Applying the TOC Project Management to Operation and Maintenance Scheduling of a Research Vessel*

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Marine research vessels and their systems are major assets in the marine resources development. Since the running costs for the ship are very high, it is necessary to reduce the total cost by an efficient scheduling for operation and maintenance. To reduce project period and make it efficient, we applied TOC project management method that is a project management approach developed by Dr. Eli Goldratt. It challenges traditional approaches to project management. It will become the most important improvement in the project management since the development of PERT and critical path methodologies. As a case study, we presented the marine geology research project for the purpose of operations in addition to repair on the repairing dock projects for maintenance of vessels.

Key Words: Project Scheduling, TOC Project Management, Activity Duration, Marine Research Vessel

1. Introduction

Indonesia is the largest archipelago in the world. Indonesia's sea area is approximately four times greater than its land which is about 1.9 million sq. km. The sea area is about 7.9 million sq. km (including an exclusive economic zone) and consists of about 81% of the total area of the country. With that wide area of the sea, it is presumed that there are many offshore resources embedded at the bottom of the sea, which have not been explored and exposed yet. To investigate, explore and develop these resources, one of the necessary facilities is a marine research vessel. Thus, the marine research vessels and their systems are major assets in the marine/offshore resource investigations and developments. Because of the running costs for the vessel are very high, it is necessary to reduce the total cost by efficient schedules for opera-

tional and maintenance activities^{(3),(4)}.

The vessel operations are all about marine research activities, including navigation and replenishment activities. Although the marine research work is under the principle of safety rules, which is mostly performed on the sea, it has high degrees of risk. Yet, it is hard to forecast the completion time of most activities due to many outdoor and sea activities. In addition, there are a lot of variations, such as the weather, wave condition and seasickness. In order to reduce the running costs, it is preferable to reduce the operational periods as long as they do not influence the marine research activities.

When it comes to the maintenance, the maintenance load consists of two categories: scheduled and unscheduled maintenance. The first category consists routine and preventive maintenance; it is determined and can be planned. The second category is emergency or breakdown maintenance. The repair on the repairing dock is one of the largest preventive maintenance for a vessel, in addition to their main system such as the propulsion, power, electricity, air condition and so on.

The operational and maintenance vessel activities are closely connected; they would influence other

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activities if either were delayed. Therefore, it is necessary for each vessel activity to be finished on time or before the schedule. In this study, to improve the performance of the operational and maintenance activities of the vessel as well as to reduce the total period, we try to apply TOC project management method and find out the contributions as for its effectiveness.

2. TOC Project Management

Dr. Goldratt applied his theory of constraints (TOC)^{(2),(11)} to PERT techniques for project scheduling to develop methods for reducing project periods. He identified several behaviors based on why projects have been late. He also noted that most of the times estimated for project activities were inflated.

Dr. Goldratt suggested that project periods could be reduced by using expected activity times (rather than inflated times), then adding a project buffer to account for errors in estimating activity task times. TOC uses the global safety time to schedule the project, and stresses that a system must have a constraint. TOC principle identified the critical path as constraints and focuses on the constraint that block the achievement of goal of the project^{(2),(5),(6)}.

Safety time

Projects have variations which are either uncertainty or statistical fluctuations in the performance time of activities. Although the time to perform individual project activities may be independent, project activity networks define activity dependencies. The project logic also demands that succeeding activities cannot start until the preceding activities are completed. Projects eventually have statistical fluctuations and dependent events^{(2),(7)}.

Most people in charge of activities attempt to account for individual activity variations by adding contingency time into each estimate. People estimating activity times for a project usually believe that the project managers want low-risk activity times, perhaps, a probability of 80% to 95% completion on or less than the estimated activity duration^{(2),(6),(7),(10)}. In most project environments, people feel good if they complete an activity within the due date. On the other hand, people feel bad if they overrun the due dates. Figure 1 illustrates a typical project activity performance time distribution⁽⁷⁾.

With the safety time added to the time required by activities, the project is definitely completed on time based on the schedule. In reality, however, the project is still behind the schedule. Student syndrome, delayed accumulations and multitasking are defined as factors of the wasted safety times.

The student syndrome is the behavior in which

Fig. 1 Project activity performance time probability distribution

people do not start a task until it gets really urgent. People do less than a third of work on an activity during the first two-thirds of the activity duration. Then, they do two-thirds of the work during the last one third of the activity duration.

Even if an activity is finished earlier, it is unlikely that the next step will start immediately. It will be probably started as it is originally scheduled. Delays, however, are usually passed on to next activities, causing late starts, disrupting schedules and eventually create resource availability conflicts.

Multitasking is also responsible for the safety consumption. By definitions, multitasking is a practice of giving people more than one task to do at the same time, without having a clear and consistent priority numbers among those tasks. Tasks that are multitasked take longer to be completed.

The combination of the effect of the "student syndrome", delayed accumulations, multi-tasking environment, and the need to cover uncertainty lead to "realistic" project task estimates that contain considerable "safety" above and beyond the actual work time required for a task^{(2),(5),(7),(10)}.

Therefore, to prevent the activity duration containing considerable safety time, TOC recommends reducing the activity duration, instead of the recommended use of the global safety. However, the explanation of how to reduce or cut the activity duration has not been clear. TOC recommends to use 50% probable estimate, which is 50% cut to the activity duration^{(2),(7),(10)}. In reality, the risk or duration of all activities is not the same with each other. By using 50% probable estimate to all activity durations possibly make some activity durations become unfeasible. As an example, for cleaning up or reconditioning, the fuel tank requires four days. By applying 50% cut to the recondition period can deteriorate the quality of the tank, or make the recondition become impracticable. Therefore, it is necessary to think an idea how to reduce activity duration, besides to how to cover

the risk of each activity.

3. Application of the TOC Project Management

The TOC method recommends to reduce the activity duration, as in this study, we used activity duration cut ratio (DCR)⁽¹²⁾. DCR is a ratio between the project duration with and without considering the resource constraint. When resource contention occurs, the project duration can be calculated using heuristic rule. The heuristics used to determine the priorities using rules such as the activity with the longest duration first (LAF), the activity with the shortest duration first (SJF), the activity with the lowest activity number first (FCFS), the activity with the earliest late finish time first (LFT), the activity with the earliest early finish time (EFT), the activity with earliest early finish time first (MEF), the activity with least slack time (MINSLK), the activity with the greatest slack time first (MAXSLK), activity with the maximum ACTIM value first (ACTIM), the activity with the maximum ACTRES value first, etc.^{(1),(8),(12)}.

Therewith, we proposed to use the risk buffer in order to cover the risk of each activity. This buffer will be added up including in the global safety time at the end of the project. The risk and implementation procedures^{(7),(12)} will be described later.

Implementation procedures

For a single project

- Step 1. Determine the critical path as well as the project duration (T_{P1}) without considering the resource constraint. The project duration can be obtained using both forward and backward computations of PERT/CPM method.
- Step 2. Calculate the critical chain as well as the project duration (T_{P2}) by considering the resource constraint, when the resources are limited^{(2),(7),(10)}. The project duration as well as resource contention can be resolved using the heuristic rules.
- Step 3. Compute the duration cut ratio ($DCR = T_{P1}/T_{P2}$), where $T_{P1}/T_{P2} < 1$. The DCR is a ratio between the project duration with and without considering the resource constraint.
- Step 4. Modify all of activity duration estimates using DCR , and calculate the project duration T_{P3} . After revising activities duration using DCR , determine the project duration considering the resource constraint.
- Step 5. Compute the aggregate sum of the difference between the original and modified estimated time of non-critical chain activities, and treat it as feeding buffers. The constraint for a project is a critical chain. Feeding buffers are placed wherever a non-critical chain task

joins the critical chain. It is done so in order to protect the critical chain from disruptions on the task feeding it and to allow critical chain tasks to start early, in case things go well. However to protect the overall project delivery time from variations in activity times, the project buffer is placed at the end of critical chain.

For multi-project

The following procedures are used for exploiting the contention resource between projects in the multi-project environment⁽⁷⁾.

- Step 6. Identify the projects constraint resource. The constraint resource should be the resource that determines the greatest amount of critical chain duration on projects.
- Step 7. Prepare the critical chain schedule for each project independently (single project, step 1-5).
- Step 8. Determine the project priority to access the constraint resource. To setting the project priority, it should be considered as the company goal. For example, it may be advantageous to give higher priority to the company's best customers, considering the company's need to make money in the future.
- Step 9. Create the constraint resource multi-project schedule. Collect the constraint demands for each project and resolve contentions among the projects to maximize project throughput.
- Step 10. Schedule each project to start based on the constraint resource schedule. Create the individual project schedules by aligning the start of the project to match up the constraint resource schedule-using activity. In another word, we work backward from the constraint resource-using activity to schedule the start of the project.

In this study, to adjust the load of resources, we used MINSLK rule^{(1),(8)}. MINSLK is gives the priority in resolving resource conflicts to the activity with minimum slack, which is computed as the differences between the critical path analysis-determined Late Start Time (LST) and Early Start Time (EST). The activity on the critical path has no slack time; thus, activity on critical path has the highest priority to use the resource.

Risk buffer

Besides using the duration cut ratio to reduce its activity duration, it is necessary to consider the risk of it. The risk could be added including in the global safety time or project buffer at the end of the project.

Here, we used the probability impact matrix as shown in the Table 1 to find the risk score (RS) of

Table 1 Probability impact matrix

Probability (P)	Impact on an Objective (I)				
	0.1	0.3	0.5	0.7	0.9
0.9	0.09	0.27	0.45	0.63	0.81
0.7	0.07	0.21	0.35	0.49	0.63
0.5	0.05	0.15	0.25	0.35	0.45
0.3	0.03	0.09	0.15	0.21	0.27
0.1	0.01	0.03	0.05	0.07	0.09

0.00 - 0.10	Low-risk
0.11 - 0.30	Medium-risk
0.31 - 1.00	High-risk

$$Risk\ Score = P \times I$$

activities⁽⁹⁾. It illustrates the simple multiplication of probability of an activity being delayed and how far that delay gives impacts for the entire project period. It also determines whether a risk is considered low, moderate, or high. We decided the activity whose risk score was 0.00-0.10 as a low-risk, 0.11-0.30 as a moderate risk and 0.31-1.00 as a high risk.

Afterwards, these risk scores were used to calculate the risk buffer. However, we didn't take into account activities with low or moderate risk, instead, only activities with a high-risk score are considered for the risk buffer.

The calculation of risk buffer could be shown as the following expression.

$$Risk\ buffer\ (RB) = \sum_{i \in hr} \sum_{i=1}^n RS(t_{i\ org} - t_{i\ mdf.})$$

where,

RS : Risk score

hr : High risk

$t_{i\ org}$: Original duration estimates of activity i ,
 $i=1, 2, \dots, n$

$t_{i\ mdf.}$: Modification duration estimates of activity i

Meanwhile, the calculation of the project buffer could be shown as the following expression.

$$PB = \sum_{i \in cc} \sqrt{\sum_{i=1}^n ((t_{i\ orig.} - t_{i\ mdf.}) + RB)^2}$$

where, PB : Project buffer,

RS : Risk score

CC : Critical Chain

As we mentioned earlier, the objective of this study is to implement and see the effectiveness of TOC project management method as well as to improve performance of project schedules for the operational and maintenance activities of the vessel. In applying TOC method, we considered the activity duration cut ratio as well as the risk buffer. As a case study, we presented the marine geology research project for the purpose of operations in addition to repair on the repairing dock project for the maintenance of vessels, and compared the results using TOC and conventional method such as PERT/CPM

method.

4. Case Study

4.1 Marine geology research project

The marine research vessel operations can be composed as one cycle by navigation, marine research and replenishment activities and it is considered as one single project. However, it is necessary to make a call at nearest ports for replenishments of fuel and perishable food every two weeks. The reason is that the storage places for the fuel and perishable food in the vessel are limited.

The captain and crew usually do not participate in the research activities, but they have responsibilities to navigate a vessel safely according to research plans. The captain and chief scientist should have good communications together along with research periods in order to make the projects successful.

4.1.1 Project constraint conditions

1. The marine geology research project had 5 (five) main research activities, which consist of 30 sub-activities.
2. Due to restricted accommodation, the numbers of researchers were limited to 1 (one) Chief scientist, 6 (six) scientists, 4 (four) engineers and 6 (six) technicians.
3. Due to most activities that were performed on the sea, it was impossible to add or change the amount of resources in the ongoing project.
4. The working time was planned for seven days in a week, with 24-hour of 3 (three) shift operations.

4.1.2 Result It was determined that the project duration (T_{P1}) without considering resource constraint was 60 days. However, it was 68.93 days by considering resource constraint using MINSLK rule (T_{P2}). The calculation of duration cut ratios is $T_{P1}/T_{P2}=86\%$. Here, for easy calculation we used 85% of duration cut ratio to revise activity duration, and the total project (T_{P3}) could be 50.22 days.

From the calculation of both risks and project buffer, 4.053 days of project buffer should be placed at the end of project period. However, we added 2 days to cover the delay if the vessel could not come to port to have replenishment in the right time (after office hours), other 5 days for replenishment duration itself, and it should be added to the project buffer. Thus we had 11.053 days to be secured in the project buffer, including one replenishment period. Eventually, the total project period becomes 61.27 days.

From these results, the total period of marine geology research schedule was reduced about 7.66 days compared with the conventional PERTmethod. Otherwise, the number of leg/sections was reduced

Fig. 2 The result of marine geology research project

from 4 legs to 3 legs. The replenishment frequency itself could be reduced to two times (Fig. 2). The reduction of replenishment frequency had great contributions to reduce the whole period. The reason is because it takes about 5 (five) days to have one replenishment, including the navigation time.

According to TOC project management, the multi-tasking is not allowed. However, in the environment that resources are strictly limited, it is impossible to add the amount of resources in the ongoing project. Also, for some big scale of research work, as loading or unloading the equipment to the surface or bottom of the sea, the shift operation is not automatically effective; almost all of the members work together. From the reason above, it is difficult to manage the resource to work without multi-tasking. In reality multi-tasking environment often occurs.

Thus, if the resource contention occurs, the Chief scientist as the survey project leader can resolve the contention which may allow the lower task's resources support the higher priority tasks. Alternatively, in case of emergency, Chief scientist can communicate with the captain to find out additional resources, especially for ordinary tasks in addition to get permissions for the crew to support research activities that are needed.

4.2 Repair on the repairing dock project

The purpose of the vessel maintenance is to improve efficiency of the operations while maintaining the performance and strength of vessels. Thus, it is important to maintain the vessel conditions that can be used anytime.

The periodical inspection is taken every two years and the vessel has been obligated to enter the repairing dock. After maintaining the performance of main and auxiliary engines or repairing recovery of damage of hull because the shipwreck is completely enforced, the vessel can be engaged in long-term navigation at ease. In this study, to repair on the repairing dock (dock project) was chosen as a case study. Because, it is one of the most important and big-scaled scheduled (preventive) maintenance of the

vessel and usually scheduled for every vessel.

In general, the dock project will start from the ship entering the dock and finish after Sea Acceptance Test (SAT) has been done. Then it is considered as one single project. In the dock project, the work can be divided into two categories:

1. Work that is only possible to perform on repairing dock.
2. Work that can be performed either on the repairing dock or on the sea.

Because of an expensive daytime rent of repairing dock, it is necessary to reduce the repairing periods on repairing dock. However, for reducing these periods the priority for working on the repairing dock should be given first.

For the dock project, we presented two cases of study:

1. Single (project A)
2. Multiple projects (project A and project B).

The purpose of these two cases of study is to see the effectiveness of the constraint resource schedule. Multiple projects were assumed that there would be another project (project B) with similar activities and using similar workers. We prioritized project A as well as both dock periods in order to minimize the total cost.

Here, three options were given as assumptions:

1. Both projects started at the same time,
2. The project B started based on constraint resource schedule.
3. Numbers of workers were limited to technicians only.

4.2.1 Project constraint conditions

1. Repairing on the repairing dock project had 7 (seven) main activities such as: dock facilities, ships building, propulsion systems, electricity system, sea and fresh water systems, deck facilities and accommodations, safety systems, and final test. Besides, it consists of 75 sub-activities.
2. The numbers of workers were limited to one dock master, ten dock assistants, 15 mechanics, 15 electricians and 40 technicians.
3. The working time was planned for six working days with ten hours per day.

4.2.2 Result For a single dock project, the total period with and without considering resource constraint is 29.50 and 38.50 days respectively. For revised activities duration, 75% of duration cut ratio was used. As a result, the dock and total period included 7.73 days of project buffer becomes 14.94 and 35.80 days respectively. In other words, the dock and total period could be reduced to about 2.7 and 0.5 days respectively compared to the conventional method.

However, in order to reduce the total cost the work schedule must be prioritized to the dock period. Thus, the dock period could be reduced to 11.34 days. Consequently, other tasks would be postponed, which eventually would delay the entire project period about one day (Fig. 3).

For the projects that the dock period was given as a priority, there were two options: to increase the number of workers or to give a high priority to the dock tasks with few workers. In this case, it is necessary to think about the trade-off for adding personnel expenses by increasing number of workers or increasing the cost due to the delay of working periods. The management should pay attention to the delay of maintenance periods, because it may influence the operational activity.

For the second case, after scheduling each project independently, we determined the "technician" as a constraint resource. Due to the project priority given to project A and based on the constraint resource schedule, starting time of project B would be delayed. Though, project B should still be minimized.

Figure 4 shows the total period of project B based on the project starting time. We can see the total period of project B depends on when the project starts. However, if the project B starts later, total project period will be less. But, the long delay of project starting time will influence the efficiency of vessel operations. Because, the period for vessel making

Fig. 3 The first case result of repairing on dock project

voyages in a fiscal year would definitely decrease. Here, we set the starting time of project B to be 16 days delayed.

Figure 5 shows the results from three options given. The dock and total periods of project A included 7.73 days project buffer for the first two options could be maintained to 11.34 and 36.91 days, meanwhile, the third option 11.34 and 35.34 days respectively. However, the dock and the total periods of project B were delayed 14.2 and 26.32 days for the first option, 0.7 and 13.32 days for the second option. While for the third option, if the numbers of workers were limited to technicians only, the delay could be minimized to 1.27 and 4.34 days.

From these results, if both projects started at the same time, the total and dock periods of project B would have long delayed. If project B started several days after project A, the delay could be minimized. However, the third option has the shortest schedule for implementing the dock project. Therefore, we must add the number of mechanics and electricians in order to implement this plan.

5. Conclusion

In this study, we made an attempt the implementation of TOC project management for scheduling operational and maintenance activities of the research vessel. We proposed to use the risk buffer to cover its

Fig. 5 The second case result of repairing on the repairing dock project (option 1, 2 and 3)

Fig. 4 Total period of project B based on the starting time

risk of activities, besides activity duration cut ratio (*DCR*) for cutting safety times. Those cutting safety time can be treated as buffers. By applying the TOC project management method, performance of the project's schedules could be improved as well as to reduce the project period. As a result, it could reduce the running and maintenance cost of the vessel.

For operational activities of the vessel, due to strictly limited resources, we cannot eliminate the multi-tasking environment. However, by taking into account of resources the priority of tasks could be focused. Thus, even the resources working under multi-task environment they know what should they do.

By using constraint resource multi-project schedule, resource contentions among the projects could be resolved, in addition to reduce the delay period of maintenance activities due to resource contentions. By applying TOC method, we hope that the workers' behaviors and performance of the operational and maintenance schedules could be improved more efficiently. Besides, human psychology factors, which affect the worker performances may be reduced. Consequently, management must thoughtfully give rewards to the workers who have given great contributions to the success of projects.

TOC project management method can possibly be applied in Indonesia because of the low cost labor. There have been indications that workers do not have efforts to finish their jobs as soon as they can. Instead, they make efforts to get overtime for increasing their income.

The difficult part to implement the TOC method is how to educate or well-inform about TOC and its sufficient process to workers, so that they can fully understand and put their best efforts to apply this method.

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