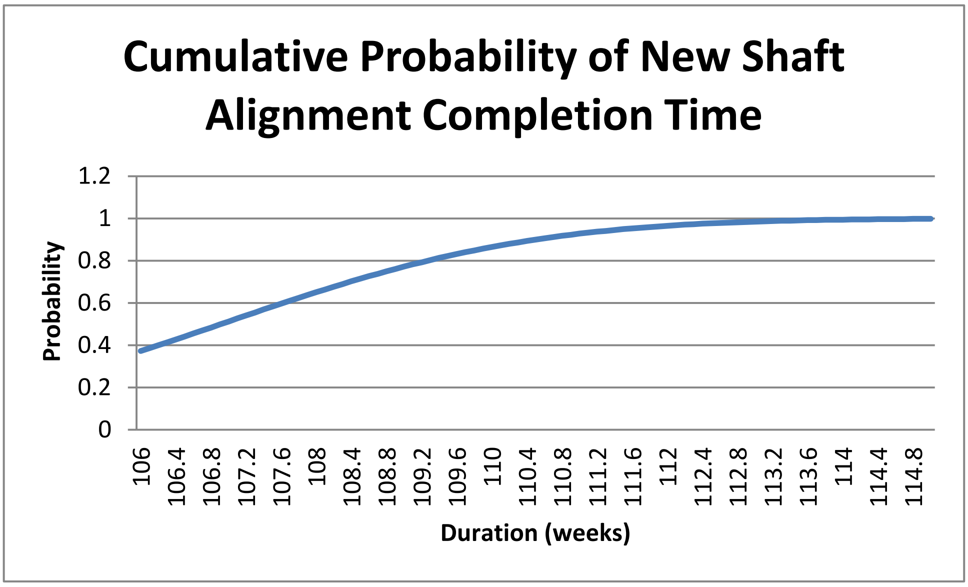


Figure 5-19 Cumulative Probability of New Shaft Alignment Completion Time
Source: compiled by author

Table 5-21 Cumulative Probability of the New Shaft Alignment Completion Time

Durations(weeks)	110	111	112	113	114	115
Confidence level	86.49%	92.78%	96.54%	98.52%	99.43%	99.81%

Source: compiled by author

As is indicated in table 5-21, with the application of split and advance strategy in the second critical path, the new cable pulling process would take only 113 weeks with 98% confidence level. In the original master planning, the total duration of the project is 138 weeks, and the corresponding acceptance range of delays is 7 weeks. After the application of the strategy in cable pulling, the cable pulling process is shortened to 113 weeks. So the new acceptance range of delays would be 7 weeks plus the difference between the original project duration and the new cable pulling completion time. In this case, a delay of 32 weeks is acceptable. So after the application of split and advance strategy, the acceptable delay in the critical path of cable pulling is extended by 25 weeks.

4) Management of Delays in Combat System Integration

Similar to the management strategy of the delays in cable pulling, when a delay occurs in the third critical path of combat system integration, the first step is to check if it is within the acceptance range of delays, which is 7 weeks in this case. If yes, we would accept it. If the delay is larger than 7 weeks, we would apply the split and advance strategy to the critical path of combat system integration. The specific strategy is only suitable for three procedures in this path. To be more specific, only activities of engineering and making propulsion equipments available are suitable to be split. Therefore, the new activities in this path are as follow.

Table 5-22 Descriptions of Activities in New Critical Path of Combat System Integration

Original Critical Path	Activity	Description
Combat System Integration	I1	engineering of module 5
	I2	engineering of the whole ship
	J1	equipments on module 5
	J2	equipments on the whole ship
	K1	FAT'S of the equipments module 5
	K2	FAT'S of the whole ship
	L	Assembling
	M	Setting to work

Source: compiled by author

The new shaft alignment process is illustrated by figure 5-20.

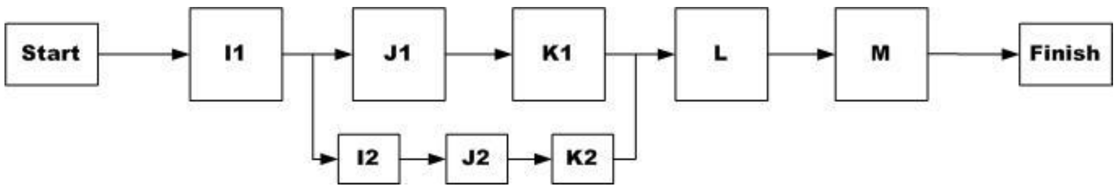


Figure 5-20 New Combat System Integration Process
Source: compiled by author

After applying the split and advance strategy in the critical path of combat system integration, the corresponding new estimates of the activity durations in the new possible critical path are made as shown on the table below.

Table 5-23 Estimates of the Activities Durations in New Combat System Integration Process

Activity	Estimates (weeks)		
	Optimistic (a)	Most probable (m)	Pessimistic (b)
I1	38	40	43
I2	43	45	48
J1	2	2	3.5
J2	2.3	3	3.5
K1	2	3	5
K2	2	3	5
L	16	17	19
M	11	13	18

Source: compiled by author based on an interview

Based on the estimates in table 5-23, we calculate the mean value (t_i) and variance (σ^2) of different activities' durations using the following formulas.

$$t_i = \frac{a+4m+b}{6}\ ,\ \sigma^2 = (\frac{b-a}{6})^2$$

The results of the calculations are listed in the following table.

Table 5-24 Mean Value and Variance of Activities in New Combat System Integration Process

Activity	t_i	σ^2
I1	40.17	0.69
I2	45.17	0.69
J1	2.25	0.063
J2	2.97	0.04
K1	3.17	0.25
K2	3.25	0.17
L	17.17	0.25
M	13.5	1.36

Source: compiled by author

Based on the results from table 5-24, we generate 1000 groups of durations to get the distribution of completion time of shaft alignment. The results of the simulation are shown on table 5-25 and figure 5-21.

Table 5-25 Simulation Results of New Combat System Integration Process

Group	Range		Frequency	Probability	Cumulative Probability
1	116	117	1	0.001	0.001
2	117	118	11	0.011	0.012
3	118	119	23	0.023	0.035
4	119	120	74	0.074	0.109
5	120	121	127	0.127	0.236
6	121	122	220	0.22	0.456
7	122	123	216	0.216	0.672
8	123	124	155	0.155	0.827
9	124	125	104	0.104	0.931
10	125	126	43	0.043	0.974
11	126	127	23	0.023	0.997
12	127	128	3	0.003	1

Source: compiled by author

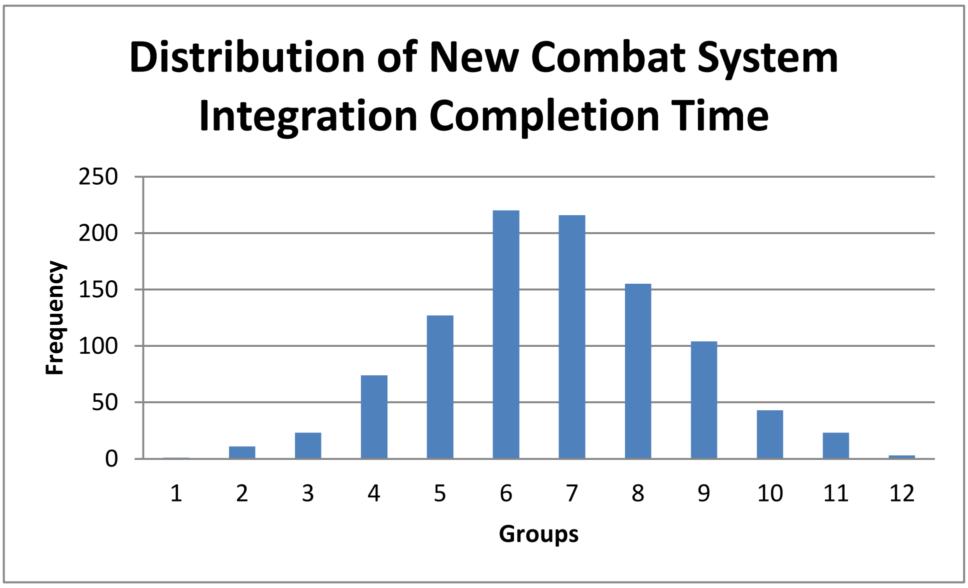


Figure 5-21 Simulation Results of New Combat System Integration Process
Source: compiled by author

Similarly, the next step is to check if the estimates are reliable. The calculation results are listed in the table 5-26.

Table 5-26 Calculation Results of the Confidence Interval – Combat System Integration

mean	standard deviation	95% confidence interval	
		lower	upper
122.2345	0.273326	122.0559	122.4131

Source: compiled by author

And the mean value of the 1000 times' simulation is 122.2381 weeks, which is located within the 95% confidence interval. Therefore, the estimations of the project completion time are reliable.

In the next step, we use the following formulas to calculate the cumulative probability of new combat system integration completion time.

$$Z = \frac{X - \mu}{\sigma}$$

$$\mathbf{P(X \leq T) = P(Z \leq \frac{X - \mu}{\sigma})}$$

In the equations above, Z follows standard normal distribution, so the probability that $Z \leq \frac{X-\mu}{\sigma}$ can be figured out by referring to the standard normal distribution table. The specific results are illustrated by table 5-27 and figure 5-22.

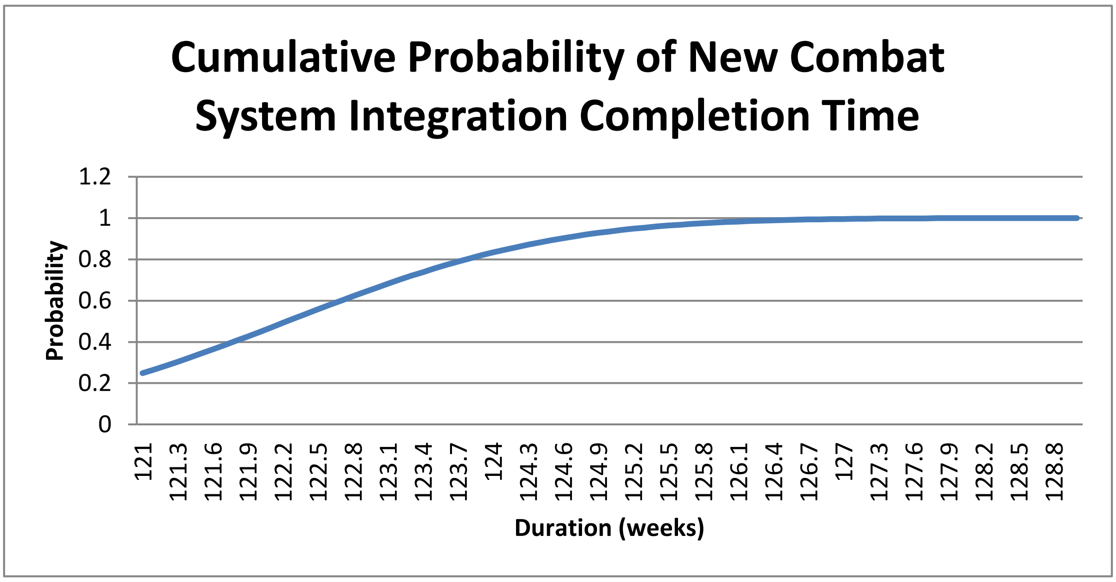


Figure 5-22 Cumulative Probability of New Combat System Integration Completion Time
Source: compiled by author

Table 5-27 Cumulative Probability of the New Combat System Integration Completion Time

Duration (weeks)	122	123	124	125	126	127
Confidence level	44.80%	66.20%	83.31%	93.52%	98.05%	99.55%

Source: compiled by author

As is indicated in table 5-27, with the application of split and advance strategy in the third critical path, the new combat system integration process would take 126 weeks with 98% confidence level. In the original master planning, the total duration of the project is 138 weeks, and the corresponding acceptance range of delays is 7 weeks. After the application of the strategy, the combat system integration process is shortened to 126 weeks. So the new acceptance range of delays would be 7 weeks plus the difference between the original project duration and the new combat system integration completion time. In this case, a delay of 19 weeks is acceptable. So after the application of split and advance strategy, the acceptable delay in the critical path of combat system integration is extended by 12 weeks.

5.5 Conclusion

After the simulation of the original project, we came to a conclusion that it is expected with 98% confidence level to finish the project in 138 weeks. Next, we provide a methodology to manage the delays occurring in three cuticle paths separately. If the delay is less than or equal to 7 weeks, we would just accept it. Otherwise, a special management strategy called split and advance would be applied to the certain critical path to help manage the delays. The outcomes of the strategy are examined by the modeling and simulation technique. It is proven that the split and advance strategy is effective because it helps to extend the acceptance range of delays by 25 weeks, 25 weeks and 12 weeks in the three critical paths separately. In addition, the different increases in the acceptance range of delays indicate that the third critical path, which is the combat system integration, is more critical in the three critical paths after the application of split and advance strategy. Because the total duration of the combat system integration process is decreased by only 12 weeks, much more smaller than that of the cable pulling and shaft alignment processes, which equals 25 weeks.

To answer the main research question for this chapter, which is how to manage the risks in a construction plan, the author develops the article with the discussion about four sub-topics. This chapter starts with the description of DSNS. After that, the so called PKR 1 project, especially the planning work of the project is discussed in detail. In the third place, delay analysis is conducted to find out the general reasons at each stage of shipbuilding. The main focus of chapter 5 is on the last part, the topic of which is “manage”. The duration of each procedure is examined in detail to conduct a better modeling and simulating of the whole project. We came to a conclusion that the expected duration of the project is 138 weeks. After that, the split and advance strategy is applied to the three critical paths separately. The outcomes are examined by similar modeling and simulation. It is proven that the management strategy of split and advance is effective because it helps to extend the acceptance range of delays by 25 weeks, 25 weeks and 12 weeks separately in the three critical paths.

In general, the special split and advance strategy in this research is applicable to only specific situations. Firstly, it is possible to split and advance procedures in a certain network. In addition, the split and advance would definitely increase costs of the whole project, but the strategy developed in this research neglect the cost part. So the methodology is more suitable for cases when the requirement of project completion time overvalues the costs perspective.

Chapter 6 Conclusions and Recommendations

6.1 Conclusions

This research focuses on the management strategy of delays in certain construction plans. In the practice of real industries, delays are regarded as one of the major concerns in planning a construction project. When referring to a complete construction plan, it is usually too complicated to be described in detail. But with the introduction of the PERT network and critical path concept, the problem is simplified. Critical path is critical because it is the longest path within a project, and it determines duration of the whole project. Identifying the critical path from a construction plan changes the focus of a research from the whole complex plan to a single path. It helps to reduce the workload of a planner. Furthermore, to estimate the delays before the start of a project is risky because of the uncertainty during the processing of the project. Besides this, to evaluate the performances of different strategies in managing the possible delays is another issue to be considered carefully.

Based on the above concerns, the strategy developed in this research consists of three steps: critical path identification, completion time estimation and delay management. In order to explain the strategy better, two cases abstracted from real construction plan are studied.

In the first case study of the Western-Hill Shopping Center Project, critical path is identified with definite activity time. In addition, it is assumed that the critical path will not change as with the change in activity time. The purpose of this study is to find the distribution pattern which is more suitable for estimating the activity time. The conclusion of this case study is that to assume that activity time follows normal distribution reduces the risk of overvaluing the probability of the project completion time.

In chapter 5, a real case abstracted from a shipbuilding project in DSNS is introduced at first. After that, the reasons and corresponding consequences of the delays are analyzed in detail. With regard to the conclusions from previous case study, it is assumed that the activity time in the project follows normal distribution. With the estimates of the activity time in the project, the author tries to apply the so-called split and advance strategy to reduce the duration of the whole project. The results of the application are explained by the comparison between the expected duration of the project with certain confidence level before application and after application.

The main conclusions from chapter 1 to chapter 5 are as below.

1) Different from common manufacturing industries, shipbuilding companies care more about finishing the project on time.

2) Managing tools for analyzing delays and scheduling projects developed a lot during the last 60 years. Different approaches rooted from classical methods such as PERT network and CPM provided abundant solutions towards different kinds of scheduling problems.

3) Classical PERT network is no longer suitable for scheduling projects in real industry because the problems under the certain assumptions oversimplified.

4) To assume that activity time follows normal distribution is better for evaluating the duration of certain construction plan.

5) The application of split and advance strategy increases the acceptable delays to a large extent. To be more specific, the acceptable ranges of delays in three critical paths are increased by 25 weeks, 25 weeks, and 12 weeks separately. It is proven that the split and advance strategy is effective in managing the delays in the specific PKR 1 project. But the methodology is more suitable for cases when the requirement of project completion time overvalues the costs perspective.

6.2 Recommendations for Further Research

In this research, the assumptions of the activity time include normal distribution and triangular distribution, because they are common and easy to conduct. In further research, more different assumptions such as gamma distribution need to be checked for the possibility to use them.

In addition, the model for DSNS is a simplified one abstracted from master planning. For further research, detailed study into the real production process is more practical to examine the results of the strategy.

Finally, this research only focuses on the time constraints of the project, but does not take costs into consideration. For further research, it is recommended to evaluate the costs in the research of management strategy of delays.

Bibliography

A. KOONCE, D., M. PARKS, C. & KEYS, L. K., 1994. Long duration manufacturing schedule monitoring and control. *computers industrial engineering*, 2, pp. 619-631.

Abbasi, G. Y. & Mukattash, A. M., 2001. Crashing PERT networks using mathematical programming. *International Journal of Project Management*, pp. 181-188.

Aghaie, A. & Mokhtari, H., 2009. Ant colony optimization algorithm for stochastic project crashing problem in PERT networks using MC simulation. *INTERNATIONAL JOURNAL OF ADVANCED MANUFACTURING TECHNOLOGY*, 5 4, p. 1051–1067.

Ahuja, V. & Thiruvengadam, V., 2004. Project scheduling and monitoring: current research status. *Construction Innovation*, 4, pp. 19-31.

Alkass, S., Mazerolle, M. & Harris, F., 1996. Construction delay analysis techniques. *Construction Management and Economics*, 4 1, p. 375± 394.

Anderson, D. R. et al., 2012. *An Introduction to Management Science.* Revised Thirteenth Edition ed. Mason, USA: South-Western, a part of Cengage Learning.

Arditi, D. & Pattanakitchamroon, T., 2006. Selecting a delay analysis method in resolving construction claims. *International Journal of Project Management*, pp. 145-155.

BADIRU, A. B., 1991. STARC 2.0: an improved PERT network simulation tool. *Computers Industrial Engineering*, 2, pp. 389-400.

Baradaran, S., Ghomi, S. F., Ranjbar, M. & Hashemin, S., 2012. Multi-mode renewable resource-constrained allocation in PERT networks. *Applied Soft Computing*, 2 1, pp. 82-90.

Bubshait, A. A. & Cunningham, M. J., 2004. Management of Concurrent Delay in Construction. *Cost Engineering*, 06, pp. 22-28.

Burgher, P. H., 1964. Pert and the Auditor. *The Accounting Review*, 1 1, pp. 103-120.

Castro, J., Go´mez, D. & Tejada, J., 2007. A rule for slack allocation proportional to the duration in a PERT network. *European Journal of Operational Research*, 24 04, pp. 556-570.

D. Roman, D., 1962. The PERT System: An Appraisal of Program Evaluation Review Technique. *The Journal of the Academy of Management*, 1 4, pp. 57-65.

Dobois, D. & Prade, H., 1987. Operations on fuzzy numbers internat. *Jounal of Systems Science*, 9, pp. 613-626.

Dubois, D. & Prade, H., 1979. Fuzzy Real Algebra: some results. *Fuzzy Sets & System*, 2, pp. 327-348.

Elmaghraby, S. E., 1967. On the Expected Duration of PERT Type Network. *Operations Research*, pp. 299-306.

Fatemi, G. & Teimouri, E., 2002. Path critical index and activity critical index in PERT networks. *European Journal of Operational Research*, pp. 147-152.

Fulkerson, D. R., 1962. Expected Critical Path Lengths in PERT Networks. *Operations Research*, 1 12, pp. 808-817.

Gallagher, C., 1987. Reply: A Note on Pert Assumptions. *Management Science*, 10, p. 1360.

Guerriero & Talarico, 2010. A solutionapproachtofindthecriticalpathinatime-constrained activity network. *Computers&OperationsResearch*, 7 3, pp. 1557-1569.

Hamzah, H. et al., 2011. Cause of Construction Delay - Theoretical Framework. *Procedia Engineering*, 11, pp. 490-495.

International Business Machines Corporation, 1961. *PERT/PEP ... a dynamic project control method.* 1st Edition ed. New York: FSD Space Guidance Center.

Kamburowski, J., 1985. Normally Distributed Activity Durations in PERT Networks. *The Journal of the Operational Research Society*, 11, pp. 1051-1057.

Keller, G., 2010. *Managerial Statistics.* 9th Edition ed. New York: South-Western Cengage Learning.

Lau, H.-S. & Somarajan, 1995. A proposal on improved procedures for estimating task-tiime distribution in PERT. *European Journal of Operational Research*, 5 8, pp. 39-52.

Lerda-Olberg, S., 1966. Bibliography on Network-Based Project Planning and Control Techniques: 1962-1965. *Operations Research*, 30 9, pp. 925-931.

Littlefield, T. K. & Randolph, P. H., 1987. Reply: An Answer to Sasieii's Question on PERT Times. *Management Science*, 10, pp. 1357-1359.

Loucks, J., 2000. *Project Scheduling,* Boston, United States: South-Western College Publishing.

Malcolm, D. G., Roseboom, J. H., Clark, C. E. & Fazar, W., 1959. Application of a Technique for Research and Development Program Evaluation. *Operations Research*, Sep-Oct, pp. 646-669.

Mouhoub, N. E., Benhocine, A. & Belouadah, H., 2011. A new method for constructing a minimal PERT network. *Applied Mathematical Modelling*, 15 3, pp. 4575-4588.

Robillard, P. & Trahan, M., 1976. Expected Completion Time of Pert Network. *Operations Research*, 31 1, pp. 177-182.

Santiago, J. & Magallon, D., 2009. *CRITICAL PATH METHOD.* [Online]
Available at: http://www.stanford.edu/class/cee320/CEE320B/CPM.pdf
[Accessed 27 07 2013].

Soroush, H., 1993. Risk taking in stochastic PERT networks. *European Journal of Operational Research*, 7 6, pp. 221-241.

SoroushSource, H. M., 1994. The Most Critical Path in a PERT Network. *The Journal of the Operational Research Society*, 1 3, pp. 287-300.

van Slyke, R. M., 1963. Monte Carlo Methods and the PERT Problem. *Operations Research*, 9, pp. 839-860.

Weiss, G., 1986. Stochastic Bounds on Distributions of Optimal Value Functions with Application to PERT Network Flows and Reliability. *Operaions Research*, 4, pp. 59-78.

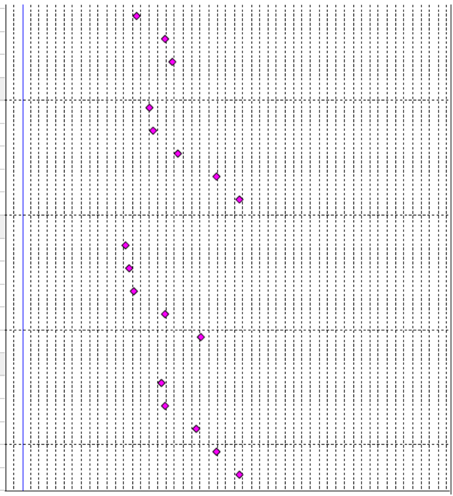
Wikipedia, 2013. *Monte Carlo method.* [Online]
Available at: http://en.wikipedia.org/wiki/Monte_Carlo_method
[Accessed 18 8 2013].

Yang, J.-B. & Kao, C.-K., 2012. Critical path effect based delay analysis method for construction projects. *International Journal of Project Management*, pp. 385-397.

Appendix 1: Operational Plan of PKR 1

Activity Name	SSWBS	STAGE GATE	Primary Constraint Date
00414 - ENGINEERING PKR SIGMA 10514			
PAYMENT TERMS			
GENERAL			
EDC			27-Dec-12
MAIN SHIPS CONSTRUCTION PLAN REVIEW			30-May-13
START CUTTING			30-Dec-13
KEELLAYING			13-Mar-14
SHIPMENT OF MODULE III TO LOCAL SHIPYARD			10-Feb-15
LAUNCHING / FLOATING			10-Dec-15
COMPLETION OF HAT			20-Sep-16
FINAL ACCEPTANCE			24-Jan-17
MAIN MILESTONES			
GENERAL			
GACAR READY			27-Dec-12
DETAILED BUILDING STRATEGY READY			01-Feb-13
SET PROJECT STANDARDS			01-Feb-13
PMP-ENG READY / BE TEAM ORGANIZED / ENG & PURCH DETAIL PLANNING READY			01-Feb-13
ORDER PLACED E/PMS INSTALLATION (READ: BASIC ENGINEERING E STARTS)			01-Feb-13
ORDER PLACED HVAC INSTALLATION (READ: BASIC ENGINEERING HVAC STARTS)			01-Feb-13
ORDERS PLACED OTHER LONG LEAD ITEMS			01-Feb-13
ORDER PLACED PROPULSION SYSTEM			27-Feb-13
CONSTRUCTION PLANS READY FOR CLASS APPROVAL			27-Mar-13
MAIN TECHNICAL SPECIFICATIONS READY (PHASED DELIVERY)			27-Mar-13
SKIDS DETERMINED / IDENTIFIED			26-Apr-13
START MODELLING 3D COMPONENT MODELS			26-Apr-13
MAIN SHIPS PLANS (ALL DISCIPLINES) READY FOR CLASS APPROVAL			26-Apr-13
MAIN ROUTING CABLING/HVAC/PIPING (PHASE 0 CADMATIC) DEFINED			30-May-13
MAIN SYSTEM DIAGRAMS (P&ID'S) READY FOR CLASS APPROVAL			30-May-13
ORDERS PLACED MAIN COMPONENTS (PHASED DELIVERY)			30-May-13
NUPAS PHASE 1 FINALIZED			27-Jun-13
ALL ENGINEERING VENDOR DATA MAIN COMPONENTS AVAILABLE & FINAL (PHASED DELIVERY)			27-Jun-13
START DETAIL ENGINEERING			26-Jul-13
PRODUCTION CONSTRUCTION DETAIL PLANNING READY			26-Jul-13
MAIN CABLE BLOCK DIAGRAMS READY			27-Aug-13
DEFINITION CONTENTS PRODUCTION INFORMATION READY			27-Aug-13
CRITICAL DESIGN REVIEW PMS (I/O LIST FROZEN, OTHER RATES FOR VARIATION WORK APPLY)			27-Nov-13
PRODUCTION OUTFITTING DETAIL PLANNING READY			27-Nov-13
START CUTTING			30-Dec-13
START CONSTRUCTION OF SECTIONS			29-Jan-14
START CABLE PULLING			01-Oct-14
COMMISSIONING /HAT/SAT DETAIL PLANNING READY			24-Dec-14
START JOINING HULL (MODULE I,II,III)			08-Apr-15
START JOINING SUPERSTRUCTURE (MODULE IV,V,VI)			08-Jun-15
START ALIGNMENT PROCEDURE SHAFTLINE			23-Jul-15
HULL COMPLETE (ALL CASCO ACTIVITIES READY)			27-Oct-15
READY FOR LAUNCHING VESSEL			10-Dec-15
START COMMISSIONING PLATFORM			11-Dec-15
START COMMISSIONING SEWACO			21-Jan-16
START HAT			24-Feb-16
START SAT			21-Sep-16
DELIVERY OF VESSEL			24-Jan-17
MODULE I (Aftship)			
DELIVERY 1ST PRODUCTION SECTION DRAWINGS MODULE I			13-Dec-13
DELIVERY 1ST PRODUCTION OUTFITTING DRAWINGS MODULE I			13-Jan-14
START CONSTRUCTION OF MODULE I			07-Apr-14
LONG LEAD ITEMS MODULE I AVAILABLE AT PRODUCTION FACILITY			25-Jul-14
START OUTFITTING MODULE I			19-Nov-14
MODULE II (Foreship)			
DELIVERY 1ST PRODUCTION SECTION DRAWINGS MODULE II			11-Dec-13
DELIVERY 1ST PRODUCTION OUTFITTING DRAWINGS MODULE II			08-Jan-14
START CONSTRUCTION OF MODULE II			03-Apr-14
LONG LEAD ITEMS MODULE II AVAILABLE AT PRODUCTION FACILITY			25-Jul-14

START CONSTRUCTION OF MODULE III			14-Feb-14
LONG LEAD ITEMS MODULE IIIAVAILABLE AT PRODUCTION FACILITY			27-May-14
START OUTFITTING MODULE III			24-Jun-14
MODULE IV (Superstr. Aft)			
DELIVERY 1ST PRODUCTION SECTION DRAWINGS MODULE IV			02-Apr-14
DELIVERY 1ST PRODUCTION OUTFITTING DRAWINGS MODULE IV			16-Apr-14
START CONSTRUCTION OF MODULE IV			14-Jul-14
LONG LEAD ITEMS MODULE IV AVAILABLE AT PRODUCTION FACILITY			27-Nov-14
START OUTFITTING MODULE IV			20-Feb-15
MODULE V (Superstr. Fwd)			
DELIVERY 1ST PRODUCTION SECTION DRAWINGS MODULE V			06-Jan-14
DELIVERY 1ST PRODUCTION OUTFITTING DRAWINGS MODULE V			20-Jan-14
START CONSTRUCTION OF MODULE V			04-Feb-14
LONG LEAD ITEMS MODULE V AVAILABLE AT PRODUCTION FACILITY			27-May-14
START OUTFITTING MODULE V			02-Oct-14
MODULE VI (Superstr. Mid)			
DELIVERY 1ST PRODUCTION SECTION DRAWINGS MODULE VI			14-May-14
DELIVERY 1ST PRODUCTION OUTFITTING DRAWINGS MODULE VI			28-May-14
START CONSTRUCTION OF MODULE VI			17-Sep-14
LONG LEAD ITEMS MODULE VI AVAILABLE AT PRODUCTION FACILITY			27-Nov-14
START OUTFITTING MODULE VI			20-Feb-15



Source: DSNS