Volume 22 (2) 2023 Page 101 - 114

Mekanika: Majalah Ilmiah Mekanika

Repair Project Acceleration Strategy of Three Ship Units using Fuzzy Logic Analysis and Critical Path Method

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Keywords:
Critical path method
Shop level planning
Fuzzy logic
Project acceleration

Abstract
This research uses the Critical Path Method (CPM) to analyze the main schedule of three combined ship repair projects. Then, shop-level planning is used to determine the productivity of each workshop so that each workshop knows the volume of work that needs to be completed daily. Furthermore, fuzzy logic is applied to analyze the risk of delays in repair project activities. The addition of working hours to critical work activities is accelerated from 30 days, the normal duration, to 23 days. Meanwhile, the addition of the workforce to critical work activities is accelerated from 30 days, the normal duration, to 22 days. The analysis of productivity values in each workshop results in the following productivity values: sandblasting and painting workshop 309.97 m^2/person-days, piping workshop 4.12 units/person-days, fabrication workshop 407.16 kg/person-days, outfitting workshop 14.8 units/person-days, tank cleaning workshop 114.36 m^3/person-days, and machining workshop 2.7 units/person-days. The fuzzy logic analysis results to determine the risk of delays in critical activities show that jobs with the codes SP1, SP2, SP3, SP4, M2, and SP5 have high risk of delay. Additionally, the collaboration with other departments in the company, such as the marketing, finance, and human resources departments, is ongoing to complete assigned tasks.

1 Introduction

The success of a project is completing activities within the constraints of time, cost, and performance within the planned period [1]. Effective management is necessary to achieve project success, and this is where project management comes into play. Project management involves the process of planning, organizing, leading, and controlling a company's resources to achieve the predetermined goals [2]. Utilizing project management, a project plan, schedule, and resource allocation are creaeted for a given project. Effective project planning is necessary to guide the implementation of agreed-upon work activities within the designated time frame. The work activities are outlined in a repair list and then formulated into a main

https://dx.doi.org/10.20961/mekanika.v22i.76502

Revised 19 August 2023; received in revised version 26 August 2023; Accepted 17 September 2023
Available Online 30 September 2023

2579-3144

schedule for ship repair work. Projects must be completed within the designated time frame and end date and should be within the specified time limits [2]. Scheduling in a project is prepared carefully and with full consideration to ensure that work activities are carried out according to the schedule and do not exceed the predetermined duration.

Numerous methods and resources have been created to enhance the project planning process. Examples of these tools include the Gantt chart, the Critical Path Method (CPM), and the Program Evaluation and Review Technique (PERT). Many project managers utilize these tools earnestly to pinpoint crucial tasks and determine the shortest duration necessary to complete a project [3-5]. Out of these approaches, the majority of conventional scheduling methods make use of the Gantt chart. While this approach remains useful, its effectiveness is restricted when arranging extensive operations. Specifically, the bar chart struggles to represent the intricate interdependencies and sequential connections among project tasks. Network-oriented techniques like PERT and CPM are renowned and extensively adopted to aid managers in the planning and oversight of projects, both substantial and minor, spanning various domains such as construction, research, and development endeavours, among others [6-8].

CPM employs a network structure to orchestrate tasks, establish timetables, and oversee project advancement [9,10]. It has been widely applied to compute operational variables such as the earliest start time, latest start time, earliest finish time, latest finish time, maximum available time, and slack time [11,12]. Nevertheless, time setbacks can arise in numerous construction ventures, underscoring the significance of adept project management methods to guarantee favourable project outcomes. Ineffectual planning strategies can steer all gains toward financial losses [13]. Indeed, it serves as a sequential project management methodology that detects tasks along the critical path. This method entails dissecting the project into various work assignments, representing them within a visual diagram, and subsequently determining the overall project duration by estimating each task's duration. It designates tasks crucial to the project's timeline, emphasizing their pivotal role in project completion [14].

Poorly planned main schedules can prevent reparations projects from experiencing delays. In addition, inefficient activity scheduling in each workshop can result in a lack of efficiency in time and labour. Therefore, risk analysis of delays is a need for each project activity. The author uses network planning and CPM to analyze the primary schedule data to reduce delays in ship repair projects. Then, shop-level planning is used to determine productivity in each workshop so that each workshop can work on the same job simultaneously at the same time when carrying out several repair projects. Finally, fuzzy logic is used to analyze the risk of delays in each critical project activity.

CPM is a technique that presents methods for determining the sequence and duration of project activities used to estimate the overall project completion time. This method is known for the critical path, which is the path that includes a series of critical activities starting from the first activity to the final activity of the project [2]. Network planning is based on the principle of interdependence between different project parts, represented by symbols. Symbols allow the identification of tasks that need to be completed first and which are dependent on the completion of other tasks, enabling the proper allocation of resources to achieve efficiency [15].

Fuzzy logic is a method of mapping an input space or input to an output space or output. Fuzzy logic maps problems from input to the desired output and derives solutions to complex real-world problems. Fuzzy sets have membership values that range from 0 to 1, where 1 indicates full membership in a set, and 0 indicates no membership [16]. A fuzzy set represents a specific condition or state in a fuzzy variable. The next step involves searching for fuzzy data, known as the fuzzy query process using the Tahani fuzzy database model. The Tahani system's fuzzy database concept is based on establishing a fuzzy database concept in a system database that utilizes membership degrees [17].

According to the study by Argyan et al. [18] regarding the analysis of shop-level planning using CPM on the repair of Tug Boat (TB). Tanjung Buyut I-206 and TB. Arek Suroboyo-3, the analysis resulted in the production values of each workshop as follows: the pipe workshop had a productivity of 3.5 m/person-days, fabrication had a productivity of 266 kg/person-days, electricity had productivity of 11 units/person-days, machinery had a productivity of 11.5 units/person-days, sandblasting had a productivity of 134 m^2/person-days, painting had a productivity of 138 m^2/person-days, outfitting had productivity of 12.4 units/person-days, and tank cleaning had productivity of 12.3 units/mandays. Referring to a study by Taufiq [19], research on the design of a decision support system for determining the production quantity using a fuzzy logic method, it was found that this method was applied to determine the production quantity, with variables including demand, labour, and production. This research was supported by a comparison Table between manual calculations and system calculations, and the result of the accuracy percentage of this system was 96%.

In the study by Argyan et al. [18], only repair list data was processed using the shop-level planning method to determine the acceleration of duration and productivity. Based on research by Taufiq [19], the accuracy percentage of the results from the system using fuzzy logic in determining the production quantity was 96%. This research uses the fuzzy logic method to analyze the risk of delay in the repair work of the three ships combined using shop-level planning based on CPM.

This research aims to develop a project management strategy by merging three ship repair project schedules and analysing the delay risk level in each project activity. This study aims to identify the critical path in the repairment activities, determine the productivity value of each workshop level, accelerate project duration, and identify work activities that risk causing delays in the repairment project.

2 Methods

2.1 Literature review

Based on Table 1, previous research landmarks are presented, which discuss the use of fuzzy logic and critical path methods in several engineering problems. Firstly, Argyan et al. [18] applied the critical path method to analyze shop-level planning in tugboat repair. This critical path was crashing the project, resulting in an alternative to adding labour, which accelerated the normal duration of the project from 60 days to 35 days (41.67% decrease). Meanwhile, the alternative of adding working hours (overtime) has accelerated the normal duration of the project from 60 days to 37 days (38.33% decrease). Moreover, Zareei [14] found that the minimum completion time for building a 50 m^3 biogas plant with a fixed dome in Iran was 38 weeks if there were no delays in the project. In addition, a project work network was proposed to show the relationship between activities and monitor project progress. Then, Taufiq [19] proved that with a comparison table between manual and fuzzy logic system calculations, the percentage of the correctness of the system is 96%. Based on the research conducted by Suprapty et al. [25], the Tahani fuzzy logic method and Simple Additive Weighting (SAW) were used in making an information system for job applicant selection. The output results were job applicant candidate rankings, ideal job applicant rankings, and final rankings.

Table 1. Research milestone

Reference No.	Author(s)	Year	Title of the paper	Remarks
[18]	W. D. Argiyan, I. P. Mulyatno, and S. Jokosisworo	2022	Analysis of Shop Level Planning with the Critical Path Method at TB Reparations. Tanjung Buyut I-206 and TB. Arek Suroboyo-3	The critical path method in this research is used to determine the acceleration of the project with additions to labour or alternative additions to working hours (overtime), which result in changes to costs. Then, a crashing project is carried out to accelerate the project duration.

Table 1. *Cont.*

Reference No.	Author(s)	Year	Title of the paper	Remarks
[14]	S. Zareei	2018	Project scheduling for constructing biogas plant using critical path method	The Critical Path Method (CPM) in this study is used for planning and scheduling to analyse the construction projects of a biogas power plant by finding the fastest completion time in the project process.
[19]	R. Taufiq	2019	Design of a Decision Support System for Determining Production Quantity Using the Tsukamoto Fuzzy Method	The fuzzy logic method in this research is applied in determining the amount of production, with variables of demand, workers, and production, to analyze the amount of production that affects the level of losses caused by the lack of workers because the amount of production of goods is too low or excessive.
[25]	B. Suprapty, R. Malani, and O. D. Nurhayati	2016	Design of Information System for Acceptance Selection of Prospective Employees Online Using Tahani Fuzzy Logic Method and Simple Additive Weighting (SAW)	This research designs and creates an online-based information system for job applicant selection using the Tahani fuzzy logic method and Simple Additive Weighting (SAW).

2.2 Reference ship data

The primary data comprised observations and interviews conducted directly with the company to obtain information on their activities and conditions in the field. PT. Janata Marina Indah provided the primary data in main schedules, repair lists, the number of workers, and operational hours from work orders. On the other hand, the secondary data resulted from analysing sources from literature or related articles without direct observation.

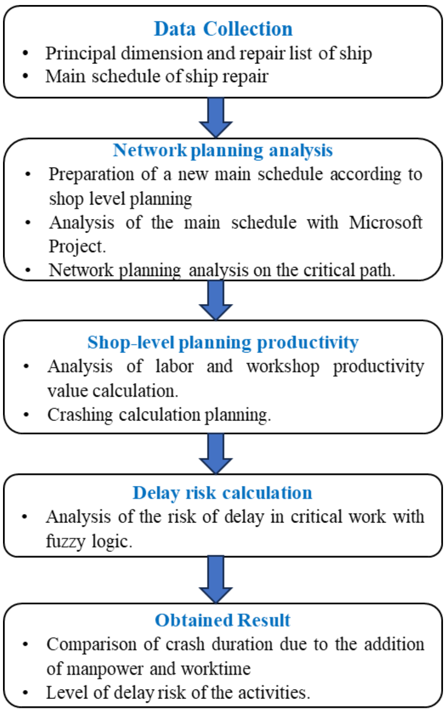

Figure 1. Flowchart of the applied method for ship repair acceleration project

The data processing method used in this study for rescheduling repair projects with fuzzy logic analysis based on the CPM comprised several steps. First, we developed a rescheduling management strategy with a shop-level plan by combining the activities listed in the three main schedules and repair lists and adjusting the workshop hierarchy using Microsoft Project. Next, we calculated the Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), and Latest Finish (LF) of the work activities by analyzing the critical path, which included the activities with a total float value of zero. After that, we analyzed the productivity calculation of the critical path work activities by adding more workers, extending working hours, and improving workshop performance. Then, we arranged the critical work activities with a technique called acceleration alternative to shorten the project duration. Finally, we analyzed the repair work activities using fuzzy logic to identify the risk of delays in each critical work activity. The complete schematic flowchart of the method is in Figure 1. The repair projects of Motor Tanker (MT). Triaksa 17, *Kapal Motor* (KM). Dharma Ferry 2, and *Kapal Motor Penyebrangan* (KMP). Dharma Rucitra 1 at PT. Janata Marina Indah was the subject of this study under the data presented in Table 2.

Table 2. Principal dimension of MT. Triaksa 17, KM. Dharma Ferry 2, and KMP. Dharma Rucitra 1

Dimension	MT. Triaksa 17	KM. Dharma Ferry 2	KMP. Dharma Rucitra 1
Length overall (m)	90.00	67.20	134.60
Length between perpendicular (m)	84.00	65.00	125.00
Breadth (m)	15.20	16.00	21.00
Depth (m)	12.03	6.04	12.03
Draft (m)	4.00	3.40	5.70
Gross tonnage (ton)	2908	2341	11479

2.3 Planning sequence of repair work

In this study, the work activity sequence was planned by analyzing the main schedule and repair list, which were arranged according to predecessors, resulting in work classified as critical path jobs. Predecessors were activities completed before the relevant work was carried out. The relationship between work activities was expressed in Finish-to-Start (FS) and Start-to-Start (SS) relationships with lag time. Lag time relationships with activities were used to determine the project's work duration to make it more efficient.

2.4 Critical path calculation

The term “critical path” referred to work activities that required special attention due to the lack of slack time. Any delay in these activities had an impact on the total project duration, resulting in a delay that exceeded the agreed-upon work schedule [20]. CPM scheduling aided in the planning of the work strategy while considering the critical activities. The total float was used in the calculation of CPM scheduling. The total float was determined using Equation 1 [20].

$$TF = LF - EF \tag{1}$$

where TF is the total float, LF is the latest possible completion time for a given task, and EF is the earliest possible start time for that task.

2.5 Productivity analysis

This study defined productivity calculation as the ratio between the output produced and the total resources used [21]. Productivity calculation was performed on critical path tasks and the overall workshop productivity. The productivity calculation was expressed in Equations 2-4 [21].

$$PN = \frac{VP}{DN} \tag{2}$$

where PN represents normal productivity, VP is work volume, and DN is the normal duration.

$$PpMd = \frac{VT}{DT\ x\ ISLTK} \tag{3}$$

where *PpMd* represents productivity per person-days, *VT* represents total volume, *DT* represents total duration, and *ISLTK* represents the shop-level workforce index. The calculation of *ISLTK* is expressed in Equation 4.

$$ISLTK = \frac{total\ workforce}{total\ duration} \tag{4}$$

2.6 Alternative acceleration

Alternative acceleration was used in the study to shorten the project's completion time preventing delays. The acceleration alternatives include adding more workforce or working overtime to reduce the duration of work. Both alternatives were found to be effective in accelerating the project completion. The project was scheduled with a normal working time of eight hours per day (08:00 – 17:00) and an hour break (12:00 – 13:00). Overtime work was scheduled after regular working hours and lasted for four hours (17:00 – 21:00). Overtime work, on the other hand, could decrease productivity by up to 70% when compared to normal working hours. The formula used to calculate this was according to Equation 5 [18].

$$PCrJK = PN + (PpJN\ x\ a\ x\ PJK) \tag{5}$$

where *PCrJK* is the crashing productivity rate during overtime, *PN* is the standard productivity rate, *PpJN* represents the standard productivity rate per hour, which is calculated by dividing daily productivity by the duration of work in one day (eight hours), α is the productivity reduction coefficient which was 0.7, and *PJK* is the additional working hours.

The second alternative is proposed by adding a workforce. The repair project study assumed that adding a workforce would increase daily productivity by 35%. The calculation for adding the number of workers in critical tasks was expressed in Equation 6 [18].

$$PPNJK = = \frac{PCrJK - PN}{PN}\ x\ 100\% \tag{6}$$

where *PPNJK* is the increase in normal productivity caused by adding working hours, *PCrJK* is the productivity increase caused by crashing working hours (overtime), and *PN* is normal productivity. The productivity calculation after acceleration alternatives with additional labour was determined using Equation 7 [18].

$$PCrTK = = PN + (PN\ x \frac{PTK}{TKA}) \tag{7}$$

where *PCrTK* is the workforce's crashing productivity, *PN* is the normal productivity, *PTK* is the additional workforce, and *TKA* is the initial workforce.

2.7 Crash duration

The crash duration was the time required to shorten the duration of work activities to shorter than normal [22]. An alternative acceleration treatment in the work activities increased productivity, resulting in a shorter duration than normal time. Therefore, the calculation of crash duration was carried out. The crash duration caused by the addition of work hours (overtime) could be calculated using the calculation formula expressed in Equation 8 [23].

$$CrD = \frac{VP}{PCrJK} \tag{8}$$

CrD is the crash duration value, *VP* is the volume of work, and *PCrTK* is the productivity of crashing labour. Equation 9 can be used to calculate the crash duration caused by the addition of labour [23].

$$CrD = \frac{VP}{PCrTK} \quad (9)$$

where *CrD* is the value of crash duration, *VP* is the volume of work, and *PCrTK* is the productivity of crashing work time.

2.8 Fuzzy logic analysis

Fuzzy logic was an approach to map an input or input space to an output or output space. A fuzzy inference system is a computational framework based on fuzzy set theory, fuzzy rules, and fuzzy reasoning. The fuzzy inference system transformed fuzzy input into fuzzy output by following rules defined in the fuzzy knowledge base. In the fuzzy logic model, each consequent in the rule set had to be represented in a fuzzy set with a monotonic membership function [24].

The steps involved in analyzing fuzzy logic in processing critical work data for three ship units were as follows: First, the variables were determined. This research consisted of three variables: duration, volume, and productivity. After determining the variables, the next step was fuzzification. Fuzzification transformed input systems with crisp values into linguistic variables with membership degrees with an interval of 0 to 1. One way to obtain membership values was using a membership function approach stored in the fuzzy knowledge base. Fuzzification was an essential concept in fuzzy logic theory. Fuzzification was a process in which crisp quantities were transformed into fuzzy quantities. Fuzzy values were formed by identifying several uncertainties that existed in crisp values. Membership functions represented the conversion of fuzzy values. In the fuzzification process used in this research, linguistic variables were used to gather the function rules. Equations 10-12 defines fuzzy logic membership functions [25].

$$\mu\, low \begin{cases} 1\,; x \leq a \\ \frac{(b-x)}{y1};\ a \leq x \leq b \\ 0\,; x \geq b \end{cases} \quad (10)$$

$$\mu\, moderate \begin{cases} 0\,; x \leq a \\ \frac{(x-a)}{y1};\ a \leq x \leq b \\ \frac{(c-x)}{y2};\ b \leq x \leq c \\ 0\,; x \geq c \end{cases} \quad (11)$$

$$\mu\, high \begin{cases} 0\,; x \leq b \\ \frac{(x-b)}{y2};\ b \leq x \leq c \\ 1\,; x \geq c \end{cases} \quad (12)$$

where *a* is the lower limit, *b* is the midpoint, *c* is the upper limit, $y_1 = b - a$, and $y_2 = c - b$.

After fuzzification, the next step was defuzzification. The input for the defuzzification process was a fuzzy set obtained from the composition of fuzzy rules, while the output produced was a number in the domain of the fuzzy set. Defuzzification, or classification, was a method of mapping values from a fuzzy set to crisp values. The input for the defuzzification process was a fuzzy set. In this study, the defuzzification method used was the Tahani fuzzy method, a defuzzification model using a standard database. In the standard database, data was classified based on rules in the function set that had been designed. This research used the union calculation formula by taking the largest membership value between members in the relevant set to analyze the Tahani fuzzy model defuzzification. This method obtained the crisp solution by taking the largest value in the fuzzy domain, using Equation 13 [26].

$$\mu_{A \cup B} = max\,(\mu_{A(x)}, \mu_{B(y)}) \quad (13)$$

where $\mu_A \cup_B$ represents the fuzzy solution membership value, then $\mu_{A(x)}$ and $\mu_{B(y)}$ are fuzzy membership values.

3 Results and Discussion

3.1 Measurement of critical tasks

The critical path was the sequence of critical tasks that had to be closely monitored because there was no slack time. Therefore, any delay in these critical tasks could have impacted the project's total duration, resulting in delays that did not meet work agreements [20]. One of the benefits of using CPM in scheduling was that it helped in planning the execution strategy by focusing on critical tasks. According to Table 3, there were 24 critical tasks. Tasks on the critical path had to be closely monitored, as they had no slack or zero slack time. Any delay in these tasks, even for just one day, could affect the project's total duration and cause delays that still need to meet work agreements. It was another benefit of using CPM in scheduling, as it helped to plan the execution strategy by focusing on critical tasks.

Table 3. List of critical tasks

Activity Code	Name of Activity	ES	EF	LS	LF	TF
SP1	Secrap	0	1	0	1	0
SP2	Sandblasting	1	2	1	2	0
SP3	Wash water using unsalted (water jet)	2	3	2	3	0
SP4	Painting 2x anti-corrosion	3	5	3	5	0
SP5	Painting 1x anti fouling	5	6	5	6	0
F1	Replating on the bottom plate	0	6	0	6	0
F2	Replating on the right hull	0	6	0	6	0
F4	Replating porous and perforated left hull plate	6	22	6	22	0
F7	Replating the outer skin plate of the lower and side bow ramp door	6	22	6	22	0
F14	Replating plate on the car deck	22	30	22	30	0
F18	Replating the passenger deck	22	30	22	30	0
F22	Replating the plate at the bottom of the water line	22	30	22	30	0
O7	Install anode for the hull, sea chest, dan rudder blade, dan bracket	22	28	22	28	0
O8	Install materials and tire fenders	28	30	22	30	0
TC3	Cleaning fuel oil tank settling for auxiliary engine and main engine No. 1	22	26	22	26	0
TC4	Cleaning air reservoir No. 1	26	28	26	28	0
TC5	Cleaning auxiliary air reservoir No. 1	28	30	28	30	0
TC7	Drain the water, free gas, and cleaning of fore peak tank	22	26	22	26	0
TC8	Drain the water, free gas, and clean of fresh water tank	26	30	26	30	0
TC9	Drain the water, free gas, and clean of water ballast tank	22	30	22	30	0
M1	Coupling disassembly	22	26	22	26	0
M2	Replace the right Gordon bearing	26	28	26	28	0
M3	Check shaft alignment	28	29	28	29	0
M4	Measure steering shaft clearance	29	30	29	30	0

3.2 Normal productivity on critical path tasks

The analysis of normal productivity on the critical path used the calculation of the daily productivity of critical path tasks. Table 4 presents the data for calculating the normal daily productivity of critical tasks on three ship units. Table 3 shows tasks related to the sandblasting and painting workshop (SP) that started from activities with codes SP1, SP2, SP3, SP4, and SP5 and had the same normal daily productivity value of 1320 m^2/day. On the other hand, the fabrication workshop task (F) with job code (F7) had a higher normal daily productivity level than other tasks in the same workshop. Similarly, the outfitting task with job code (O7) had a high level of productivity in the outfitting workshop (O). Finally, the tasks with codes (TC7) and (M2) had a high level of productivity, which was appropriate for their respective workshops.

Table 4. Calculation of daily normal productivity

Activity Code	Duration (day)	Manpower	Volume	Normal Daily Productivity (volume/day)
SP1	1	7	1320	1320
SP2	1	6	1320	1320
SP3	1	4	1320	1320
SP4	2	5	2640	1320
SP5	1	4	1320	1320
F1	6	2	700	116.66
F2	6	2	720	120
F4	16	7	8000	500
F7	16	9	8500	531.25
F14	8	3	825	103.12
F18	8	4	740	92.5
F22	8	3	875	109.37
O7	6	2	85	14.16
O8	2	2	18	9
TC3	4	1	86.3	21.57
TC4	2	1	20	10
TC5	2	1	30	15
TC7	4	1	170.8	42.7
TC8	4	1	104.5	26.12
TC9	8	3	466.4	58.3
M1	4	4	2	0.5
M2	2	2	6	3
M3	1	2	1	1
M4	1	2	1	1

3.3 Shop level productivity

This study’s calculation of shop-level planning productivity analyzed six levels of shops. Table 5 presents data on the six shop types: fabrication, sandblasting and painting, outfitting, tank cleaning, and machining shops. The data on productivity calculation presented in Table 4 showed the volume that each shop had to complete daily. Therefore, the shop-level planning productivity calculation results became the target for each shop to ensure that the project ran according to plan.

Table 5. Shop level productivity

Shop Code	Name of Shop	Productivity
SP	Sandblasting and Painting	309.97 m^2/mandays
P	Piping	4.12 unit/mandays
F	Fabrication	407.16 kg/mandays
O	Outfitting	14.8 unit/mandays
TC	Tank Cleaning	114.36 m^3/mandays
M	Machinery	2.7 unit/mandays

3.4 Alternative acceleration using additional working hours

Based on the calculated results of alternative acceleration by adding working hours to critical activities presented in Table 6, where *a* represents normal productivity (kg/day), *b* represents normal productivity per hour (kg/hour), *c* represents the productivity reduction coefficient, *d* represents the addition of working hours, and *e* represents crashing productivity by adding working hours (kg/day). The data presented in Table 6 shows that productivity increased with the addition of 4 hours of working time.

Table 6. Alternative calculation results of acceleration of additional working hours

Activity Code	a	b	c	d	e
SP1	1320	165	0.7	4	1782
SP2	1320	165	0.7	4	1782
SP3	1320	165	0.7	4	1782
SP4	2640	165	0.7	4	3564
SP5	1320	165	0.7	4	1782
F1	116.66	14.58	0.7	4	157.5
F2	120	15	0.7	4	162
F4	500	62.5	0.7	4	675
F7	531.25	66.40	0.7	4	717.18
F14	103.12	12.89	0.7	4	139.21
F18	92.5	11.56	0.7	4	124.87
F22	109.37	13.67	0.7	4	147.65
O7	14.16	1.77	0.7	4	19.12
O8	9	1.125	0.7	4	12.15
TC3	21.57	2.69	0.7	4	29.12
TC4	10	1.25	0.7	4	13.5
TC5	15	1.87	0.7	4	20.25
TC7	42.7	5.33	0.7	4	57.64
TC8	26.12	3.26	0.7	4	35.26
TC9	58.3	7.28	0.7	4	78.7
M1	0.5	0.06	0.7	4	0.67
M2	3	0.37	0.7	4	4.05
M3	1	0.12	0.7	4	1.35
M4	1	0.12	0.7	4	1.35

3.5 Alternative acceleration using additional manpower

Based on the results of the alternative calculation of accelerating the addition of labour presented in Table 7, with information *a* is normal daily productivity (kg/hour), *b* is crashing productivity by adding work hours (kg/hour), *c* is the increase in normal daily productivity by adding work hours, *d* is initial labour (person), *e* is additional labour (person), and *f* is crashing productivity by adding labour (kg/day), the highest increase in productivity was in the job with code (F7). It was due to the job's high volume and duration in the project execution process. The data in Table 7 also showed that the addition of labour significantly impacted productivity, with the highest increase observed when adding one person to the job.

Table 7. Alternative calculation results of acceleration of manpower addition

Activity Code	a	b	c	d	e	f
SP1	1320	1782	0.35	7	3	1885.71
SP2	1320	1782	0.35	6	2	1760
SP3	1320	1782	0.35	4	2	2640
SP4	1320	1782	0.35	5	2	1848
SP5	1320	1782	0.35	4	2	2640
F1	116.66	157.5	0.35	2	1	175
F2	120	162	0.35	2	1	180
F4	500	675	0.35	7	3	714.28
F7	531.25	717.18	0.35	9	4	767.36
F14	103.12	139.21	0.35	3	1	137.5
F18	92.5	124.87	0.35	4	2	138.75
F22	109.37	147.65	0.35	3	1	145.83
O7	14.16	19,.12	0.35	2	1	21.25
O8	9	12.15	0.35	2	1	13.5
TC3	21.55	29.12	0.35	1	1	43.15
TC4	10	13.5	0.35	1	1	20
TC5	15	20.25	0.35	1	1	30
TC7	42.7	57.64	0.35	1	1	85.4
TC8	26.12	35.26	0.35	1	1	52.25
TC9	58.3	78.7	0.35	3	1	77.73
M1	0.5	0.67	0.35	4	2	0.75
M2	3	4.05	0.35	2	1	4.5
M3	1	1.35	0.35	2	1	1.5
M4	1	1.35	0.35	2	1	1.5

3.6 Crash duration measurement

The analysis of duration acceleration on the repair project for the third ship's work activities was conducted using two alternatives: adding workers or working hours to the critical path activities. Based on Figures 2 and 3, the results obtained from this study indicate that the normal duration of critical path activities before acceleration was 30 days. According to Figure 2, after adding working hours, the duration of critical path activities was shortened to 23 days, with a duration acceleration of 23%. Meanwhile, based on Figure 3, after adding workers, critical path activities were shortened to 22 days, with a duration acceleration of 26%. Based on the results of both alternatives, the effective crash duration was achieved by adding workers.

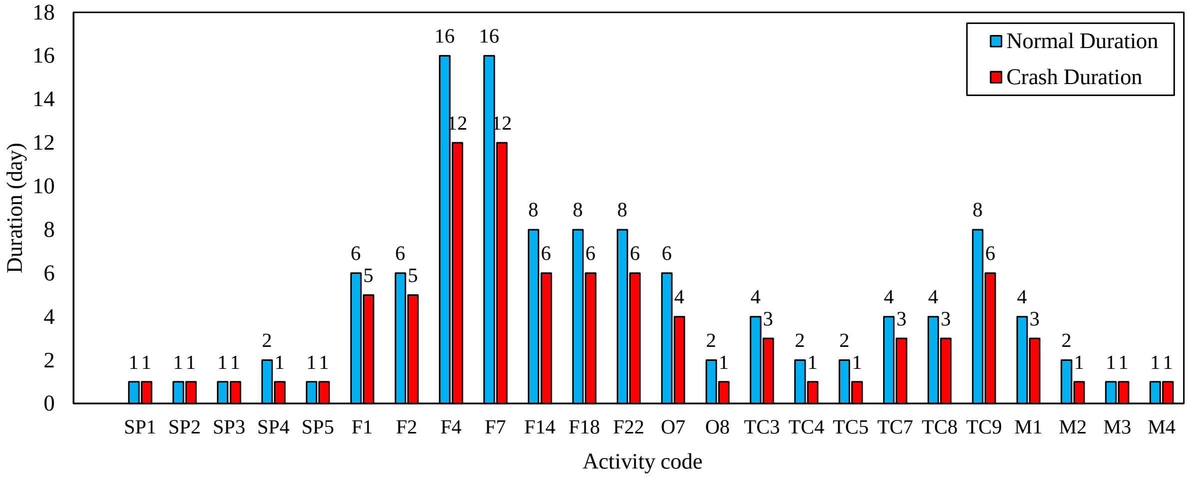

Figure 2. Comparison between normal duration calculation and crash duration calculation results for the alternative of adding working hours

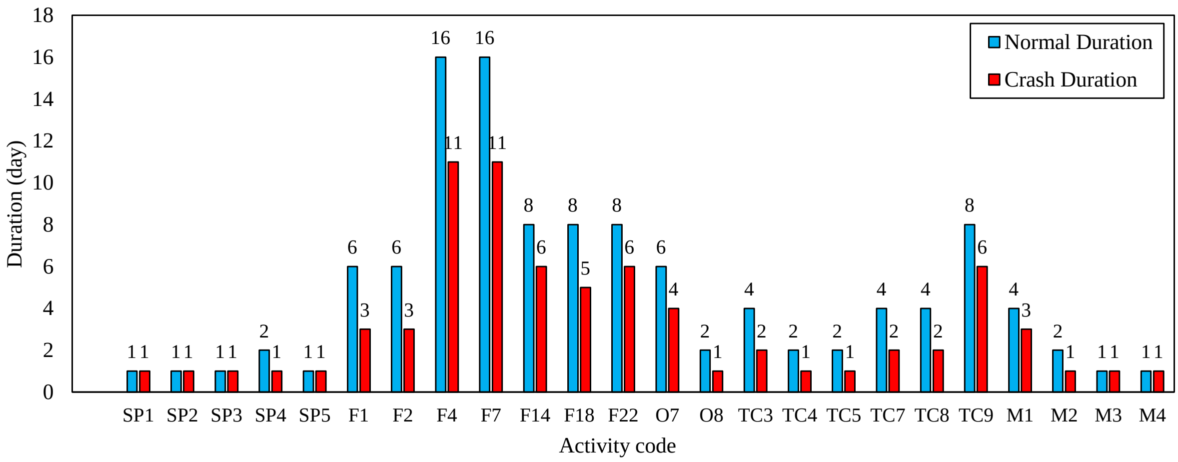

Figure 3. Comparison between normal duration calculation and crash duration calculation for the alternative of adding manpower

3.7 Result of fuzzy logic analysis

Based on the analysis result of the risk level of delays in the repair project of three ships, as shown in Table 8, it was found that activities with high-risk levels of delays were activities with codes SP1, SP2, SP3, SP4, M2, and M2. On the other hand, activities with low-risk delays were with codes F18, F14, F22, F1, and F2. Activities with high-risk levels of delays had been given special attention during the implementation process as they posed a high risk of causing delays, which could impact the overall progress and duration of the project.

Table 8. Result of risk level of delay using fuzzy logic analysis

Activity Code	Name of Activity	Risk Level of Delay
F18	Replating the passenger deck	Low
F14	Replating plate on the car deck	Low
F22	Replating the plate at the bottom of the water line	Low

Table 8. *Cont.*

Activity Code	Name of Activity	Risk Level of Delay
F1	Replating on the bottom plate	Low
F2	Replating on the right hull	Low
TC4	Cleaning air reservoir No. 1	Moderate
TC5	Cleaning auxiliary air reservoir No. 1	Moderate
TC3	Cleaning fuel oil tank settling for auxiliary engine and main engine No. 1	Moderate
TC8	Draining the water, free gas, and cleaning fresh water tank	Moderate
F4	Replating porous and perforated left hull plate	Moderate
F7	Replating the outer skin plate of the lower and side bow ramp door	Moderate
M1	Coupling disassembly	Moderate
TC7	Draining the water, free gas, and cleaning fore peak tank	Moderate
O8	Installing materials and tire fenders	Moderate
TC9	Draining the water, free gas, and cleaning water ballast tank	Moderate
O7	Installing anode for the hull, sea chest, rudder blade, and bracket	Moderate
M3	Checking shaft alignment	Moderate
M4	Measuring steering shaft clearance	Moderate
SP1	Scraping	High
SP2	Sandblasting	High
SP3	Washing water using unsalted (water jet)	High
SP4	Painting 2x anti-corrosion	High
M2	Replacing the right Gordon bearing	High
SP5	Painting 1x anti fouling	High

4 Conclusions

The project management strategy for repairing MT. Triaksa 17, KM. Dharma Ferry 2, and KMP. Dharma Rucitra 1 is analyzed using fuzzy logic based on CPM. The analysis shows two alternatives to reduce the duration of critical path activities. Firstly, increasing working hours can reduce the duration of critical activities from 30 days to 23 days, which results in a 23% reduction in duration. Secondly, increasing the workforce can reduce the duration of critical activities to 22 days, which is a 26% reduction compared to the normal duration of 30 days. Additionally, the productivity analysis of each workshop reveals that the sandblasting and painting workshop has a productivity of 309.97 m^2/person-days, the piping workshop has a productivity of 4.12 unit/person-days, the fabrication workshop has a productivity of 407.16 kg/person-days, the outfitting workshop has a productivity of 14.8 unit/person-days, the tank cleaning workshop has a productivity of 114.36 m^3/person-days, and the machining workshop has a productivity of 2.7 unit/person-days.

Finally, the fuzzy logic analysis result indicates that the scraping, sandblasting, fresh water washing (water jet), double Anti Corrosion (AC) painting, Gordon bearing replacement on the right, and single Anti Fouling (AF) painting activities are highly likely to be delayed. These activities should be carefully executed as they may have an impact on the overall project duration. The study's findings can help shipyard management in managing the main ship repair schedule and providing a solution plan for identifying essential activities that cause delays in the ship repair project. Future studies in ship repair project acceleration can use network-based PERT and CPM techniques to assist managers in planning and controlling large and small projects, including ship construction projects.

5 Acknowledgements

The authors would like to express their gratitude to the Laboratory of Ship Material and Strength at Diponegoro University, Indonesia, for providing research facilities and assistance.

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