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Modeling a traditional fishing boat building in East Java, Indonesia

Yugowati Praharsi[a,*], Mohammad Abu Jami'in[a], Gaguk Suhardjito[a], Hui-Ming Wee[b]

[a] Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Sukolilo, Surabaya, 60111, Indonesia
[b] Department of Industrial and System Engineering, Chung Yuan Christian University, Chung Pei Road No. 200, Chungli City, 32023, Taiwan

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ABSTRACT

Indonesia being an archipelago country have a long fishing industry history. Even in the modern age, there are still a lot of traditional boats that are being utilized, while researches onto modeling them are limited. In this paper, we try to model the tasks for building traditional boat. The stages for building a traditional fishing boat are separated into the following: cutting wood, hull construction, frame installation, hatches installation, the wheelhouse building installation, engines installation, painting, and sea trial. While the resources that are being used are the man hours, raw materials required, the material cost, and the labor cost. With the manhours and material requirement are in direct correlation of their ship tonnage. Modeling for the ships are done in a multivariate linear regression and simple linear regression based on the material requirement and the manhours needed. Furthermore, improvements on the construction of the ship itself were proposed with the model validation error of 5.72% and 5.78% for multivariate and linear regression respectively, providing proof that the validation error is not over fitting with the model error being 8.9% and 6.06% respectively.

1. Introduction

Shipbuilding is considered a tradition in Indonesia, where handmade wooden boats are built through techniques passed down by their ancestors (Jokosisworo and Santosa, 2015; Trimulyono et al., 2015). The traditional shipbuilding technique are also passed down without any standardized calculations and are being built in contrary to modern shipbuilding logic, where the hull would be made prior to the ships frame. Stipulating the process of architectural heritage of shipbuilding experiences rather than knowledge.

In this study, insights from several prior studies would be used to provide the underlying theories. Son and Kim (2014) provided the business process management based on job assignment that could be used as an estimate to the man hours needed. Montwill et al., (2018), Sharma and Gandhi (2017), and Liu et al. (2018) provided insights into the importance of key phases in shipbuilding, the effects of lean principles in shipbuilding, and design of the bilge keel in Indonesia's East Java boats which contributes to their safety performance.

Using the insights provided by prior studies, the model being proposed by this research would include the man hours, materials required, their cost, and the total labor cost needed. Subsequently, the costs involve could be determined by the number of required materials and the total man hours needed for each types of ship tonnage, otherwise known as Gross Tonnage (GT). Furthermore, the research would also be conducted in two parts, research and modeling, with the conclusion, limitations, and future directions of the research provided at the end. Further elaboration on the research would also be discussed based on the result of sample profiles, ship characters and their production process, materials and man hours.

2. Research methodology

2.1. Research design

Based on Fig. 1, first the research would start by conducting a survey and observation on traditional shipyard, providing a sequential production process that is required in building a ship. Secondly, the characteristic profile of each vessel would be collected, based on the eight product quality dimension. The data collected would include the size of the vessels and hatches. Furthermore, if the team leader/project manager do not know of the size, direct measurement would be taken, providing a data on their GT and hatches size. Material cost, labor hours and cost would also be calculated at this step. Third, the materials required would be calculated using a linear regression analysis based on the tonnage of the vessel. The outcome provided would be the building time of each vessel and the model for multivariate linear regression of

* Corresponding author.
E-mail addresses: yugowati@ppns.ac.id (Y. Praharsi), jammy@ppns.ac.id (M.A. Jami'in), gaguksh@ppns.ac.id (G. Suhardjito), weehm@cycu.edu.tw (H.-M. Wee).

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the materials required to build the vessel, based on their GT. Finally, to ensure practicality and data validation for management use, an error forecast would be done on the resulting data gathered through all steps of observations and analysis.

2.2. Research sample

The purposive sampling was applied to collect the data. A total of fourteen vessels from eight different traditional shipyards in Lamongan were selected as samples. Fourteen samples were taken because there are merely few traditional shipyards which manufacture the new vessel. Most of the traditional shipyards are vessel repair. In addition, the data has been representatives. The minimum vessel is 16 GT and the maximum one is 64 GT. All the vessels have *ijon-ijon* type which the hull construction shape is U and the vessels do not have a taper pole. The *ijon-ijon* type is the uniqueness of hull construction in Lamongan regency and East Java province. In this study, we use seven data of traditional fishing boats as a regression model. Subsequently, we validate the model with other data of 7 traditional fishing boats with the same hull construction and fish catching tool. The description of each vessel is presented in Fig. 2.

The LOA, the breadth, and the height for each boat are then calculated by using the equation (Admiralty and Maritime Law Guide, 1969):

$$GT = k_1 \times V \tag{2.1}$$

where:

$k_1 = 0.2 + 0.02 \times \mathrm{Log}(V)$
$V = LOA \times Bm \times Hm \times 0.5$
LOA: Length over all
Bm: Breadth molded
Hm: Height molded

The calculation of GT size is summarized in the Table 1.

2.3. Data collection

Data collection starts with an interview on the project team leader for each vessel type. The question are semi structured to record the shipbuilding process. Other aspects such as worker skill, the numbers of workers, daily wage, working hours, and material required are also gathered in this process. The characteristic profile for each vessel are collected based on their product quality dimension, i.e. durability, performance, reliability, serviceability, features, aesthetics, perceived quality and conformance.

Furthermore, to properly measure the quality criteria, the measurements of each factor will be explained in greater detail, starting from the durability, where the durability of the vessel is based on the length of time the vessel are being used in comparison to their size, or gross tonnage. The performance index is represented by the number of engines, the gearbox ratio, engine horsepower, the engine RPM (Rotations per Minute), engine brand and type, engine position (inboard/ outboard), propeller diameter, boat speed, fuel capacity and the number of generator and accumulator. The reliability is stated by the travel distance, boatload, hatches capacity and the holding capacity of ice blocks. The serviceability factor is described by the suppliers place of engine, propeller, wood type and number of crew needed to operate the vessel. The features are determined by the availability of different fishing tools, capacity of the net, and additional equipment such as lamp, multimedia, and GPS. The aesthetics of the vessel is described as the shape of hull construction, while the perceived quality is reflected by ship owner's quality control. Finally, the conformance is the product assurance to the defined specification.

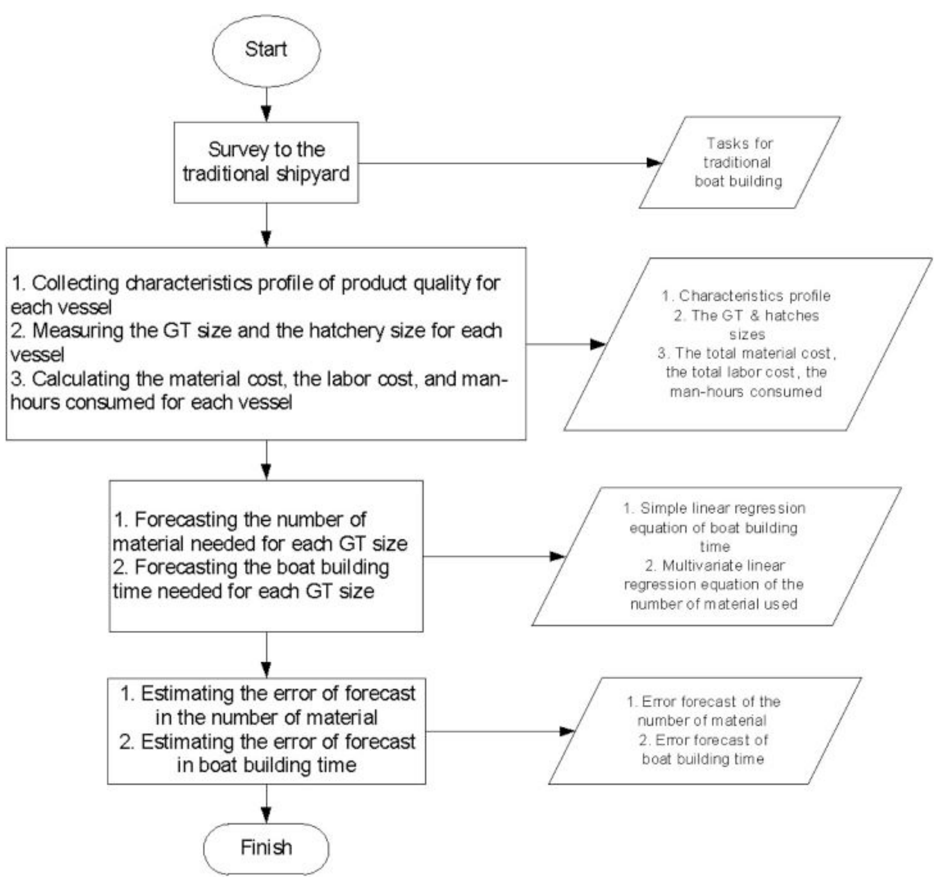

Fig. 1. The research stages.

Fig. 2a. Vessel in 53 GT

Fig. 2b. Vessel in 31 GT

Fig. 2c. Vessel in 22 GT

Fig. 2d. Vessel in 16 GT

2.4. Characteristics profile

The vessels being observed in this research are narrowed down to four different sizes with their characteristics displayed in Table 2. In observation, it is observed that each of the four types have three engines each, two working to drive the boat, while one is a reserve should any of

Table 1
The calculation of GT size.

No	Size (Loa × Bm × Hm)	V	K1	Size (GT)	Type
1	16 m × 8 m x 4 m	256	0.248165	64	Ijon-ijon
2	18 m × 7.6 m x 3.7 m	253.08	0.248065	63	Ijon-Ijon
3	15 m × 8 m x 4 m	240	0.247604	59	Ijon-Ijon
4	16 m × 6.8 m x 4 m	217.6	0.246753	54	Ijon-Ijon
5	16 m × 6.7 m × 4 m	214.4	0.246624	53	Ijon-Ijon
6	14 m × 6.5 m x 4.25 m	193.375	0.245728	48	Ijon-Ijon
7	17 m × 7 m x 3 m	178.5	0.245033	44	Ijon-Ijon
8	15 m × 7 m x 3 m	157.5	0.243946	38	Ijon-Ijon
9	16 m × 6 m × 2.7 m	129.6	0.242252	31	Ijon-Ijon
10	14 m × 5 m x 3.5 m	122.5	0.241763	30	Ijon-Ijon
11	12 m × 6 m x 3.5 m	126	0.242007	30	Ijon-Ijon
12	15 m × 5.5 m x 3 m	123.75	0.241851	30	Ijon-Ijon
13	13 m × 5 m × 2.8 m	91	0.239181	22	Ijon-Ijon
14	12 m × 4.5 m × 2.5 m	67.5	0.236586	16	Ijon-Ijon

the other engine happen to fail. The engine RPM are at 2400, with Mitsubishi and Yanmar being the manufacturers behind the engines, with propeller diameters of 20/30, 32/20, or 38/36 and speed under full load of 5 miles/hour, 6 miles/hour, or 7 miles/hour. Their boatload, number of ice blocks, number of hatches and their size varies depending on gross tonnage, with maneuvering characteristic varied between 16 and 28 m in diameter and fuel capacity is linearly correlated to the GT. On average, the crew needed to operate the vessels is 12, but this is dependent on the types of tools they use to fish, i.e. trawl. This would subsequently affect the size of the wheelhouse.

2.5. Correlation

Correlation coefficient (r) is a quantitative measure to indicate the relationship between two variables. The relations could start with totally unrelated, −1, weakly related or unrelated, with coefficient values near 0 and highly related with values nearing +1 or at +1, representing both positive and negative relationship between variables.

The general equation of correlation coefficient is (Lind et al., 2013):

$$r=\frac{n(\sum x_iy_i)-(\sum x_i)(\sum y_i)}{\sqrt{\left\{n(\sum x_i^2)-(\sum x_i)^2\right\}\left\{n(\sum y_i^2)-(\sum y_i)^2\right\}}} \tag{2.2}$$

Where:

r: coefficient correlation
x_i: independent variable
y_i: dependent variable

We used correlation to measure the relationship between the man hours and the GT sizes. Besides, we also measure the relationship between the GT sizes and the number of material used.

2.6. Simple linear regression

Regression equation represents the linear relationship between two variables. Simple linear regression involves one independent variable. The general form of simple linear regression is as follows (Kutner et al., 2008):

$$\widehat{Y}=a+bx \tag{2.3}$$

where:

$\widehat{Y}$: The estimation of Y value for each chosen x value
a: the intercept of Y
b: the gradient
x: independent variable

In this study, simple linear regression is used to model the

Table 2
The characteristics profile of each vessel.

Indicator	The Type of Ijon - Ijon (53 GT)	The Type of Ijon - Ijon (31 GT)	The Type of Ijon - Ijon (22 GT)	The Type of Ijon - Ijon (16 GT)
Size	16 × 6,7 × 4	16 × 6 x 2,7	13 × 5 x 2,8	12 × 4,5 × 2,5
GT Size	53 GT	31 GT	22 GT	16 GT
Fish Capacity	26.4 ton	18 ton	7.2 ton	5 ton
The Number of Engine	3	3	3	3
Gear Box Ratio	3 : 1	3 : 1	3 : 1	3 : 1
Maximum Continuous Rating (MCR)	Center: 160 PS = 118 kW Side: 2 x @125 PS (92 kW)	Center: 160 PS = 118 kW Side: 2 x @125 PS (92 kW)	Center: 125 PS (92 kW) Side: 2 x @30 PS (22 kW)	Center: 125 HP (92 kW) Side: 2 x @30 HP (22 kW)
Engine Speed (rpm)	2400 rpm	2400 rpm	2400 rpm	2400 rpm
Brand and Type of Engine	Main Engine: Mitsubishi Fuso MB 70 Side: Mitsubishi MB 40	Main Engine: Mitsubishi Fuso D16 Side: Mitsubishi PS 125	Main Engine: Mitsubishi 4D PS 32 Side: Yanmar 30 PK	Main Engine: Mitsubishi PS 125 Side: Yanmar 30 PK
Inboard or Outboard Engine	Inboard	Inboard	Inboard	Inboard
Propeller (radius/width at 70% radius)	Center: 38/36 Side: 32/24	Center: 32/20 Side: 32/20	Center: 20/30 Side: 32/34	Center: 20/30
Speed (Full and Empty) (knots)	Empty: 7 knots Full: 6 knots	Empty: 9 knots Full: 7 knots	Empty: 8 knots Full: 7 knots	Empty: 5 knots Full: 5 knots
Maneuvering radius	16 Meter	28 Meter	20 Meter	20 Meter
Fuel Capacity	22 Drum @200 L/Drum	20 Drum @200 L/Drum	10 Drum @200 L/Drum	5 Drum @200 L/Drum
Generator	Electricity Inverter	Inverter and Solar Cell	Electricity inverter	Dump Inverter
Accumulator (Battery)	4 Accumulator @150 AH	3 Accumulator @ 120 AH	4 Accumulator 2 x @120 AH, 2 x @100 AH	2 accumulator 100 AH and accumulator 150 AH
The Capacity of Ice Block	1584 Ice Blocks (31680 kg)	1125 Ice Blocks (22500 kg)	400 Ice Blocks (8000 kg)	120 Ice Bloks (2400 kg)
Number of Crew	12-18 Persons	12 Persons	10-12 Persons	12 Persons
Sailing radius	320 Miles	200 Miles	200 Miles	120 Miles
Type of fishing method	Trawl	Trawl	Trawl	Trawl
Fishing Gear	Mitsubishi 30 HP (22.38 kW)	Mitsubishi 30 HP (22.38 kW)	Yanmar 30 HP (22.38 kW)	Yanmar 30 HP (22.38 kW)
Hatch	Center: 9 Hatch, with size @ (105 × 95 × 300 cm) Side Long: 6 Hatch, with size @ (95 × 60 × 260 cm)	Center: 9 Hatch, with size @ (120 × 90 × 270 cm) Side: 6 Hatch, with size @ (120 × 120 × 220 cm)	Center: 4 Hatch, with size @ (110 × 75 × 240 cm) Side: 4 Hatch, with size @ (80 × 60 × 185 cm)	Center: 4 Hatch, with size @ (120 × 80 × 150 cm)
Wheelhouse Size	3,2 × 2,2 × 2,1 Meter	4 × 2 x 2,2 Meter	2,5 × 1,7 × 1,8 Meter	3 × 1,6 × 2 Meter
Equipment	Lamp, gps, radio, pump	Lamp, gps, radio, pump	Lamp, gps, radio, pump	Lamp, gps, radio, pump

relationship between the GT sizes (Y) and the man hours in shipbuilding (x).

2.7. Multivariate linear regression

The general form of multivariate linear regression is (Kutner et al., 2008):

$$\hat{y} = a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_kx_k \tag{2.4}$$

where:

a: the intercept-y
b_j: the delta-y when x_j increasing one unit with other independent variables are constant
k: the number of independent variables

If there are only two independent variables, the multivariate linear regression equation will be

$$\hat{y} = a + b_1x_1 + b_2x_2 \tag{2.5}$$

In this study, multivariate linear regression is used to model the relationship between the GT sizes (y) and the number of teak wood (x_1) and the number of mahogany wood (x_2).

2.8. Standard deviation of error estimation

The forecasting result of linear regression is measured by using standard error estimation. Estimating standard error is dispersion measurement from the observed value around linear regression for each x value. The equation of standard error estimation is as follows (Lind et al., 2013):

$$s_{y.x} = \sqrt{\frac{\sum (y - \hat{y})^2}{n}} \tag{2.6}$$

$s_{y.x}$: The standard error estimation
$\hat{y}$: Predicted value of dependent variable
y: Actual value of dependent variable

The standard deviation of error estimation is used to measure the error of forecast by simple and multivariate linear regressions. As a result, any data that were not utilized in generating the regression equations would be validated.

3. Results and discussions

3.1. Production process of traditional boat

Based on Fig. 3, the production process starts from wood cutting, requiring four persons, with 7m^3/day of lumber processed with a width of $\geq$4 cm. Next is the hull construction which is done using no specifications, rather using time old knowledge and experience. Following that is the placement of the frame. The unusual process of hull before frame once again, is the indication of tradition rather than specification and production process that have to be passed down through generations of shipbuilders bypassing the need for formal education to some degree.

After the construction of the hull and frame, the next step is the installation of the hatches, with their numbers depended on the size or GT of the vessel. Afterwards, is the installation of the wheelhouse, their size depended on the boat size and the types of tools available for the fishermans. After the shipyard finishes the installation of the wheelhouse, the ship are then given to a third party service for the installation of both the driving and net engines. Afterwards, the final painting and sea trials are conducted by the workers from the shipyard themselves. After finishing the sea trials, the fishing vessel are delivered directly to the customers.

3.2. Man-hours consumed in traditional boat building process

After the interview done with the shipbuilding leader, the man hours necessary for producing a ship is separated into seven activities, they are wood cutting, hull construction, frame construction, hatch installation, main engine installation, net engine installation, and wheelhouse building. On average, the number of workers working at the same time on the project varies between 2 and 7 people and the time taken to finish a section between 2 and 7 days, with the most time spent in the hull, frame, and hatch construction and installation. Furthermore, the man hours needed for the construction are calculated as a multiplication of workers number times the number of day and working hours per day, with the working hours starts at 8 a.m. and finishes at 4 p.m., including a break of 1 h.

This resulted in a standard production rate, a rate of production in which the ships are being deployed in a unit of ship/months, which is the number of hours divided by total working day, 6 days a week with the assigned number of workers, a 53 GT vessel in 7826 h or equal to 7.3 months per ship, a 31 GT vessel in 7040 h or equal to 7.9 months per ship, a 22 GT vessel in 5194 h or equal to 4.9 months per ship and the 16 GT vessel in 3904 h or equal to 3..4 months. It should also be noted that the reason the 31 GT vessel took longer to finished is caused by the lack of manpower assigned to the vessels construction, while the 16 GT have an 8 h per day workshifts, resulting in a faster production time than other vessels. A full description of the observations could be seen on Table 3, with the overall man hours consumed for each vessel are

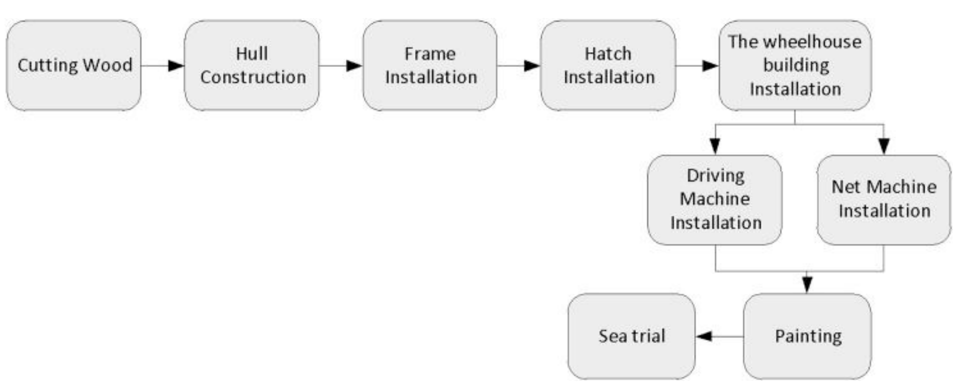

Fig. 3. Tasks in the traditional boat building process.

Table 3
Man-hours consumed of boat "53 GT","31 GT", "22 GT" and "16 GT".

Vessel Tonnage		Number of Worker	Number of Days	Man – Hours Consumed	Time In Calender Month
53 GT	Cutting Woods	4	9	252	175 Days = 7.3 Months
	Hull Construction	7	60	2940	
	Frame Installation	7	18	882	
	Hatch Installation	7	72	3528	
	Driving Engine Installation	2	5	70	
	Net Engine Installation	2	1	14	
	The Wheelhouse Building Installation	2	10	140	
	Total		175	7826 h	
31 GT	Cutting Woods	4	8	256	189 Days = 7.9 Months
	Hull Construction	5	72	2880	
	Frame Installation	5	6	240	
	Hatch Installation	5	84	3360	
	Driving Engine Installation	2	6	96	
	Net Engine Installation	2	1	16	
	The Wheelhouse Building Installation	2	12	192	
	Total		189	7040 h	
22 GT	Cutting Woods	4	5	140	118.5 Days = 4.9 Months
	Hull Construction	7	24	1176	
	Frame Installation	7	65	3185	
	Hatch Installation	7	10	490	
	Driving Engine Installation	2	4.5	63	
	Net Engine Installation	2	3	42	
	The Wheelhouse Building Installation	2	7	98	
	Total		118.5	5194 h	
16 GT	Cutting Woods	4	3.5	112	82.5 Days = 3.4 Months
	Hull Construction	7	24	1344	
	Frame Installation	7	36	2016	
	Hatch Installation	4	8	256	
	Driving Engine Installation	2	2	32	
	Net Engine Installation	2	1	16	
	The Wheelhouse Building Installation	2	8	128	
	Total		82.5	3904 h	

summarized in Table 4.

3.3. The labor cost in the building process of traditional boat

In this section, this study goes into further detail by separating the cost of labour into three categories, beginner, medium, and expert, with the cost components represented for each of the production processes. The range of daily wages also differs between each steps and the level of expertise is not necessarily come from the time spent working with the ship building company. For greater detail on the amount of salary for all types of vessel, it could be seen in Table 5 through 8.

For the dataset on Table 8, it should be noted that the values are taken from another site for ship building, which is the Lamongan site, Brondong sub-district, which is different from the construction site for the 22 to the 53 GT vessels. Furthermore, a summary of total labor cost is also given in Table 9.

3.4. The material cost in the building process of traditional boat

For the material costing, the wood cutting division chosen as the observation sample is the Brondong sub-district, Lamongan. There are 4 classes for each types of wood which is divided by their diameters and length, with name assignments of A1, A2, A3 and A4. There are also two types of wood being used, teak and mahogany, with the sample of the wood with a length of 2 m on average each. Each wood sample have a diameter ranging from smaller than 20 cm to more 40 cm and the price range of 7.000.000 to 13.000.000 IDR and 1.200.000 to 4.000.000 IDR for Teak and Mahogany respectively, with the details explained in Table 10. Furthermore, the usage of different types of woods in each vessel type is due to the cost saving factor, making the use of teak wood for the hull below the water line and mahogany being used as part of the hull above the water line and the wheelhouse. Further detail on wood usage and their quantity is detailed in Table 11.

Table 4
Summary of man-hours consumed.

GT Size	Man-hours consumed (hours)
16 GT	3904
22 GT	5194
31 GT	7040
53 GT	7826

The reason for the difference in wood type is because teak is waterproof and the fibers would not crack easily under bending pressure, with mahogany being a type of wood that is comparatively cheaper than teak.

3.5. Modeling of the GT size and the composition of wood material type

Prior to modeling with linear regression, the correlation between the GT size and the number of material was calculated. The results show that $R^2 = 0.98$ or $r = 0.99$. It can be inferred that there is a high correlation between the GT size and the number of teak and mahogany woods. Subsequently, the linear regression between the GT size and the composition of wood material type can be calculated by using the multivariate linear regression. The data to generate the model is summarized in Table 12. By using the multivariate linear regression in equation 2.5, we obtained the model:

$$\hat{y} = 3.64 + 1.2131\, x_1 + 0.318\, x_2 \quad (3.1)$$

where:

$\hat{y}$: the GT size
x_1: the number of teak wood
x_2: the number of mahogany wood

The output of multivariate linear regression using Minitab version 17.0 is summarized in Table 13.

To validate the multivariate linear regression model, the data as

Table 5
Total labor cost of boat “53 GT”.

Activities	The worker skill and the number of worker			StandardCost of Labour			Number Of Days	Total Cost
	Beginner	Medium	Expert	Beginner	Medium	Expert		
Cutting Woods	1	2	1	Rp 90.000	Rp 100.000	Rp 110.000	9	Rp 3.600.000
Hull Construction	1	5	1	Rp 125.000	Rp 150.000	Rp 200.000	60	Rp 64.500.000
Frame Installation	1	5	1	Rp 125.000	Rp 150.000	Rp 200.000	18	Rp 19.350.000
Hatch Installation	1	5	1	Rp 125.000	Rp 150.000	Rp 200.000	72	Rp 77.400.000
Driving Engine Installation (3 Engines)		1	1	1.800.000/Engine			5	Rp 5.400.000
Net Engine Installation		1	1	Rp 750.000			1	Rp 750.000
The Wheelhouse Building Installation		1	1	Rp 125.000	Rp 150.000	Rp 200.000	10	Rp 3.500.000
Total							175 days	Rp 174.500.000

Table 6
Total labor cost of boat “31 GT”.

Activities	The worker skill and the number of worker			StandardCost of Labour			Number of Days	Total Cost
	Beginner	Medium	Expert	Beginner	Medium	Expert		
Cutting Woods	1	2	1	Rp 90.000	Rp 100.000	Rp 110.000	8	Rp 3.200.000
Hull Construction		4	1		Rp 175.000	Rp 200.000	72	Rp 64.800.000
Frame Installation		4	1		Rp 175.000	Rp 200.000	6	Rp 5.400.000
Hatch Installation		4	1		Rp 175.000	Rp 200.000	84	Rp 75.600.000
Driving Engine Installation (3 Engine)		1	1	Rp. 1.500.000/Engine			6	Rp 4.500.000
Net Engine Installation		1	1	Rp 750.000			1	Rp 750.000
The Wheelhouse Building Installation		1	1		Rp 175.000	Rp 200.000	12	Rp 4.500.000
Total							189 days	Rp 158.750.000

Table 7
Total labor cost of boat “22 GT”.

Activities	The worker skill and the number of worker			StandardCost of Labour			Number of Days	Total Cost
	Beginner	Medium	Expert	Beginner	Medium	Expert		
Cutting Woods	1	2	1	Rp 90.000	Rp 100.000	Rp 110.000	5	Rp 2.000.000
Hull Construction	1	5	1	Rp 125.000	Rp 150.000	Rp 200.000	24	Rp 25.800.000
Frame Installation	1	5	1	Rp 125.000	Rp 150.000	Rp 200.000	65	Rp 69.875.000
Hatch Installation	1	5	1	Rp 125.000	Rp 150.000	Rp 200.000	10	Rp 10.750.000
Driving Engine Installation (3 Engine)		1	1	Rp. 1.000.000			4.5	Rp 3.000.000
Net Engine Installation		1	1	Rp 750.000			3	Rp 750.000
The Wheelhouse Building Installation		1	1	Rp 125.000	Rp 150.000	Rp 200.000	7	Rp 2.450.000
Total							118.5 days	Rp114.625.000

Table 8
Total labor cost of boat “16 GT”.

Activities	The worker skill and the number of worker			StandardCost of Labour			Number Of Days	Total Cost
	Beginner	Medium	Expert	Beginner	Medium	Expert		
Cutting Woods	1	2	1	Rp 90.000	Rp 100.000	Rp 110.000	3.5	Rp 1.400.000
Hull Construction	1	5	1	Rp 125.000	Rp 150.000	Rp 175.000	24	Rp 25.200.000
Frame Installation	1	5	1	Rp 125.000	Rp 150.000	Rp 175.000	36	Rp 37.800.000
Hatch Installation		3	1	Rp 125.000	Rp 150.000	Rp 175.000	8	Rp 5.000.000
Driving Engine Installation (2 Engine)		1	1	Rp. 600.000/Engine			2	Rp 1.200.000
Net Engine Installation		1	1	Rp 600.000			1	Rp 600.000
The Wheelhouse Building Installation		1	1	Rp 125.000	Rp 150.000	Rp 175.000	8	Rp 2.600.000
Total							82.5 days	Rp 73.800.000

Table 9
Summary of total labor cost.

GT Size	The number of workers	The estimation of total labor cost
16 GT	7	Rp. 73.800.000
22 GT	7	Rp. 114.625.000
31 GT	5	Rp. 158.750.000
53 GT	7	Rp. 174.500.000

Table 10
The material price.

Class	Diameter	Teak woods (per m^3)	Mahogany woods (per m^3)
A4	≥40 cm	Rp. 13.000.000	Rp. 4.000.000
A3	30–39 cm	Rp. 12.000.000	Rp. 3.000.000
A2	20–29 cm	Rp. 11.000.000	Rp. 1.800.000
A1	≤20 cm	Rp. 7.000.000	Rp. 1.200.000

Source: Survey to the traditional shipyard (August 2018)

Table 11
The material cost.

Size	Material		Standard Cost		Total Cost
	Teak (m^3)	Mahogany (m^3)	Teak	Mahogany	
53 GT	28	35	Rp 13.000.000	Rp 4.000.000	Rp 504.000.000
31 GT	15	40	Rp 11.000.000	Rp 1.800.000	Rp 237.000.000
22 GT	7	25	Rp 13.000.000	Rp 4.000.000	Rp 191.000.000
16 GT	7	18	Rp 12.000.000	Rp 3.000.000	Rp 108.000.000

Table 12
Data to generate the model of material.

GT size	The number of teak wood (m^3) (x_1)	The number of mahogany wood (m^3) (x_2)
16	7	18
22	7	25
31	15	40
38	18	32
48	25	40
59	35	35
64	43	32

Table 13
Minitab output of multivariate linear regression.

Model Summary					
	S	R-sq	R-sq(adj)	R-sq(pred)	
	2.91824	98.28%	97.43%	92.56%	
Coefficients					
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.64	4.89	0.74	0.498	
teak	1.2131	0.0994	12.20	0.000	1.31
mahogany	0.318	0.171	1.86	0.137	1.31
Regression Equation					
GT = 3.64 + 1.2131 teak +0.318 mahogany					

Table 14
Data to validate the model of material.

GT size	The number of teak wood (m^3) (x_1)	The number of mahogany wood (m^3) (x_2)
30	12	28
30	12	30
30	15	27
44	23	37
54	28	42
53	28	35
63	40	30

described in Table 14 are used. The data consists of 7 vessels with ijon-ijon type. The data were selected by purposive sampling to the traditional shipyards in Lamongan regency.

Moreover, the standard error estimation of the multivariate linear regression ($\hat{y}$) is calculated by using Equation (2.6). The result of error and validation models is shown in Tables 15 and 16.

By dividing the standard deviation ($s_{x.y}$) to the average of gross tonnage, the measurement error is attained. The error estimation in validating the multivariate linear regression is 5.72%. Comparing to the error of model data i.e. 8.90%, the error of validation is less than the model. It can be inferred that the model of the number of material is not over fitting. Moreover, the data also shows that from 14 samples is that the usage of teak wood at least 22%–57% of the total number of material. Meanwhile, the rest of the material is mahogany wood, which is approximately 43%–78%. When the owner has a higher capital, the use of teak wood could be more than 57%.

3.6. Modeling of the GT size and the man hours

In order to get the simple linear regression between GT size and man hours, the data as described in Table 17 are used. The output of simple linear regression by using Minitab 17.0 is described in Table 18.

The results show that $R^2 = 0.95$ or $r = 0.97$. It means that there is a significant correlation between GT size and man hours. Subsequently, the linear regression between the GT size and the man hours was modeled by using simple linear regression equation. Thus, the model was obtained as follows:

$$\hat{y} = 2822 + 110\,x \tag{3.2}$$

where:

$\hat{y}$: the man hours (hour)
x: the GT size

To validate the simple linear regression model, the other seven data as described in Section 3.8 are used and then summarized in Table 19.

Subsequently, the estimation error of the simple linear regression ($\hat{y}$) was measured by dividing the standard error estimation to the average of man hours. The result of error estimation in model and validation is displayed on Tables 20 and 21.

The error estimation in validating the simple linear regression is 5.78%. Comparing to the error of model data i.e. 6.06%, the error of validation is less than the model. It can be inferred that the model of man hours is not over fitting. Moreover, in traditional shipyard, delays could come due to many reasons, especially in rainy season where a delay can last for one to two months. other reasons for delay could also come from delay in wood shipments, failed wood processing, painting process and caulking time. The reason why rainy season hampers work on vessel is due to electrical machinery used on the making of the vessel are being done outdoors, while delay in wood shipment comes from inventory shortages from the suppliers side. There are also red tape, hampering wood orders from the forestry department which in turn increase lead

Table 15
Standard error estimation of the model of material.

GT (y)	x_1	x_2	$\hat{y}$	$(y-\hat{y})^2$
16	7	18	17.8557	3.443622
22	7	25	16.4417	30.8947
31	15	40	34.5565	12.64869
38	18	32	35.6518	5.514043
48	25	40	46.6875	1.722656
59	35	35	53.5885	29.28433
64	43	32	65.9793	3.917628
			$S_{x.y}$	3.534032
			error	0.088986

Table 16
Standard error estimation of the validation of material.

GT (y)	x_1	x_2	$\hat{y}$	$(y-\hat{y})^2$
30	12	28	27.1012	8.403041
30	12	30	27.7372	5.120264
30	15	27	30.4225	0.178506
44	23	37	43.3073	0.479833
54	28	42	48.7368	18.17487
53	28	35	50.9628	9.224584
63	40	30	61.704	1.679616
			$S_{x.y}$	2.485981
			error	0.057243

Table 17
Data to generate the man hour model.

GT size	The man hours
16	3904
22	5194
31	7040
38	7344
48	8064
59	9216
64	9568

Table 18
Minitab output of simple linear regression.

Model Summary					
	S	R-sq	R-sq(adj)	R-sq(pred)	
	515.540	94.76%	93.71%	88.84%	
Coefficients					
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2822	499	5.65	0.002	
GT	110.0	11.6	9.51	0.000	1.00
Regression Equation					
Man hours = 2822 + 110.0 GT					

Table 19
Data to validate the man hour.

GT Size	The man hours
30	6016
30	5952
30	6016
44	7008
53	7826
54	8484
63	9712

Table 20
Standard error estimation of the model of man hour.

x	y (hours)	$\hat{y}$ (hours)	$(y-\hat{y})^2$
16	3904	4582	459684
22	5194	5242	2304
31	7040	6232	652864
38	7344	7002	116964
48	8064	8102	1444
59	9216	9312	9216
64	9568	9862	86436
			435.7116
error			0.0606

Table 21
Standard error estimation of the validation of man hour.

x	y (hours)	$\hat{y}$ (hours)	$(y-\hat{y})^2$
30	6016	6122	11236
30	5952	6122	28900
30	6016	6122	11236
44	7008	7662	427716
53	7826	8652	682276
54	8484	8762	77284
63	9712	9752	1600
			420.9255
error			0.057758

time. The failings in wood processing, which in turn increase delay, is due to the fact that most treatment are being done traditionally using fire and manual labor, while the painting and caulking processes takes time because of the amount of detail and general time needed for trying.

In terms of paint type, there are specific guidelines provided by Indonesian Classification Bureau, which specified the standards of paints to be used in the making of the vessel. Furthermore, it should be noted that equations (3.1) and (3.2) are specifically used for fishing vessel above 15 GT and uses trawl as their fishing tool.

3.7. The optimization of man hours

The function of time consumption ($\widehat{t_c}$) of building traditional boats to the GT size is modeled by Equation (2.7):

$$\widehat{t_c}(c_1,c_2,c_3,GT)=\frac{a_1\,GT}{e^{c_1}}+\frac{a_2\,GT}{e^{c_2}}+\frac{a_3\,GT}{e^{c_3}}+\frac{a_4\,GT}{e^{\frac{(c_1+c_2)}{2}}}+\frac{a_5\,GT}{e^{\frac{(c_1+c_3)}{2}}}+\frac{a_6\,GT}{e^{\frac{(c_2+c_3)}{2}}}+\frac{a_7\,GT}{e^{\frac{(c_1+c_2+c_3)}{3}}} \tag{2.7}$$

where:

c_1 : The number of beginner worker
c_2 : The number of medium worker
c_3: The number of expert worker

Exponential is used in the model because there are data without any beginner worker as in Table 6, from the hull construction stage to the wheelhouse building installation. To avoid the division by zero, we use an exponential number. Each own worker performs theirs capability as described in exponents of c_1, c_2, c_3. Besides, the interaction among beginner, medium, and expert also influences another worker. For example, the beginner gets a guidance from the expert or medium workers in hull construction process. Therefore, the exponent with the combination of c_1 and c_2, c_1 and c_3, c_2 and c_3, and c_1, c_2, c_3 are used in the model.

The optimization of labor cost is multiplication of $\widehat{t_c}$, the labor cost in each skill level, and the number of worker as given in Equation (2.8):

$$\widehat{LC}=\widehat{t_c}B_{c_1}c_1+\widehat{t_c}B_{c_2}c_2+\widehat{t_c}B_{c_3}c_3 \tag{2.8}$$

where:

$\widehat{LC}$: Labor cost
B_{c_1} : the labor cost of beginner per day
B_{c_2} : the labor cost of medium per day
B_{c_3} : the labor cost of expert per day

With c_1, c_2, c_3 is the number of beginner, medium, and expert worker, respectively.

In this study, we set the daily wage of beginner, medium, and expert levels by Rp. 125.000,00; Rp. 150.000,00; and Rp. 200.000,00, respectively.

Finally, the total labor cost (TLC) is the summation of labor cost and the cost of woods cutting as presented in Equation (2.9):

$$\widehat{TLC}=\widehat{LC}+85000\,GT \tag{2.9}$$

The cost of woods cutting —Rp. 85.000,00 per GT—is obtained by average cost of cutting from Tables 5–8 divided by total GT sizes.

The data of model and observation of determining $\widehat{t_c}$ and $\widehat{TLC}$ is presented in Table 22.

Table 22 shows the combination of c_1, c_2, c_3 in determining $\widehat{tc}$ and $\widehat{TLC}$ for several measurements of 53 GT, 31 GT, 22 GT, and 16 GT. The coefficients model of a_1, a_2, …, a_7 as in Eq. (2.7) are 2.26, 7.54, 7.12, −8.15, −7.26, −12.69, 34.81, respectively. Thus, the average error of $\widehat{t_c}$ is 4.46% and $\widehat{TLC}$ is 4.76%. These average errors are in tolerance threshold of less than 5% significance level.

Figs. 4 and 5 shows the time consumption ($\widehat{t_c}$) and the labor cost ($\widehat{TLC}$) between observation and model output with respect to error,

Table 22
Model and observation data of $\widehat{t_c}$ and. $\widehat{TLC}$

Sample (s)	c_1	c_2	c_3	t_c (day)	GT	$\widehat{t_c}$ (day)	TLC (Rp)	$\widehat{TLC}$ (Rp)	Error of $\widehat{t_c}$	Error of $\widehat{TLC}$
1	1	5	1	150	53	168	165.755	185.105	18	19.35
2	2	5	2	86	53	76	124.905	110.905	10	14
3	0	5	2	152	53	155	179.305	182.755	3	3.45
4	3	2	2	135	53	132	149.63	146.405	3	3.225
5	4	2	2	108	53	104	134.105	129.305	4	4.8
6	3	4	2	72	53	62	103.505	89.755	10	13.75
7	3	3	2	138	53	139	173.555	174.78	1	1.225
8	2	3	1	203	53	212	187.205	195.305	9	8.1
9	4	1	1	217	53	223	188.955	194.055	6	5.1
10	4	2	1	169	53	171	173.505	175.505	2	2
11	3	3	2	103	53	97	130.68	123.33	6	7.35
12	5	3	2	70	53	63	107.755	97.43	7	10.33
13	5	5	2	60	53	54	111.005	100.355	6	10.65
14	0	4	1	162	31	156	132.235	127.435	6	4.8
15	2	2	1	152	31	154	116.635	118.135	2	1.5
16	3	1	1	162	31	165	120.085	122.26	3	2.175
17	2	2	1	151	31	154	115.885	118.135	3	2.25
18	2	1	1	197	31	210	120.835	128.635	13	7.8
19	0	2	2	184	31	187	131.435	133.535	3	2.1
20	1	2	1	188	31	196	120.135	125.135	8	5
21	2	2	2	106	31	99	103.335	96.685	7	6.65
22	3	1	2	126	31	125	119.185	118.26	1	0.925
23	4	1	1	131	31	131	113.985	113.985	0	0
24	0	4	2	117	31	114	119.635	116.635	3	3
25	3	2	1	125	31	123	112.01	110.26	2	1.75
26	3	3	1	109	31	105	114.36	110.26	4	4.1
27	4	2	1	103	31	100	105.635	102.635	3	3
28	1	4	1	104	22	86	98.07	81.42	18	16.65
29	2	2	2	77	22	70	75.02	68.37	7	6.65
30	3	1	2	93	22	89	87.895	84.195	4	3.7
31	4	1	1	96	22	93	83.47	80.92	3	2.55
32	0	5	1	91	22	87	88.32	84.52	4	3.8
33	2	2	1	111	22	109	85.12	83.62	2	1.5
34	3	1	1	118	22	117	87.42	86.695	1	0.725
35	5	1	1	78	22	74	77.92	74.02	4	3.9
36	3	2	2	61	22	55	67.445	60.995	6	6.45
37	4	2	1	75	22	71	76.87	72.87	4	4
38	3	3	1	77	22	74	80.795	77.72	3	3.075
39	1	5	1	68	16	51	74.46	56.185	17	18.28
40	2	3	2	44	16	37	49.76	42.06	7	7.7
41	2	2	1	83	16	79	63.61	60.61	4	3
42	3	1	1	89	16	85	65.885	62.985	4	2.9
43	0	3	1	106	16	104	70.26	68.96	2	1.3
44	0	2	2	100	16	97	71.36	69.26	3	2.1
45	2	1	1	110	16	108	67.36	66.16	2	1.2
46	1	2	1	102	16	101	65.11	64.485	1	0.625
Average				117			108.9436		5.2	5.184
Model accuracy of time consumption ($\widehat{t_c}$)										
Mean of abs(error) =							5.195652			
Mean of time consumption (day) =							116.5			
Average error (%) =							4.459787			
Model accuracy of Labour cost ($\widehat{TLC}$)										
Mean of abs(error) =							5.184239			
Mean of labour cost (million) =							108.9436			
Average error (%) =							4.758646			

respectively.

In searching the minimum labor cost, we do the numerical example for traditional fishing boat with the size of 53 GT. We assume that the maximum number of expert worker is 2 persons. The time consumption ($\widehat{t_c}$) for single expert worker ($c_3 = 1$) is presented in Table 23.

Based on the Table 23 and Fig. 6, the highest $\widehat{t_c}$ is obtained at 461 days with one beginner, one medium, and one expert workers. Meanwhile, the lowest $\widehat{t_c}$ is attained at 115 days with six beginner, two medium, and one expert workers. However, the lowest $\widehat{t_c}$ does not guarantee to achieve the lowest total labor cost ($\widehat{TLC}$).

Based on Table 24 and Fig. 7, the lowest total labor cost ($\widehat{TLC}$) is obtained by Rp.148.260.000,00 with six beginner, two medium, and one expert workers. On the other hand, the highest total labor cost is resulted by Rp. 246.860.000,00 with six beginner, six medium, and one expert workers. It can be inferred that the lowest time consumption and the lowest total labor cost for building traditional boats of 53 GT is at 115 days and at the set of six beginner, two medium, and one expert workers, respectively.

Based on Table 25 and Fig. 8, the highest $\widehat{t_c}$ is obtained at 334 days with one beginner, one medium, and two expert workers. Moreover, the lowest $\widehat{t_c}$ is attained at 49 days with six beginner; alternative of four, five, or six medium; and two expert workers. Again, the lowest $\widehat{t_c}$ could not guarantee for providing the lowest total of labor cost.

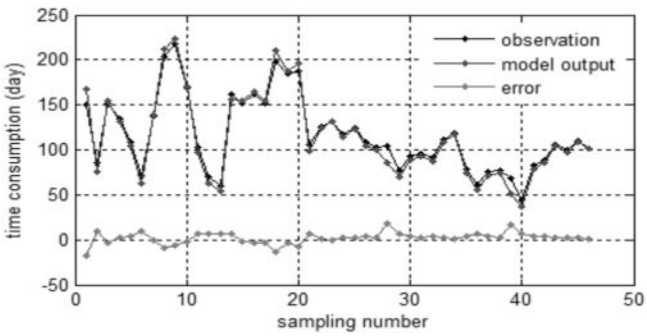

Fig. 4. the time consumption between observation and model output.

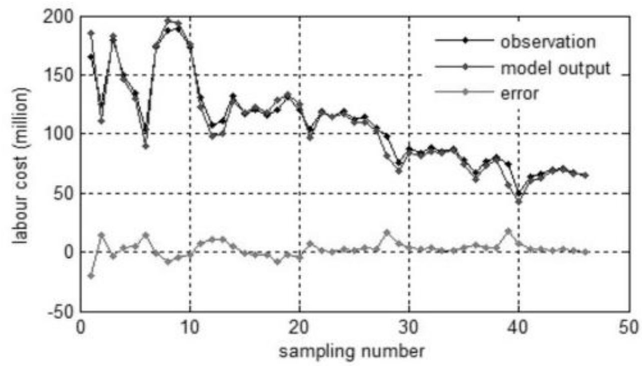

Fig. 5. The labor cost between observation and model output.

Table 23
Time consumption for single expert worker (days).

c_1, c_2	1	2	3	4	5	6
1	**461**	335	260	208	168	137
2	359	263	212	179	154	134
3	282	211	179	160	146	134
4	223	171	153	145	140	134
5	177	140	133	134	134	133
6	142	**115**	117	124	129	131

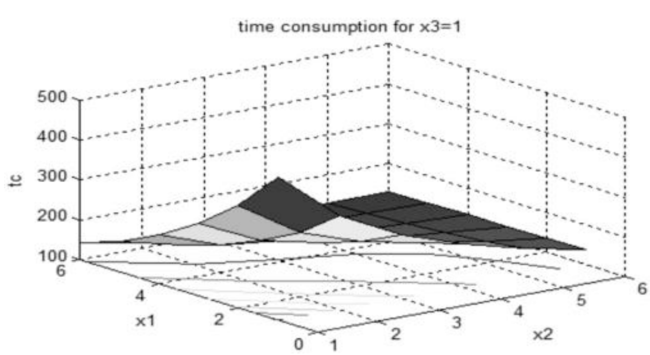

Fig. 6. Time consumption for single expert worker.

Based on Table 26 and Fig. 9, the lowest $\widehat{TLC}$ is achieved at Rp. 86.110.000,00 with six beginner, three medium, and two expert workers. Meanwhile, the highest $\widehat{TLC}$ is resulted at Rp. 229.960.000,00 with one beginner, one medium, and two expert workers. It can be inferred that the lowest $\widehat{t_c}$ for double expert workers did not provide the lowest total labor cost/$\widehat{TLC}$. The set of six beginner, three medium, and two expert workers is the best combination for building traditional boats of 53 GT in 51 days and achieving the lowest labor cost of Rp. 86.110.000,00.

By comparing the total labor cost (TLC), as shown in Table 27, the use of two experts have proven to lower the labor cost, for all combinations of workers, beginner, medium and experts. The minimum total labor cost that is the most optimum being 86,110,000.00 IDR with a combination of six beginners, three medium and two experts.

Table 24
The total labor cost for single expert worker (million IDR).

c_1, c_2	1	2	3	4	5	6
1	223.48	213.88	206.01	196.91	185.11	172.33
2	219.91	201.76	195.31	192.46	189.31	185.41
3	208.96	189.13	187.98	192.51	197.96	202.16
4	194.06	175.51	180.46	193.01	207.51	218.91
5	177.08	162.01	174.08	195.46	215.56	233.93
6	160.71	**148.26**	168.31	196.71	223.81	**246.86**

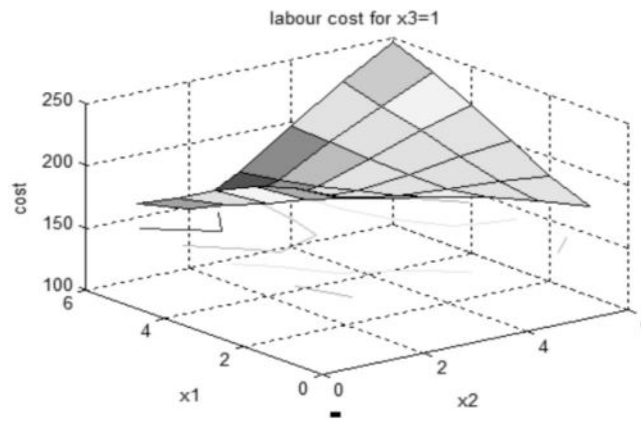

Fig. 7. The total labor cost for single expert worker.

Table 25
Time consumption for double expert workers (days).

c_1, c_2	1	2	3	4	5	6
1	**334**	225	165	127	98	77
2	264	170	123	96	76	62
3	214	132	97	78	66	56
4	175	104	78	66	59	54
5	144	82	63	56	54	51
6	120	65	51	**49**	**49**	**49**

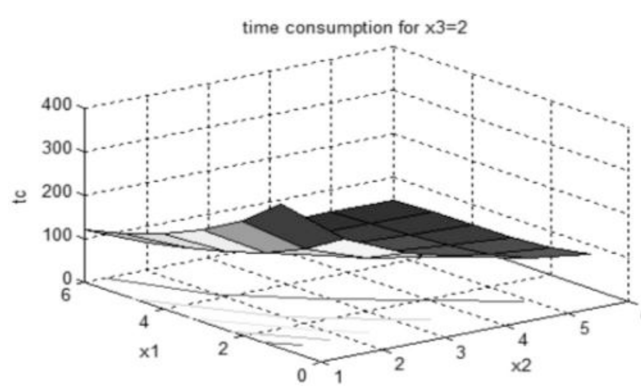

Fig. 8. Time consumption for double expert workers.

Table 26
The total labor cost for double expert workers (million IDR).

c_1, c_2	1	2	3	4	5	6
1	**229.96**	190.13	165.38	147.38	129.46	114.23
2	215.71	166.01	139.81	124.51	110.91	100.61
3	202.46	146.41	123.33	111.76	105.16	98.31
4	188.26	129.31	109.81	103.51	101.86	101.71
5	173.71	113.16	97.43	95.51	100.36	102.68
6	160.51	98.76	**86.11**	90.26	97.61	104.96

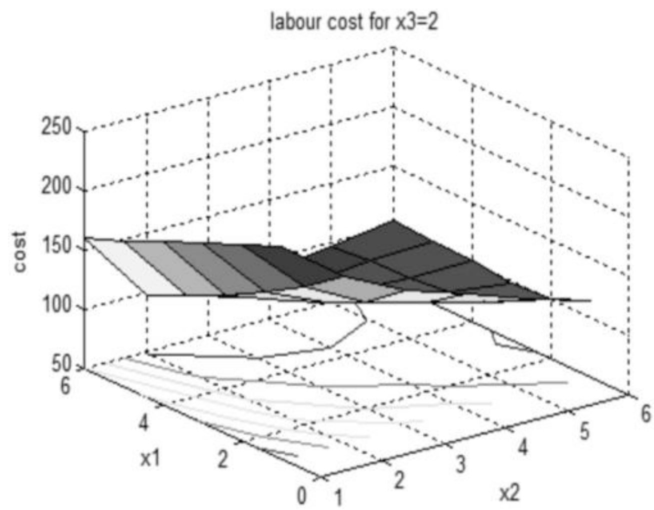

Fig. 9. The total labor cost for double expert workers.

Table 27
The optimal labor cost (in million IDR).

c_1, c_2, c_3	6,1,1	6,2,1	6,3,1	2,4,1	1,5,1	1,6,1
$\widehat{TLC}$	160.71	**148.26**	168.31	192.46	185.11	172.33
c_1, c_2, c_3	6,1,2	6,2,2	6,3,2	6,4,2	6,5,2	3,6,2
$\widehat{TLC}$	160.51	98.76	**86.11**	90.26	97.61	98.31

4. Conclusion and future research

Based on the result of the research, it is shown that each tonnage type of vessels has different characteristics and in turn, they require different amounts of labor and material requirements. The process that is observed in this research are separated into wood cutting or processing, hull construction, frame installation, hatches installation, wheelhouse installation, engines installations, in which they are outsourced to a third party provider, and finally the painting and sea trials. There are four types of vessels being observed, 53 GT, 31 GT, 22 GT and 16 GT, with 7826, 7040, 5194and 3904 total labor hours needed to construct each ship respectively. Furthermore, with the resulting multivariate linear regression for the time and expenses validation error being 5.72%, below the model error of 8.9%, the result is not over fitting.

The characteristics profiles of traditional boats in 53, 31, 22, and 16 GT are presented based on the dimension of product quality. Several tasks in the building process, i.e.: cutting wood, hull construction, frame installation, hatches installation, the wheelhouse building installation, enginery installation, painting, and sea trial has been discussed. The man hours of all tasks for each vessel have been estimated. The results show that the man hours are 7826, 7040, 5194, and 3904 h for 53, 31, 22, and 16 GT, respectively. The number of wood material needed and subsequently forecasted in accordance to the GT size. The results provide the multivariate linear regression with the validation error estimates of 5.72%. The validation error is lower than model error of 8.9%. It means that the multivariate linear regression model is not over fitting. The remarkable data of eight different traditional shipyards is that the owner will use the teak wood at least 22%–57% of the total number of material. Meanwhile, the rest of material is mahogany wood which is approximately 43%–78%. Thus, the material cost is correspondingly increasing to the GT size. Furthermore, the man hours are estimated based on the GT size. The results reveal the simple linear regression with the validation error estimates of 5.78%. The validation error is lower than model error of 6.06%. It means that the simple linear regression model is not over fitting. In addition, the project can be finished in delay for one month to two months due to the rainy seasons, the delay of wood material arrival, failing in wood bending, and the painting and caulking times. Besides, the labor cost is directly proportional to the GT size. This research provides significant contribution to the building of traditional fishing boat that the GT size is larger than 15 GT, the type of fish catching tool is *trawl*, and the type of hull construction is *ijon-ijon*.

The optimization how many beginner, medium, and expert workers are needed to finish all the tasks to minimize the labor cost and time consumption in building traditional fishing boat has been addressed. The modeling of time consumption and total labor cost ($\widehat{TLC}$) give the average error of 4.46% and 4.76%, respectively. Subsequently, we also do the numerical example of 53 GT and we use the assumption of maximum 2 expert workers. The results show that the double expert workers provide the lower labor cost for any combination of the number of beginner and medium workers. Furthermore, the lowest time consumption and labor cost of 53 GT is attained at 51 days and at Rp. 86.110.000,00 with the set of six beginner, three medium, and two expert workers. This study gives managerial insight to the traditional shipyard in minimizing the labor cost and estimating the time to build the traditional boats.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.oceaneng.2019.106234.

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