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Ship Repair and Maintenance Management: Application of PERT Analysis on a Tanker Vessel

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The costs in shipbuilding and ship repair and maintenance activities are massive and need several materials in the same production phase. Construction without planning is not rational, and any mistake in the planning phase will cause major loss of time, quality, and financial resources. Planning in ship repair and maintenance yards is more complicated than new building shipyards because the duration time is limited. In this study, 200-m-long tanker's repair and maintenance period has been planned by program evaluation and review technique analysis in light of the data acquired from X shipyard in Turkey to reflect critical activities that affect the total duration time.

Keywords: shipyard; repair; maintenance; planning; PERT

1. Introduction

Projects are influenced by a multitude of factors which can be external or internal to the organization responsible for its management and execution. The important thing for the project manager is to recognize what these factors are and how they impact the project during the various phases from inception to final handover, or even disposal. These external or internal influences are known as the project context or project environment. The external factors making up this environment are the client or customer, various external consultants, contractors, suppliers, competitors, politicians, national and local government agencies, public utilities, pressure groups, the end users, and even the general public. Internal influences include the organization's management, the project team, internal departments (technical and financial), and possibly the shareholders. Some of these influences are political, economic, social, technical, legal, and environmental influences (Lester 2017).

Ship production is a project type of production, and shipyards need production planning more than previous years because the projects are more technological and complicated. Before starting the shipbuilding process, it has to be planned what, when, where, and how to do the process because of the internal structure of shipyards and external sources. In the modern shipbuilding process, prefabricated sections are mainly used, and hull, superstructure, and deck segments are built in the workshops of the shipyards and afterwards transported to the dock or slipway. This process is named as block construction. Installation of engines, equipment, and pipes, and outfitting are carried out during the slipway/dock stage before launching. This construction type is also adopted in the Turkish shipyards.

As of April 2018, there are 78 active shipyards in Turkey, whereas this figure was 37 shipyards in 2002. Shipyards in Turkey are mainly located in Marmara and West Black Sea regions. Turkish shipyards delivered 609 ships of totally 3,887,000 deadweight tonnage (DWT) between 1995 and 2007. After global crisis, shipyards came across with difficulties for new orders and the volume in new building activities has declined sharply. In 2017, our shipyards have delivered 21 ships and a tonnage of 98,940 DWT. While the order books of the Turkish shipyards are analyzed, it is seen that it consists of 43 ships of 147,539 DWT as of April 2017 (Chamber of Shipping 2017). Turkish shipyards have a good reputation in building small and medium tonnage chemical tankers. By April 2018, Turkey was in the sixth place among the countries that take tanker orders.

Having difficulty in receiving new shipbuilding orders, the sector turned its face towards maintenance and repair activities. The maintenance and repair tonnage that was 15,755,206 DWT in 2013 has increased up to approximately 20,000,000 DWT by the end of 2014 and 21,500,000 DWT by the end of 2015. It was also recorded that the ship repair and maintenance sector has reached up to

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21,500,000 DWT at the end of 2017, whereas the capacity was 22,000,000 DWT (Chamber of Shipping 2017). This figure reflects that ship repair business in Turkey has given service nearly with a full capacity. Moreover, the number of floating docks was 11 in 2002, 17 in 2008, and reached 21 in 2012. As of April 2018, 30 floating docks and 10 dry docks were operative in Turkey (Chamber of Shipping 2017).

In addition to maintenance and repair activities, projects about the defense industry have gained a great acceleration within the last few years in Turkey. Turkish shipyards have also started to take orders from abroad for the naval shipbuilding projects in which a high ratio of local industry participation exists. It is known that there are approximately 162 countries that have the naval forces around the world. Turkey is one of the 10 countries that have the ability of designing, building, and maintaining a naval ship, and in this context, today, Turkey's naval needs are provided by the shipyards of their own country (Chamber of Shipping 2017).

Contributing a lot to employment, whereas the number of staff directly employed by our shipyards was 33,480 in 2007, it dropped to 17,000 in 2013 because of the order cancellations due to the economic crisis. It is confirmed that the labor force in the industry was 27,189 workers by 2017 (Chamber of Shipping 2017).

According to valid data, the sector achieved an export of 10.6 million USD at the end of 2008 and reached to 1.16 billion USD in 2013. Ship and yacht export value was 1.28 billion USD, with a slight increase in 2014. By the end of 2015, it is calculated as 1.02 billion USD, and it was 972 million DWT by 2016, and the rate was recorded as 1.33 billion USD, with 37.6% increase in 2017 (Chamber of Shipping 2017).

In recent years, with the increase in production in shipbuilding, planning becomes very important and studies on the planning of shipyard activities are increasing in the literature. Main difficulty is reaching the real data from the industry such as the production period, activity lists, and precedencies because these kinds of data are accepted as private by the shipyards. In this study, real data for 200-m tanker repair works have been received from X shipyard in Turkey.

In the literature, Frankel (1982) mentioned in his study that uncertainties in material and component delivery as well as fabrication, assembly, and erection process times make it difficult to effectively use traditional critical path method (CPM), program evaluation and review technique (PERT), and similar methods for shipbuilding project management. Ozyigit (2006) examined in detail the period from the decision-making process for a ship to be constructed up to the stage it starts to operate. The process initialized by decision of the ship owner about the type and sizes of the ship is discussed in this study along with identification of design, classification, shipbuilding stages, and the relations between these stages. Turan (2008) defined the production stages of platform supply vessel hull, prepared a mesh diagram subject to the block production plan of the vessel, and calculated the delivery time of the vessel by using CPM for building a new hull. Hajdu (2013) evaluated PERT analysis in detail and investigated the effects of the application of activity calendars on the distribution of project duration in PERT networks. Agyei (2015) applied CPM and PERT techniques with linear programming to a house building project to determine the optimal completion time and calculated the shortest time for the project. Mazlum and Guneri (2015) used the classical PERT and CPM with a fuzzy PERT and fuzzy CPM techniques for planning the project of an online Internet branch and compared these methods. They have reached the conclusion that there are not huge differences between the methods except working processes. Hajdu and Bokor (2016) also investigated the effect of activity duration distribution types (PERT-beta, uniform, triangular, and lognormal) on the project duration and pointed out that planners should devote more effort to adequately determine the activity durations. Mishakova et al. (2016) made PERT analysis which is one of the probabilistic modelling techniques for the control of time and earned value management method for cost controls in investment and construction projects.

2. Methods and methodology

A project is a temporary endeavor undertaken to create a unique product, service, or result. The temporary nature of projects indicates that a project has a definite beginning and end. The end is reached when the project's objectives have been achieved or when the project is terminated because its objectives will not or cannot be met, or when the need for the project no longer exists (Moeller 2015). There are several types of production according to the quantities of production involved, and these are commonly classified as job production, batch production, and continuous production. Project management is a significant process in all these production types. Project management is defined as the planning, monitoring, and control of all aspects of a project and the motivation of all those involved in it to achieve the project objectives within agreed criteria of time, cost, and performance (Lester 2017). While solving project problems, we may use some management techniques and tools that can be useful. Some of these methods are bar charts, network analysis, CPM, and PERT methods. In this study, PERT analysis has been applied to a vessel in which repair and maintenance works have been carried out in a Turkish shipyard. The selection of PERT analysis among other project management techniques is because of the convenience of the method to a probabilistic approach. The CPM method has not been selected because of requirement of exact duration times of each activity; it is hard to determine the repair duration in a certain time because some unexpected situations may occur during ship repair. PERT considers uncertainty of time, whereas CPM is a deterministic approach and needs certain time frame.

PERT is based on a beta distribution that is useful in real-world planning because it accounts for a degree of randomness (that all humans bring to the table). Based on its theoretical model, PERT delivers a task or project completion estimate based on pessimistic, optimistic, and most likely estimates provided by the user. PERT also provides a probability of completion on any date selected by the user. PERT calculations are simple and straightforward, but tend to get lengthy when many tasks are used. Before the task calculations can be made, however, two steps must be taken in any project planning (Hugg 2005):

1) Defining the goal of the project and the tasks required to complete it
2) Placing tasks in a logical order and determining the critical path (it is helpful to diagram the tasks); the critical path is the longest time path through the network of tasks.

When these steps are complete, generate a set of duration estimates for each task; each set should contain a pessimistic, most likely, and optimistic estimate. To keep the estimates straight, it is

useful to label pessimistic estimates as TP, optimistic estimates as TO, and most likely estimates as TL (any labeling system can be used, but these are fairly intuitive). For each task, calculate the PERT-derived expected duration (TE) based on the following formula (Hugg 2005; Wiest & Levy 2013):

$$(\mathrm{TP} + 4\mathrm{TL} + \mathrm{TO})/6 = \mathrm{TE}$$

1) Read this formula as the sum of pessimistic plus 4 times likely plus optimistic divided by 6 equals the expected duration.
2) Compete this calculation for all tasks, making sure to group tasks on the critical path separately; the critical path is the longest time path through the network of tasks, and the sum of duration of tasks on the critical path will determine the project duration.

A second set of calculations are necessary to determine information that will be useful later in the process. These calculations will yield the standard deviation (SD) and variance (V) for each task duration. The SD is the average deviation from the estimated time; as a general rule, the higher the SD is the greater amount of uncertainty exists. The V reflects the spread of a value over a normal distribution. The SD and V will be useful in determining the probability of the project meeting a desired completion date. The formula and steps for calculating SD and V are as follows (Wiest & Levy 2013):

1) SD = (TP − T0)/6 (read as [pessimistic − optimistic]/6).
2) $V = \mathrm{SD}^2$.
3) Compete this calculation for all tasks, making sure to group tasks on the critical path separately; the critical path is the longest time path through the network of tasks, and the sum of duration of tasks on the critical path will determine the project duration.

3. Case study: determination of a ship

3.1. Repair time by using PERT analysis

PERT analysis has been aimed to apply for 200-m tanker ship maintenance and repair works and designate the critical path for the project. First, we need to know how much time with optimistic, average, and pessimistic approach for each maintenance and repair process requires. For this purpose, all activities during repair of the vessel have been defined, and durations for each activity were taken from X shipyard and are given in Table 1. Previous activities, mean, and variance values have also been shown in Table 1.

3.1.1. Precedence diagram. The precedence diagram for 200-m tanker vessel repair and maintenance works with respect to the data in Table 1 is shown in Fig. 1. In the precedence diagram, all activities have been drawn with respect to their precedencies. Some activities are sequacious where some of them are in parallel.

3.1.2. Determining the critical path. There are some definitions while determining the critical path. These are "the early start (ES), early finish (EF), late start (LS), and late finish (LF) dates" of a project schedule. The early start dates of the project schedule are the earliest that any activity in the schedule can be commenced. The early finish of an activity in the schedule is the earliest that the activity can be completed in the schedule. The late start of an activity is the latest date that a project activity can be scheduled to be started, and the late finish of an activity is the latest that a project activity can be finished. The late finish of the project is the late finish of the last activity to be completed in the project. The time period between earliest and latest start times (ES and LS) is named as the slack time or float for a task. Thereby, slack is the amount of time that a task can be delayed without affecting the total project period. In critical tasks, there is no slack in the process, and the earliest and latest end times are observed as the same.

3.1.3. Forward calculation. In forward calculation, if D represents the duration of activity and i represents each activity, early start time is $\mathrm{ES}_i = \max.\ (\mathrm{ES}_i + D)$:

Activity 1: Duration is 4 hours. $\mathrm{ES}_1 = 0$ and $\mathrm{EF}_1 = 4$

Activity 2: Duration is 2 hours. $\mathrm{ES}_2 = \mathrm{EF}_1 = 4$ and $\mathrm{EF}_2 = \mathrm{ES}_2 + 2 = 6$

Activity 3: Duration is 7.17 hours. $\mathrm{ES}_3 = \mathrm{EF}_2 = 6$ and $\mathrm{EF}_3 = \mathrm{ES}_3 + 7.17 = 13.17$

Activity 4: Duration is 1.13 hours. $\mathrm{ES}_4 = \mathrm{EF}_3 = 13.17$ and $\mathrm{EF}_4 = \mathrm{ES}_4 + 1.13 = 14.3$

Activity 5: Duration is 5.67 hours. $\mathrm{ES}_5 = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_5 = \mathrm{ES}_5 + 5.67 = 19.97$

Activity 6: Duration is 2 hours. $\mathrm{ES}_6 = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_6 = \mathrm{ES}_6 + 2 = 16.3$

Activity 7: Duration is .25 hour. $\mathrm{ES}_7 = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_7 = \mathrm{ES}_7 + .25 = 14.55$

Activity 8: Duration is .25 hour. $\mathrm{ES}_8 = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_8 = \mathrm{ES}_8 + .25 = 14.55$

Activity 9: Duration is 1.08 hours. $\mathrm{ES}_9 = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_9 = \mathrm{ES}_9 + 1.08 = 15.38$

Activity 10: Duration is 3.5 hours. $\mathrm{ES}_{10} = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_{10} = \mathrm{ES}_{10} + 3.5 = 17.8$

Activity 11: Duration is .25 hour. $\mathrm{ES}_{11} = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_{11} = \mathrm{ES}_{11} + .25 = 14.55$

Activity 12: Duration is 10 hours. $\mathrm{ES}_{12} = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_{12} = \mathrm{ES}_{12} + 10 = 24.3$

Activity 13: Duration is 3.17 hours. $\mathrm{ES}_{13} = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_{13} = \mathrm{ES}_{13} + 3.17 = 17.47$

Activity 14: Duration is 24 hours. $\mathrm{ES}_{14} = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_{14} = \mathrm{ES}_{14} + 24 = 38.3$

Activity 15: Duration is 4.17 hours. $\mathrm{ES}_{15} = \mathrm{EF}_4 = 14.3$ and $\mathrm{EF}_{15} = \mathrm{ES}_{15} + 4.17 = 18.47$

Activity 16: Duration is 16.33 hours. $\mathrm{ES}_{16} = \mathrm{EF}_7 = 14.55$ and $\mathrm{EF}_{16} = \mathrm{ES}_{16} + 16.33 = 30.88$

Activity 17: Duration is 3.83 hours. $\mathrm{ES}_{17} = \mathrm{EF}_8 = 14.55$ and $\mathrm{EF}_{17} = \mathrm{ES}_{17} + 3.83 = 18.38$

Activity 18: Duration is 3.5 hours. $\mathrm{ES}_{18} = \mathrm{EF}_{10} = 17.8$ and $\mathrm{EF}_{18} = \mathrm{ES}_{18} + 3.5 = 21.3$

Activity 19: Duration is 1.04 hours. $\mathrm{ES}_{19} = \mathrm{EF}_{18} = 21.3$ and $\mathrm{EF}_{19} = \mathrm{ES}_{19} + 1.04 = 22.34$

Activity 20: Duration is 25.33 hours. $\mathrm{ES}_{20} = \mathrm{EF}_{15} = 18.47$ and $\mathrm{EF}_{20} = \mathrm{ES}_{15} + 25.33 = 43.8$

Activity 21: Duration is 4.17 hours. $\mathrm{ES}_{21} = \mathrm{EF}_{20} = 43.8$ and $\mathrm{EF}_{21} = \mathrm{ES}_{21} + 4.17 = 47.97$

Activity 22: Duration is 8 hours. $\mathrm{ES}_{22} = \mathrm{EF}_{21} = 47.97$ and $\mathrm{EF}_{22} = \mathrm{ES}_{22} + 8 = 55.97$

Table 1 Activity list for 200-m tanker repair and maintenance works

Activity	Symbol	Duration (hours)			Previous activities	Mean	Variance
		Optimistic	Average	Pessimistic			
Docking	1	3.00	4.00	5.00	–	4.00	.11
Cooling water attachment	2	1.00	2.00	3.00	1	2.00	.11
Deballasting	3	5.00	7.00	10.00	2	7.17	.69
Grounding	4	.75	1.00	2.00	3	1.13	.04
Opening sea chests	5	2.00	6.00	8.00	4	5.67	1.00
Cherry picker(for high-pressure water jet)	6	1.00	2.00	3.00	4	2.00	.11
Cherry picker(for anode renewable)	7	.17	.25	.33	4	.25	.00
Cherry picker(for measuring rudder clearance)	8	.17	.25	.33	4	.25	.00
Opening bottom plug	9	.50	1.00	2.00	4	1.08	.06
Scaffolding rope guard	10	3.00	3.50	4.00	4	3.50	.03
Opening rudder plug	11	.17	.25	.33	4	.25	.00
Setting up scrapper for overboard	12	8.00	10.00	12.00	4	10.00	.44
Shell inspection	13	2.00	3.00	5.00	4	3.17	.25
Overboard valves	14	20.00	24.00	28.00	4	24.00	1.78
Chain spreading	15	3.00	4.00	6.00	4	4.17	.25
Anode renewable	16	14.00	16.00	20.00	7	16.33	1.00
Measure rudder clearance	17	2.00	4.00	5.00	8	3.83	.25
Disassembly rope guard scaffold	18	3.00	3.50	4.00	10	3.50	.03
Measure depth gauge	19	.75	1.00	1.50	18	1.04	.02
Chain cleaning	20	16.00	24.00	40.00	15	25.33	16.00
Chain calibration	21	3.00	4.00	6.00	20	4.17	.25
Chain marking	22	4.00	8.00	12.00	21	8.00	1.78
High-pressure water jet	23	18.00	24.00	30.00	5; 6	24.00	4.00
Blasting	24	12.00	24.00	35.00	17; 19; 23	23.83	14.69
First coat painting	25	3.00	4.00	6.00	9; 24	4.17	.25
Hosedown	26	3.00	4.00	6.00	25	4.17	.25
Second coat painting	27	3.00	4.00	6.00	26	4.17	.25
Third coat painting	28	3.00	4.00	6.00	27	4.17	.25
Fourth coat painting	29	3.00	4.00	6.00	28	4.17	.25
Ship marking	30	6.00	8.00	10.00	29	8.00	.44
Ballasting	31	5.00	7.00	10.00	29	7.17	.69
Polishing of the propeller	32	6.00	8.00	10.00	29	8.00	.44
Dye penetrant testing for propeller	33	.50	1.00	2.00	32	1.08	.06
Undocking	34	3.00	4.00	5.00	33	4.00	.11

Activity 23: Duration is 24 hours. $ES_{23} = \max(EF_5, EF_6) = EF_5 = 19.97$ and $EF_{23} = ES_{23} + 24 = 43.97$

Activity 24: Duration is 23.83 hours. $ES_{24} = \max(EF_{17}, EF_{19}, EF_{23}) = EF_{23} = 43.97$ and $EF_{24} = ES_{24} + 23.83 = 67.8$

Activity 25: Duration is 4.17 hours. $ES_{25} = \max(EF_9, EF_{24}) = EF_{24} = 67.8$ and $EF_{25} = ES_{25} + 4.17 = 71.97$

Activity 26: Duration is 4.17 hours. $ES_{26} = EF_{25} = 71.97$ and $EF_{26} = ES_{26} + 4.17 = 76.14$

Activity 27: Duration is 4.17 hours. $ES_{27} = EF_{26} = 76.14$ and $EF_{27} = ES_{27} + 4.17 = 80.31$

Activity 28: Duration is 4.17 hours. $ES_{28} = EF_{27} = 80.31$ and $EF_{28} = ES_{28} + 4.17 = 84.48$

Activity 29: Duration is 4.17 hours. $ES_{29} = EF_{28} = 84.48$ and $EF_{29} = ES_{29} + 4.17 = 88.65$

Activity 30: Duration is 8 hours. $ES_{30} = EF_{29} = 88.65$ and $EF_{30} = ES_{30} + 8 = 96.65$

Activity 31: Duration is 7.17 hours. $ES_{31} = EF_{29} = 88.65$ and $EF_{31} = ES_{31} + 7.17 = 95.82$

Activity 32: Duration is 8 hours. $ES_{32} = EF_{29} = 88.65$ and $EF_{32} = ES_{32} + 8 = 96.65$

Activity 33: Duration is 1.08 hours. $ES_{33} = EF_{32} = 96.65$ and $EF_{33} = ES_{33} + 1.08 = 97.73$

Activity 34: Duration is 4 hours. $ES_{34} = EF_{33} = 97.73$ and $EF_{34} = ES_{34} + 4 = 101.73$

3.1.4. Backward calculation. In backward calculation, last activity of the project duration time is (ES = LS) and (EF = LF). If D represents the duration of activity and i represents each activity, late finish time for each activity in 200-m tanker repair works is LF_i = minimum ($LF_i - D$):

Activity 34: Duration is 4 hours. $LF_{34} = EF_{34} = 101.73$ and $LS_{34} = ES_{34} = 97.73$

Activity 33: Duration is 1.08 hours. $LF_{33} = LS_{34} = 97.73$ and $LS_{33} = LF_{33} - 1.08 = 96.65$

Activity 32: Duration is 8 hours. $LF_{32} = LS_{33} = 96.65$ and $LS_{32} = LF_{32} - 8 = 88.65$

Activity 31: Duration is 7.17 hours. $LF_{31} = LF_{34} = 101.73$ and $LS_{31} = LF_{31} - 7.17 = 94.56$

Activity 30: Duration is 8 hours. $LF_{30} = LF_{34} = 101.73$ and $LS_{30} = LF_{30} - 8 = 93.73$

Activity 29: Duration is 4.17 hours. $LF_{29} = \min(LS_{30}, LS_{31}, LS_{32}) = LS_{32} = 88.65$ and $LS_{29} = LF_{29} - 4.17 = 84.48$

Activity 28: Duration is 4.17 hours. $LF_{28} = LS_{29} = 84.48$ and $LS_{28} = LF_{28} - 4.17 = 80.31$

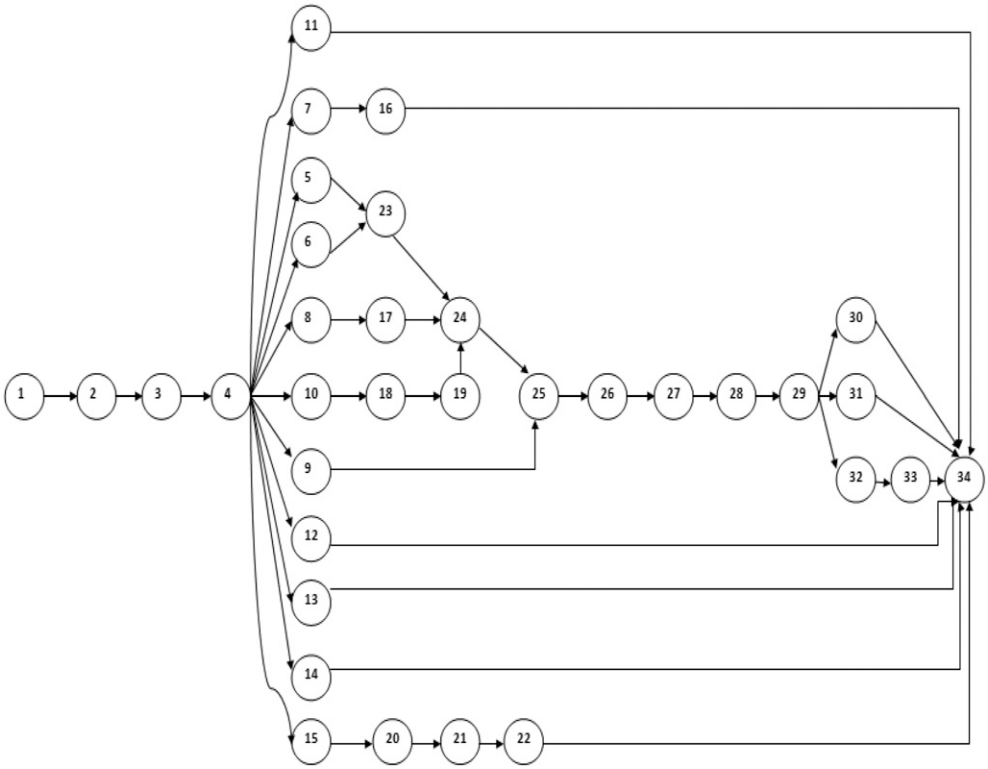


Fig. 1 Precedence diagram for maintenance and repair works

Activity 27: Duration is 4.17 hours. $LF_{27} = LS_{28} = 80.31$ and $LS_{27} = LF_{27} - 4.17 = 76.14$

Activity 26: Duration is 4.17 hours. $LF_{26} = LS_{27} = 76.14$ and $LS_{26} = LF_{26} - 4.17 = 71.97$

Activity 25: Duration is 4.17 hours. $LF_{25} = LS_{26} = 71.97$ and $LS_{25} = LF_{25} - 4.17 = 67.8$

Activity 24: Duration is 23.83 hours. $LF_{24} = LS_{25} = 67.8$ and $LS_{24} = LF_{24} - 23.83 = 43.97$

Activity 23: Duration is 24 hours. $LF_{23} = LS_{24} = 43.97$ and $LS_{23} = LF_{23} - 24 = 19.97$

Activity 22: Duration is 8 hours. $LF_{22} = LF_{34} = 101.73$ and $LS_{22} = LF_{22} - 8 = 93.73$

Activity 21: Duration is 4.17 hours. $LF_{21} = LS_{22} = 93.73$ and $LS_{21} = LF_{21} - 4.17 = 89.56$

Activity 20: Duration is 25.33 hours. $LF_{20} = LS_{21} = 89.56$ and $LS_{20} = LF_{20} - 25.33 = 64.23$

Activity 19: Duration is 1.04 hours. $LF_{19} = LS_{24} = 43.97$ and $LS_{19} = LF_{19} - 1.04 = 42.93$

Activity 18: Duration is 3.5 hours. $LF_{18} = LS_{19} = 42.93$ and $LS_{18} = LF_{18} - 3.5 = 39.43$

Activity 17: Duration is 3.83 hours. $LF_{17} = LS_{24} = 43.97$ and $LS_{17} = LF_{17} - 3.83 = 40.14$

Activity 16: Duration is 16.33 hours. $LF_{16} = LF_{34} = 101.73$ and $LS_{16} = LF_{16} - 16.33 = 85.4$

Activity 15: Duration is 4.17 hours. $LF_{15} = LS_{20} = 64.23$ and $LS_{15} = LF_{15} - 4.17 = 60.06$

Activity 14: Duration is 24 hours. $LF_{14} = LF_{34} = 101.73$ and $LS_{14} = LF_{14} - 24 = 77.73$

Activity 13: Duration is 3.17 hours. $LF_{13} = LF_{34} = 101.73$ and $LS_{13} = LF_{13} - 3.17 = 98.56$

Activity 12: Duration is 10 hours. $LF_{12} = LF_{34} = 101.73$ and $LS_{12} = LF_{12} - 10 = 91.73$

Activity 11: Duration is .25 hour. $LF_{11} = LF_{34} = 101.73$ and $LS_{11} = LF_{11} - .25 = 101.48$

Activity 10: Duration is 3.5 hours. $LF_{10} = LS_{18} = 39.43$ and $LS_{10} = LF_{10} - 3.5 = 35.93$

Activity 9: Duration is 1.08 hours. $LF_9 = LS_{25} = 67.8$ and $LS_9 = LF_9 - 1.08 = 66.72$

Activity 8: Duration is .25 hour. $LF_8 = LS_{17} = 40.14$ and $LS_8 = LF_8 - .25 = 39.89$

Activity 7: Duration is .25 hour. $LF_7 = LS_{16} = 85.4$ and $LS_7 = LF_7 - .25 = 85.15$

Activity 6: Duration is 2 hours. $LF_6 = LS_{23} = 19.97$ and $LS_6 = LF_6 - 2 = 17.97$

Activity 5: Duration is 5.67 hours. $LF_5 = LS_{23} = 19.97$ and $LS_5 = LF_5 - 5.67 = 14.3$

Activity 4: Duration is 1.13 hours. $LF_4 = \min(LS_5, LS_6, LS_7, LS_8, LS_9, LS_{10}, LS_{11}, LS_{12}, LS_{413}, LS_{14}, LS_{15}) = LS_5 = 14.3$ and $LS_4 = LF_4 - 1.13 = 13.17$

Activity 3: Duration is 7.17 hours. $LF_3 = LS_4 = 13.17$ and $LS_3 = LF_3 - 7.17 = 6$

Activity 2: Duration is 2 hours. $LF_2 = LF_3 = 6$ and $LS_2 = LF_2 - 2 = 4$

Activity 1: Duration is 4 hours. $LF_1 = LF_2 = 4$ and $LS_1 = LF_1 - 4 = 0$

3.1.5. Calculation of slacks (floats). After forward and backward calculations, flexibility or float in the network should be calculated because this is very significant for the project manager to decide on the allocation of resources with respect to their utilization.

There are two types of floats: free float and total float.

3.1.6. Total slacks (floats). Total slack defines the amount of the permissible delay time that an activity has, without affecting the project completion time. Then, total slacks for each activity in 200-m tanker repair and maintenance works are calculated as follows:

$TS_{activity} = LF_{activity} - EF_{activity}$

Activity 1: $LF_1 - EF_1 = 4 - 4 = 0$
Activity 2: $LF_2 - EF_2 = 6 - 6 = 0$
Activity 3: $LF_3 - EF_3 = 13.17 - 13.17 = 0$
Activity 4: $LF_4 - EF_4 = 14.3 - 14.3 = 0$
Activity 5: $LF_5 - EF_5 = 19.97 - 19.97 = 0$
Activity 6: $LF_6 - EF_6 = 19.97 - 16.3 = 3.67$
Activity 7: $LF_7 - EF_7 = 85.4 - 14.55 = 70.85$
Activity 8: $LF_8 - EF_8 = 40.14 - 14.55 = 25.59$
Activity 9: $LF_9 - EF_9 = 67.8 - 15.38 = 52.42$
Activity 10: $LF_{10} - EF_{10} = 39.43 - 17.8 = 21.63$
Activity 11: $LF_{11} - EF_{11} = 101.73 - 14.55 = 87.18$
Activity 12: $LF_{12} - EF_{12} = 101.73 - 24.3 = 77.43$
Activity 13: $LF_{13} - EF_{13} = 101.73 - 17.47 = 84.26$
Activity 14: $LF_{14} - EF_{14} = 101.73 - 38.3 = 63.43$
Activity 15: $LF_{15} - EF_{15} = 64.23 - 18.47 = 45.76$
Activity 16: $LF_{16} - EF_{16} = 101.73 - 30.88 = 70.85$
Activity 17: $LF_{17} - EF_{17} = 43.97 - 18.38 = 25.59$
Activity 18: $LF_{18} - EF_{18} = 42.93 - 21.3 = 21.63$
Activity 19: $LF_{19} - EF_{19} = 43.97 - 22.34 = 21.63$
Activity 20: $LF_{20} - EF_{20} = 89.56 - 43.8 = 45.76$
Activity 21: $LF2_1 - EF2_1 = 93.73 - 47.97 = 45.76$
Activity 22: $LF_{22} - EF_{22} = 101.73 - 55.97 = 45.76$
Activity 23: $LF_{23} - EF_{23} = 43.97 - 43.97 = 0$
Activity 24: $LF_{24} - EF_{24} = 67.8 - 67.8 = 0$
Activity 25: $LF_{25} - EF_{25} = 71.97 - 71.97 = 0$
Activity 26: $LF_{25} - EF_{25} = 76.14 - 76.14 = 0$
Activity 27: $LF_{26} - EF_{26} = 80.31 - 80.31 = 0$
Activity 28: $LF_{28} - EF_{28} = 84.48 - 84.48 = 0$
Activity 29: $LF_{29} - EF_{29} = 88.65 - 88.65 = 0$
Activity 30: $LF_{30} - EF_{30} = 101.73 - 96.65 = 5.08$
Activity 31: $LF_{31} - EF_{31} = 101.73 - 95.82 = 5.91$
Activity 32: $LF_{32} - EF_{32} = 96.65 - 96.65 = 0$
Activity 33: $LF_{33} - EF_{33} = 97.73 - 97.73 = 0$
Activity 34: $LF_{34} - EF_{34} = 101.73 - 101.73 = 0$

3.1.7. Free slacks (floats). Free slack defines the amount of the permissible time period that an activity can delay without affecting the succeeding activity. This can be calculated by subtracting the Early Finish of an activity from the Early Start of its subsequent activity. Thus, free slacks for each activity in 200-m tanker repair and maintenance works are calculated as follows:

$FS_{activity} = \text{min. } ES_{successor} - ES_{activity} - D_{activity}$

Activity 1: $ES_2 - ES_1 - D_1 = 4 - 0 - 4 = 0$
Activity 2: $ES_3 - ES_2 - D_2 = 6 - 4 - 2 = 0$
Activity 3: $ES_4 - ES_3 - D_3 = 13.17 - 6 - 7.17 = 0$
Activity 4: $ES_5 - ES_4 - D_4 = 14.3 - 13.17 - 1.13 = 0$
Activity 5: $ES_{23} - ES_5 - D_5 = 19.97 - 14.3 - 5.67 = 0$
Activity 6: $ES_{23} - ES_6 - D_6 = 19.97 - 14.3 - 2 = 3.67$
Activity 7: $ES_{16} - ES_7 - D_7 = 14.55 - 14.3 - .25 = 0$
Activity 8: $ES_{17} - ES_8 - D_8 = 14.55 - 14.3 - .25 = 0$
Activity 9: $ES_{25} - ES_9 - D_9 = 67.8 - 14.3 - 1.08 = 52.42$
Activity 10: $ES_{18} - ES_{10} - D_{10} = 17.8 - 14.3 - 3.5 = 0$
Activity 11: $EF_{34} - ES_{11} - D_{11} = 101.73 - 14.3 - .25 = 87.18$
Activity 12: $EF_{34} - ES_{12} - D_{12} = 101.73 - 14.3 - 10 = 77.43$
Activity 13: $EF_{34} - ES_{13} - D_{13} = 101.73 - 14.3 - 3.17 = 84.26$
Activity 14: $EF_{34} - ES_{14} - D_{14} = 101.73 - 14.3 - 24 = 63.43$
Activity 15: $ES_{20} - ES_{15} - D_{15} = 18.47 - 14.3 - 4.17 = 0$
Activity 16: $EF_{34} - ES_{16} - D_{16} = 101.73 - 14.55 - 16.33 = 70.85$
Activity 17: $ES_{24} - ES_{17} - D_{17} = 43.97 - 14.55 - 3.83 = 25.59$
Activity 18: $ES_{19} - ES_{18} - D_{18} = 21.3 - 17.8 - 3.5 = 0$
Activity 19: $ES_{24} - ES_{19} - D_{19} = 43.97 - 21.3 - 1.04 = 21.63$
Activity 20: $ES_{21} - ES_{20} - D_{20} = 43.8 - 18.47 - 25.33 = 0$
Activity 21: $ES_{22} - ES_{21} - D_{21} = 47.97 - 43.8 - 4.17 = 0$
Activity 22: $EF_{34} - ES_{22} - D_{22} = 101.73 - 47.97 - 8 = 45.76$
Activity 23: $ES_{24} - ES_{23} - D_{23} = 43.97 - 19.97 - 24 = 0$
Activity 24: $ES_{25} - ES_{24} - D_{24} = 67.8 - 43.97 - 23.83 = 0$
Activity 25: $ES_{26} - ES_{25} - D_{25} = 71.97 - 67.8 - 4.17 = 0$
Activity 26: $ES_{27} - ES_{26} - D_{26} = 76.14 - 71.97 - 4.17 = 0$
Activity 27: $ES_{28} - ES_{27} - D_{27} = 80.31 - 76.14 - 4.17 = 0$
Activity 28: $ES_{29} - ES_{28} - D_{28} = 84.48 - 80.31 - 4.17 = 0$
Activity 29: $ES_{30} - ES_{29} - D_{29} = 88.65 - 84.48 - 4.17 = 0$
Activity 30: $EF_{34} - ES_{30} - D_{30} = 101.73 - 88.65 - 8 = 5.08$
Activity 31: $EF_{34} - ES_{31} - D_{31} = 101.73 - 88.65 - 7.17 = 5.91$
Activity 32: $ES_{33} - ES_{32} - D_{32} = 96.65 - 88.65 - 8 = 0$
Activity 33: $ES_{34} - ES_{33} - D_{33} = 97.73 - 96.65 - 1.08 = 0$
Activity 34: $EF_{34} - ES_{34} - D_{34} = 101.73 - 97.73 - 4 = 0$

3.1.8. Critical path. None of the tasks through the network have slack in the critical path, which means that ES = LS and EF = LF for all tasks in the path. Any delay in the critical path delays the total project completion time. In case of aiming to complete the project sooner, the total duration time in the critical path activities should be reduced.

Red line in Fig. 2 shows critical path which is 1 – 2 – 3 – 4 – 5 – 23 – 24 – 25 – 26 – 27 – 28 – 29 – 32 – 33 – 34. According to Fig. 2, critical activities are "docking, cooling water attachment, deballasting, grounding, opening sea chests, high-pressure water jet, blasting, first coat painting, hosedown, second coat painting, third coat painting, fourth coat painting, polishing of the propeller, dye penetrant testing for propeller, and undocking" works.

Total duration time for critical activities which generates the critical path have been calculated as follows:

4 hours (Activity 1) + 2 hours (Activity 2) + 7.17 hours (Activity 3) + 1.13 hours (Activity 4) + 5.67 hours (Activity 5) + 24 hours (Activity 23) + 23.83 hours (Activity 24) + 4.17 hours (Activity 25) + 4.17 hours (Activity 26) + 4.17 hours (Activity 27) + 4.17 hours (Activity 28) + 4.17 hours (Activity 29) + 8 hours (Activity 32) + 1.08 hours (Activity 33) + 4 hours (Activity 34) = 101.73 hours = 12.72 days.

Workday is assumed as 8 hours during calculations, and there are five workdays for a week (Monday, Tuesday, Wednesday, Thursday, and Friday) in X shipyards that the data have been handled.

3.1.9. Statistic analysis of project. In PERT analysis, variances should also be considered to designate the time period accurately and prevent wrong calculations. The time estimation phase is a significant stage during the quotation submission to the owner, and wrong estimations regarding time incur losses both for the owner and shipyard sides. The project completion time may vary because

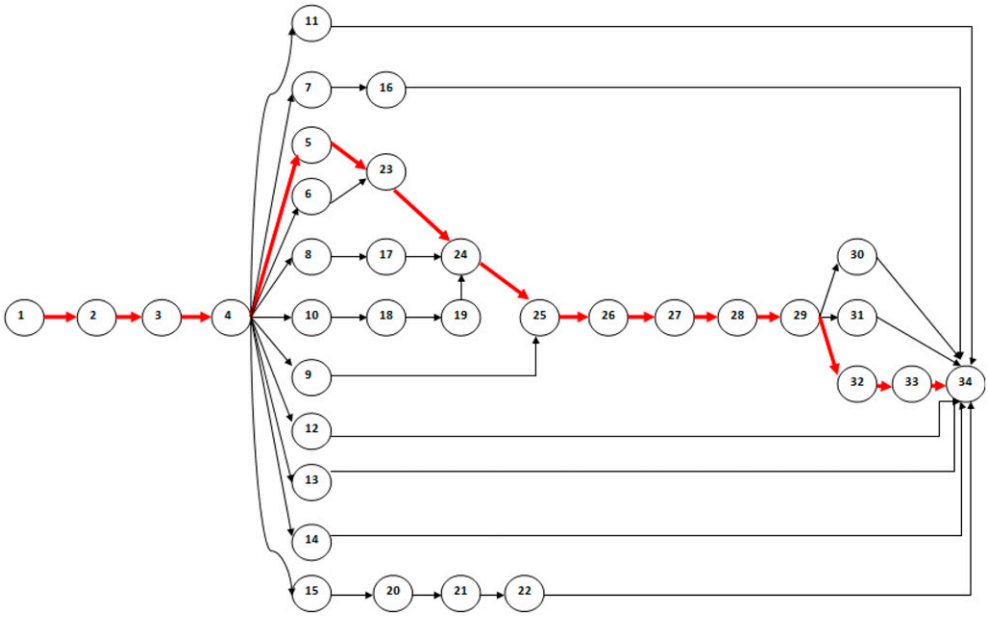


Fig. 2 Critical path for 200-m tanker repair and maintenance works

of variances. The SD should also be calculated after variance calculation as the square root of total variance. The project completion time can be estimated by using Z tables in a probabilistic manner.

In this context, variance of critical path is $.11 + .11 + .69 + .04 + 1 + 4 + 14.69 + .25 + .25 + .25 + .25 + .25 + .44 + .06 + .11 = 22.5$ hours, whereas SD is 4.74 hours.

After this, all probabilities of the project can be calculated by using the Z table. Z value can be calculated as $Z = (Y - \mu)/\sigma$.

When $Y = 97$ hours and project completion time is 101.73 hours and σ (SD) is 4.74 hours, Z value is $(97 - 101.73)/4.74 = -1.0$. On the Z table, for .1586 against -1.0, p ($y \leq 97$ hours) = %15.86.

By using p ($y \leq ?$) = .95; Z is 1.645 for .95. $Y = \mu + \sigma \times Z$ and $Y = 101.73 + 4.74 \times 1.645$, then $Y = 109.52$ hours.

By using p ($y \leq ?$) = .90, Z is 1.28 for .90. $Y = \mu + \sigma \times Z$ and $Y = 101.73 + 4.74 \times 1.28$ then $Y = 107.79$ hours.

The repair and maintenance duration time has been estimated at around 110 hours according to the previous calculation. The vessel may leave the shipyard in 110 hours, which equals 13.75 days with 8 hours of working period in X shipyard. Shipyards may form these network plans and avoid coming across with unexpected situations during the repair and maintenance period of the vessels.

4. Conclusions

PERT, which is one of the project management methods, has been applied to calculate the total repair and maintenance period and determine the critical path for a 200-m tanker vessel in this study. This method is based on the activity lists and duration periods of each activity in the projects. The vessel is a real case study in this study, and it has been repaired in one of the well-known Turkish shipyards. All activities and durations during repair and maintenance of the vessel have been listed initially. Precedence diagrams have been drawn with respect to the duration times, and critical path have been analyzed by using forward and backward calculations.

Ship repair is a highly sophisticated business type, and minor delays may also cause huge losses for the owner of the ship such as loss of hire, loss of cargo, and cancellation of the total voyage. Delays in the repair period of a vessel also affect the shipyard side severely, and this is unsolicited status. The position of the shipyard may be damaged, and repair shipyard may lose reputation and prestige among its rivals. Therefore, the duration time should be calculated and submitted to the owner company accurately during the tender stage by the shipyard personnel to protect both sides. The method presented in this article enables the repair team to calculate the repair period truly and see the critical paths before the commencement of the repair activities. In addition, the shipyard team may also notice time lags while following the repair planning schedule. Therefore, this method is practical and effective for application to a ship repair business and assists shipyards and ship owners to designate the period of time and prevent additional and unexpected costs due to the delays. The consequences of this study have scientific, practical, and sectoral value. Planners, managers, and decision makers of the shipyards can use from the results of the study to calculate exact dates of the ship repair period. The results could also be used to follow the whole repair and maintenance period of a ship and realize delays if any. In addition, the study comprises a basis for future studies on the estimation of repair periods and gives actual database with real calculations to the scientists who study optimization of production and manufacturing processes both in the shipbuilding sector and other production sectors.

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