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The Selection of Propeller and Primary Engine Matching Level of a 30 GT Fishing Vessel with Analytic Hierarchy Process (Case Study KM Inka Mina 759)

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Abstract

Reducing fuel consumption and carbon emissions in the development of ship propulsion systems following the required Energy Efficiency Design Index (EEDI) has become a concern for the fishing industry, as determined by the International Maritime Organization (IMO). This study aims to analyze the level of suitability of the use of a 30 GT fishing boat propeller and engine propulsion for optimum propulsion efficiency. The analysis focuses on developing a propulsion system selection model, studying the characteristics of the ship resistance, loading propellers, and selecting the appropriate engine. The engine-propeller matching procedure is used to predict the optimum speed power. Furthermore, the Analytic Hierarchy Process (AHP) method determines the suitability level for the propeller and diesel engine. The results showed the highest level of suitability for the Yanmar 6CH-HHTEC engine versus the A.30X34 type propeller (SP_{23}), with 31.7%. Then the Deutz BF06M1013MC engine versus the B.30X28 propeller type (SP_{32}), the Yuchai YC6A170C engine versus the B30X28 propeller type (SP_{12}), and the Volvo D7ATA engine versus the B30X28 propeller type (SP_{42}) with percentages of 26.6%, 26.4%, and 15.3%, respectively. The high level of SP_{23} selection is due to the propulsion system having minimal noise levels, dimensions, and engine weight but having maximum power.

1. Introduction

The ship propulsion system has an essential role in supporting the operational capabilities of ships, especially fishing vessels that operate with changes in load and speed. The propulsion system consists of three components: i) main engine, ii) transmission gear and iii) propellers. The main engine is the power generator to propel the ship through the propeller. It should be suitable for optimal propulsion efficiency. Several researchers have developed this propulsion system optimization study through propeller-engine matching procedures on the effect of hull shape, propeller parameters, and primary engine type. Muhammad et al. [1], in their research, stated that the shape of the chined hull has a total resistance of 3.27% greater than the round hull shape. This has an impact on the loading of the propeller and the increasing need for ship power. Besides being influenced by the hull form, the increase in ship resistance which affects the loading of the propeller, can also be influenced by changes in the water flow (narrow and shallow water). So the propeller parameters need to be optimized [2]. Ogar et al. [3], in their research, state that the change in propeller loading due to this operating load will be more effective if the ship uses a CPP-type propeller compared to using FPP through the pitch setting used. In addition to reducing fuel use, this propeller parameter setting can also be verified for the propeller strength, cavitation, and noise level [4].

The 30 GT fishing vessels produced by fishing communities along Indonesian waters generally use a diesel engine as the driving force for the ship, the determination of which is based solely on the experience of the artisans and the availability of machinery components on the market. This factor makes it impossible to achieve the vessel speed [5-7]. The low propulsion efficiency of fishing vessels, in addition to impacting the high use of fuel oil consumption [8], also affects the vibration and noise generated. Furthermore, this impact of vibration and noise can cause damage to structures, machinery equipment, and crew discomfort [9]. Researchers have made several efforts to optimize the propulsion efficiency of fishing vessels, including redesigning the propeller [10] and rearranging the propeller placement [11–13]. In their research, Muhammad et al. [14] stated that the order of asymmetric propellers, which is widely applied to some fishing vessels, affects the maneuvering performance of ships. However, studies regarding selecting the primary engine as a propulsion motor for a 30 GT ship are still very minimal.

Muhammad et al. [1] mentioned several considerations in the selection of the ship main engine, including i) the adequacy of power, torque, and rpm required following the ship service speed, ii) the type of fuel used, and; iii) permitted main engine space and weight availability. Furthermore, the determination of the propulsion system also considers the following factors: i) low investment costs; ii) a good level of system reliability and maintenance; iii) low level of vulnerability and operational risk of the system [15], and; iv) the low level of noise produced [16] and the availability of spare parts in the market [17, 18]. Faustinus [17] stated that through the application of the Analytic Hierarchy Process (AHP) method, which is one of the Multi Criteria Decision Making (MCDM) methods, He was able to complete the selection of the ship main engine optimally. In addition, the AHP method has been widely used in the choice of other vehicle engines [19, 20].

Based on the above phenomena, this study aims to analyze the suitability of propellers and propulsion motors for 30 GT fishing vessels for optimum propulsion efficiency. Technical analysis is focused on determining the optimum speed-power of the propeller and diesel engine pair through the engine-propeller matching procedure. Furthermore, the suitability level of the propulsion system is based on the criteria for selecting fishing vessel engines using the Analytic Hierarchy Process (AHP) method

2. Methods

2.1. Fishing Vessel Data

The object of this research is KM Inka Mina 759. A fishing vessel with a capacity of 30 GT with a service speed (VS) of 5.504 m/s is a purse seiner-type fishing vessel operating in the waters of Majene, West Sulawesi Province. Complete data on fishing vessels in the form of waterline plans, main vessel sizes, and propeller/motor parameters are shown in Fig. 1 and Table 1.

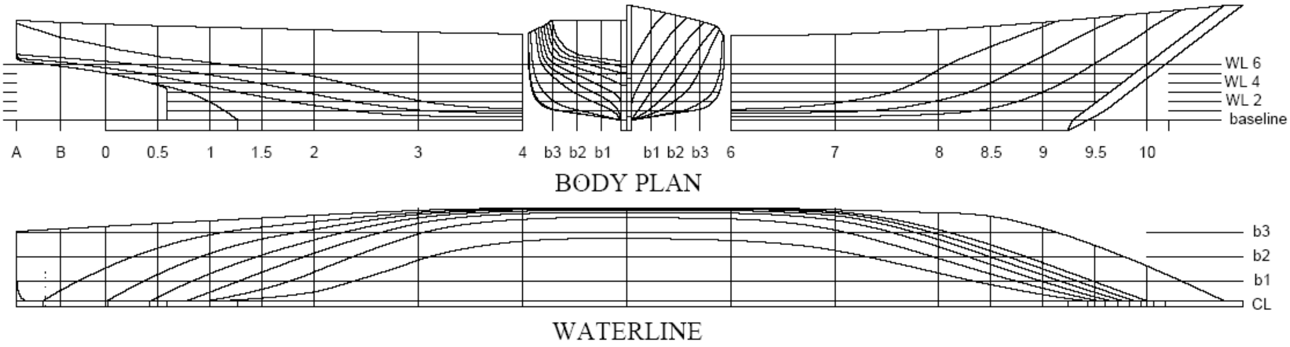

Figure 1. Lines plan of KM Inka Mina759

Table 1. The main dimension of the vessel

Hull parameters	Sym.	Value	Propeller and Engine parameters	Sym.	Value
Length overall, (m)	LOA	26.25	Blade propeller number	Z	4
Length water line, (m)	LWL	24.00	Propeller diameter, (m)	D	0.76
Length between perpendiculars, (m)	LBP	22.70	Blade area ratio	AE/AO	0.55
Breadth, (m)	B	4.20	Pitch diameter ratio	P/D	0.93
Depth, (m)	H	1.80	Propeller rev, (1/s)	n	12.17
Draft, (m)	T	1.20	Wake fraction	w	0.174
Speed, (m/s)	VS	5.504	Thrust deduction	t	0.087
Displacement, (ton)	Δ	65.74	Engine power, (HP)	PB	170
			Engine rev, (1/s)	nE	1500

2.2. Ship Resistance and Propeller Correlation

The correlation between the ship resistance as hull drag and the thrust generated by the propeller is the initial stage in the design of the propulsion system before the engine -propeller matching process is carried out. This study correlation between total resistance and propeller is formed into a mathematical equation of ship resistance and propeller thrust [1]. The ship per-displacement resistance as a function of velocity can be modeled according to Eq. (1):

$$R_T / \Delta = \alpha \{ V_S^2 \} \tag{1}$$

where $\alpha = \frac{1}{2} C_T \rho S$

Furthermore, Eq. 1 can be modeled in a 2nd-order polynomial regression equation as Eq. (2):

$$R_T = \alpha_1 V_S^2 + \alpha_2 V_S + c \tag{2}$$

if know: $R_T = T(1-t)$; $V_A = V_S(1-w)$; $J^2 = \dfrac{V_a^2}{n^2 D^2}$ and $T = K_T \rho n^2 D^4$

Then Eq. (2) can be written as Eq. (3) – (6):

$$T(1-t) = \alpha_1 \left(\frac{V_a}{(1-w)} \right)^2 + \alpha_2 \left(\frac{V_a}{(1-w)} \right) + c \tag{3}$$

$$K_T = \frac{\alpha_1 V_a^2 + \alpha_2 (1-w) V_a^2 + c(1-w)^2}{(1-w)^2 (1-t) \rho n^2 D^2} \tag{4}$$

$$K_T = \frac{\left\{ \alpha_1 + \alpha_2 (1-w) / V_a + c(1-w)^2 / V_a^2 \right\}}{(1-w)^2 (1-t) \rho D^2} J^2 \tag{5}$$

$$K_T = K^* . J^2 \tag{6}$$

where; $K^* = \dfrac{\left\{ \alpha_1 + \alpha_2 (1-w) / V_a + c(1-w)^2 / V_a^2 \right\}}{(1-w)^2 (1-t) \rho D^2}$

2.3. Engine-Propeller Matching

The engine-propeller matching process is the final stage in the design of optimum propulsion efficiency, where the loading characteristics of the diesel engine must be balanced in a speed-power relationship obtained from vessel resistance and propeller loading. This propeller loading includes an increase in resistance caused by fouling and sea conditions known as sea-margin (SM). For ships operating in East Asian waters, an increase in ship resistance is estimated by 20-25% [21]. Furthermore, to optimize the propulsion efficiency of KM Inka Mina 759. In this research, the engine-propeller matching process has analyzed five alternative types of propellers and four types of diesel motors (or there are 20 propulsion system candidates). Furthermore, from the results of the engine-matching process, four candidates for the propeller and diesel motor pairs with the optimum speed-power percentage were selected using the AHP method. The propeller and diesel motor data analyzed are shown in Tables 2 and 3.

Table 2. Propeller data

Type	D (m)	Z	Pitch (m)	A_E/A_O	P/D
A.32X30 (1)	0.81	4	0.76	0.53	0.94
B.30X28 (2)	0.76	4	0.71	0.55	0.93
A.30X34 (3)	0.76	4	0.86	0.55	1.13
B.28X26 (4)	0.71	4	0.66	0.55	0.93
B.28X24 (5)	0.71	4	0.61	0.53	0.86

Table 3. Motor diesel data

Tipe Motor	Power (HP/kW)	rpm	Gear ratio
Yuchai YC6A170C (1)	170/125	1500	1:1.94
Yanmar 6CH-HHTE3 (2)	170/125	2550	1:3.53
Deutz BF06M1013MC (3)	198/174	2300	1:2.82
Volvo D7A TA (4)	177/130	1900	1:2.50

2.4. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) method was introduced initially by American Thomas L. Saaty, a mathematician from the University of Pittsburgh. AHP is a method that has been widely used in multi-criteria decisions. The stages of the AHP method consist of four main parts [22]: i) Determination of the hierarchical structure; ii) Determination of the comparison matrix (pair-wase); iii) Determination of eigenvector value and maximum eigenvalue, and; iv) Calculation of Consistency Index (CI) and Consistency Ratio (CR). To see the level of consistency in the assessment, Saaty requires the CR value not to exceed or be equal to 0.1 ($CR \leq 0.1$). This study selected the propulsion system suitability level based on the propulsion system selection (SP) hierarchical structure in Fig. 2. The assessment was determined in 2 groups, where Level 1 consisted of the criteria: SFOC, Noise, Weight, Space, Speed, and RAM. Furthermore, Level 2 consists of the best four alternative propulsion systems, which are selected based on an analysis of the optimal speed power. Moreover, Table 4 shows the pair-wise comparison scale (pair-wise) 1-9 used in the AHP method.

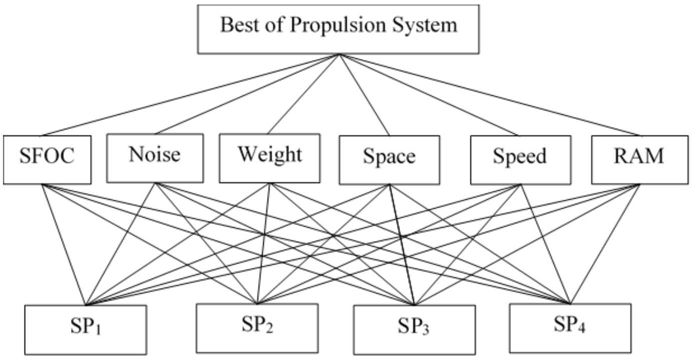

Figure 2. Hierarchy structure for propulsion system selection

Table 4. Paired comparative rating scale of AHP. [22]

Intensity of Interest	Information
1	The two components are equally important
3	One component is slightly more important than the other
5	One component is more importance than the other
7	One component is more critical importance than the other component
9	One component is critical importance than the other component
2, 4. 6. 8	The value between two value of adjacent consideration

3. Results and Discussion

3.1. Ship Resistance

The total resistance of KM Inka Mina 759 was predicted using the Holtrop Method [23, 24] with the help of the Maxsurf commercial package. Prediction results of total resistance at speeds between 3.6 - 6.17 m/s, as shown in Fig. 3. The prediction results of the total resistance of the ship are needed as a basis for modeling the propeller loading equation, which is formulated in a mathematical model that relates the characteristics of resistance and ship speed with a 2nd-order polynomial regression model as Eq. (7)

$$R_T = 1.775V_S^2 + 12.32V_S + 24.78 \tag{7}$$

where; R_T is the total resistance of ship (kN) and V_S is the ship speed (m/s). The complete parameters of the total resistance at ship speed are shown in Table 5.

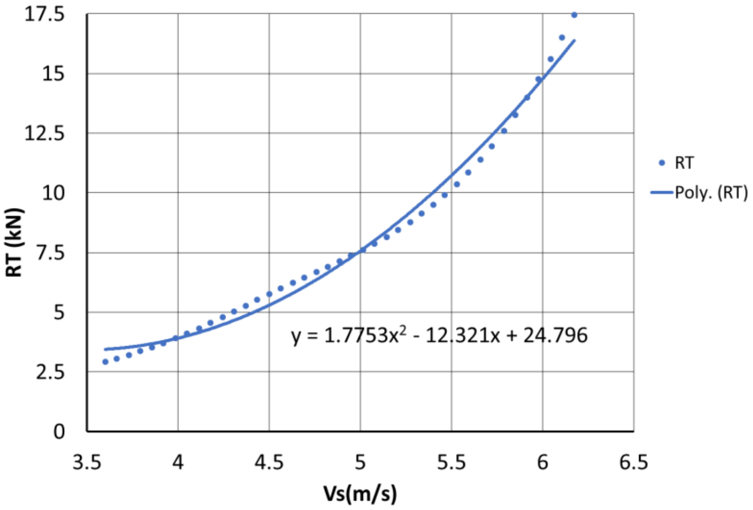

Figure 3. The relationship between total resistance (kN) and ship speed (m/s).

Table 5. Parameters of total resistance at a service speed

Vs (m/s)	RT (kN)	EHP (HP)	x^2	x	C
5.53	10.77	76.71	1.775	12.32	24.79

3.2. Propeller Load

The significant propeller loading is analyzed to optimize the ship propulsion system. In this study, the propeller analyzed was based on the propeller used by KM Inka Mina 759. Furthermore, to obtain optimal propeller efficiency, a selection analysis was developed on five alternative types of propellers on the market (including the propeller used on the sample ship), as shown in the data in Table 4. The characteristics of the propeller in the form of thrust (kN) and torque (kNm) have been predicted using the open water test method with the help of CFD software (Ansys 15.0). The geometry of the propeller model used in the CFD simulation (Ansys 15.0) has previously been modeled using Rhinoceros 5.0 Software, as shown in Fig. 4a. The movement of fluid flow around the propeller model is modeled by the Reynolds Averaged Navier Stokes (RANS) equation in determining the Cartesian flow field and water pressure around the propeller. An equation consisting of a general solution of the 3-dimensional Navier-Stokes equation and a k-epsilon turbulence model has been used in the simulation. The boundary conditions are formed with a cylindrical domain, as shown in Fig 4b. The upstream length, downstream length, and zonal domain diameter are 2.5 and 3 times the diameter of the tested propeller model, respectively (*D*), as shown by Purnama and Hidayati [25]. The mesh used in the analysis is unstructured (Tetrahedral), as shown in the meshing process in Fig. 4c. Finally, the display of the propeller flow around the simulation results is shown in Fig. 4d. Based on the comparison between the results of the CFD simulation and the Wageningen graph (B4-40, *P*/*D*=0.8). There are differences (errors) in the values of K_T, K_Q, and η_o with an average of 2.13, 8.93, and 0.92% at prices J=0.1-0.5.

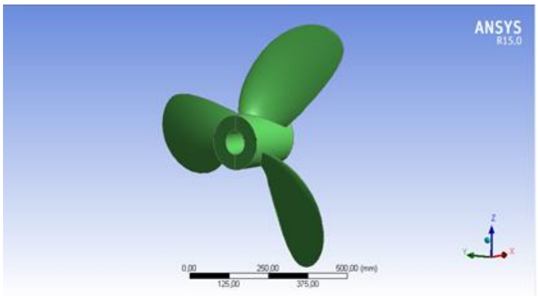

Figure 4a. Model geometry

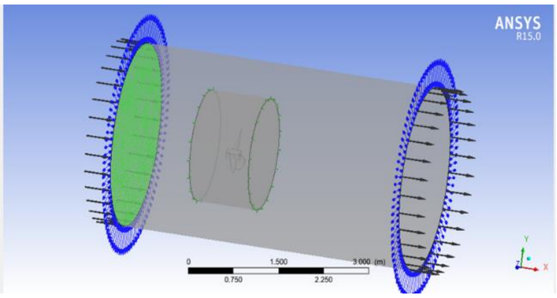

Figure 4b. Domain setup

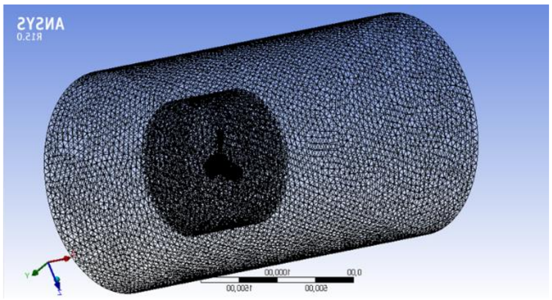

Figure 4c. Meshing process

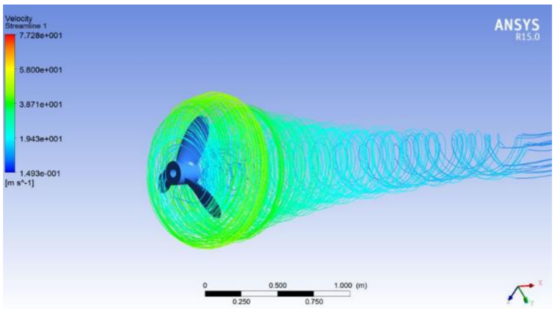

Figure 4d. View flow of simulation result

Fig. 5 shows the results of the thrust and torque propeller predictions and the propeller data in Table 4 through CFD simulation in the forward number range (J=Va/nD) between 0.2 - 0.6. Fig. 5 shows the correlation line between resistance and ship propeller (KT-ship) at sea-margin (SM) conditions as in Eq. (8).

$$K_T = 1.048.J^2 \tag{8}$$

Where; K_T is the ship thrust coefficient (kN), and J is the forward number. Furthermore, the parameters K_Q, η_O, and J are obtained based on the intersection line between K_T-*ship* and K_T-*prop*. The recapitulation of the propeller prediction results is shown in Table 6. The table also shows the predicted power delivery results (P_D=$2\pi nQ$).

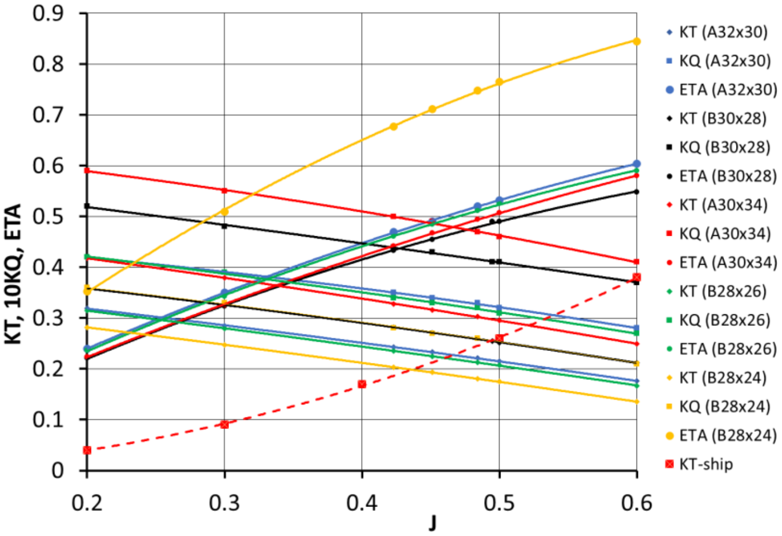

Figure 5. The relationship between K_T. K_Q,η_O and speed advance coefficient (J).

Table 6. Propellers parameter

Type	J	K_T	K_Q	η_O	rps_{prop}	T (kN)	Q (kNm)	P_D (kw)	P_D (HP)
A.32X30 (1)	0.461	*0.230*	*0.0335*	0.505	12.175	15.043	1.775	135.697	182.144
B.30X28 (2)	0.495	*0.255*	*0.041*	0.505	12.085	12.735	1.556	118.101	158.525
A.30X34 (3)	0.521	*0.285*	*0.045*	0.525	11.482	12.848	1.542	111.169	149.221
B.28X26 (4)	0.461	*0.221*	*0.033*	0.492	13.890	11.106	1.177	102.704	137.858
B.28X24 (5)	0.435	*0.200*	*0.0275*	0.695	14.720	11.288	1.102	101.869	136.736

3.3. Selection of propeller-engine

Table 7 shows the combination of the propeller-engine pair that can be used as a propulsion system for the KM Inka Mina 759 according to the propeller and diesel engine data in Tables 5 and 6. The engine-engine procedure analyzes the propeller-engine pair combination based on speed-power requirements. Propeller matching, as shown in Fig. 6a-6d. Fig 6a shows a graphical presentation of the Yuchai YC6A170C diesel motor loading on five types of propeller loading (A.32X30, B.30X28, A.30X34, B.28X26, and B.28X24). Based on the speed-power analysis, three propellers have the best suitability, respectively, B.30X28, A.30X34, and A.32X30 propeller types, with matching points at 95, 92, and 91% rpm. Meanwhile, the

Yanmar 6CH-HHTE3 diesel engine has the best suitability for two propellers (A.30X34, and A.32X30) with matching points at 99 and 98% rpm, respectively, as shown in the graph of the speed-power presentation in Fig. 6b.

Fig. 6c also shows a presentation graph of the loading of the Deutz BF06M1013MC diesel motor, the results of the analysis show that three types of propellers have the best fit, namely B.30X28, A.30X34, and A32X30, with matching points at 95, 92 and 91% rpm, respectively. Likewise, for the use of the Volvo D7ATA diesel engine, it has the best suitability for the same three propellers, namely B.30X28, A.30X34, and A32X30, with matching points at 98, 95, and 94% rpm, as shown in the graph of the speed-power presentation in Fig. 6d. The complete results of the speed-power analysis of the combination of the propeller and propulsion motors are shown in Table 8a-8d. Furthermore, based on the results of the speed-power study in Fig. 6a-6d, four pairs of propeller engines have been selected that have the best suitability, namely: Yuchai YC6A170C, Deutz BF06M1013MC, and Volvo D7ATA diesel engine, each paired with a B.30X28 propeller type with their respective matching points. -at 93, 92, and 97% rpm, respectively. Meanwhile, the Yanmar 6CH-HHTE3 diesel engine is paired with the A.30X34 propeller type with a matching point at 98% rpm.

Table 7. Candidate pair propeller – engine propulsion

Engine/Propeller	A.32X30 (1)	B.30X28 (2)	A.30X34 (3)	B.28X26 (4)	B.28X24 (5)
Yuchai YC6A170C (1)	SP$_{11}$	SP$_{12}$	SP$_{13}$	SP$_{14}$	SP$_{15}$
Yanmar 6CH-HHTE3 (2)	SP$_{21}$	SP$_{22}$	SP$_{23}$	SP$_{24}$	SP$_{25}$
Deutz BF06M1013MC (3)	SP$_{31}$	SP$_{32}$	SP$_{33}$	SP$_{34}$	SP$_{35}$
Volvo D7ATA (4)	SP$_{41}$	SP$_{42}$	SP$_{43}$	SP$_{44}$	SP$_{45}$

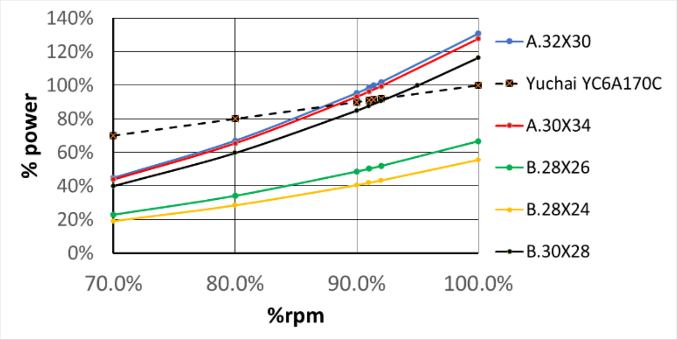

Figure 6a. The matching point between propeller loading and power for Yuchai YC6A170C engine

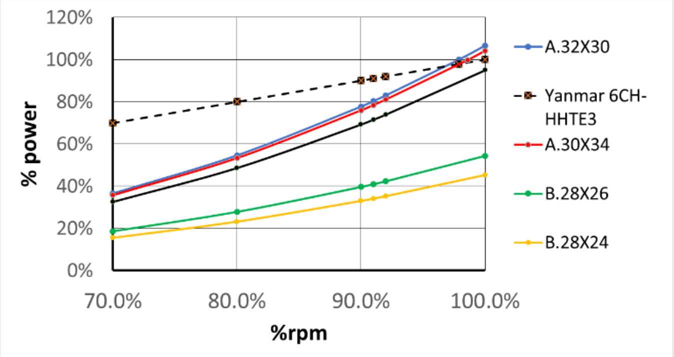

Figure 6b. The matching point between propeller loading and power for Yanmar 6CH-HHTE3 engine

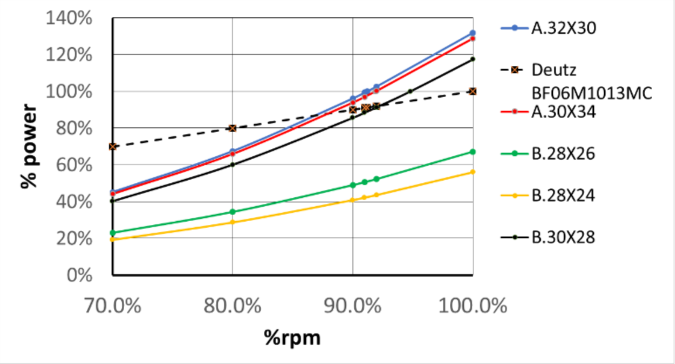

Figure 6c. The matching point between propeller loading and power for Deutz BF06M1013MC engine

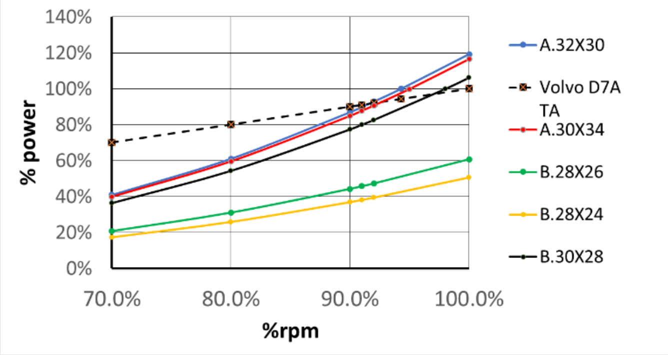

Figure 6d. The matching point between propeller loading and power for Volvo D7ATA engine

Table 8a. Propeller loading for Yuchai YC6A170C engine

Propeller	rpm-$_{Eng.}$	rpm-$_{Prop}$	%rpm-$_{Prop}$	Q-$_{Prop}$	BHP (kW)	BHP (%)
A.32X30 (1)	1500	667.68	91%	1.661	126.659	100%
B.30X28 (2)	1500	688.85	95%	1.597	126.575	100%
A.30X34 (3)	1500	633.81	92%	1.644	126.174	100%
B.28X26 (4)	1500	833.40	100%	1.013	84.554	67%
B.28X24 (5)	1500	883.20	100%	0.845	70.461	56%

Table 8b. Propeller loading for Yanmar 6CH-HHTE3 engine

Propeller	rpm-Eng.	rpm-Prop	%rpm-Prop	Q-Prop	BHP (kW)	BHP (%)
A.32X30 (1)	2550	715.16	98%	1.663	126.932	100%
B.30X28 (2)	2550	725.10	100%	1.545	120.394	95%
A.30X34 (3)	2550	679.28	99%	1.648	126.668	100%
B.28X26 (4)	2550	833.40	100%	0.885	68.954	54%
B.28X24 (5)	2550	883.20	100%	0.737	57.462	45%

Table 8c. Propeller loading for Deutz BF06M1013MC engine

Propeller	rpm-Eng.	rpm-Prop	%rpm-Prop	Q-Prop	BHP (KW)	BHP (%)
A.32X30 (1)	2300	666.22	91%	1.840	147.689	100%
B.30X28 (2)	2300	687.39	95%	1.769	147.629	100%
A.30X34 (3)	2300	633.12	92%	1.825	147.612	100%
B.28X24 (4)	2300	883.20	100%	0.940	82.703	56%
B.28X24 (5)	2300	883.20	100%	0.940	82.703	56%

Table 8d. Propeller loading for Volvo D7ATA engine

Propeller	rpm-Eng.	rpm-Prop	%rpm-Prop	Q-Prop	BHP (kW)	BHP (%)
A.32X30 (1)	1900	688.86	94%	1.708	132.100	100%
B.30X28 (2)	1900	710.60	98%	1.642	131.956	100%
A.30X34 (3)	1900	654.47	95%	1.693	131.932	100%
B.28X26 (4)	1900	833.40	100%	0.979	80.298	61%
B.28X24 (5)	1900	883.20	100%	0.816	66.915	51%

Furthermore, the optimum propulsion system is selected by the AHP method based on the hierarchical structure in Fig. 2. The system assessment is determined in 2 levels, where Level 1 consists of the criteria: SFOC, noise, weight, space, speed, and RAM. Furthermore, Level 2 consists of the four best alternative propulsion systems, which are selected based on an analysis of the optimal speed power. Such as SP$_{12}$ (Yuchai YC6A170C engine versus propeller type of B.30X28), SP$_{23}$ (Yanmar 6CH-HHTEC engine versus propeller type of A.30X34), SP$_{32}$ (Deutz BF06M1013MC engine versus type propeller of B.30X28) and, SP$_{42}$ (Volvo D7ATA engine versus propeller type of B.30X28 propeller). The complete specifications of the alternative propulsion system candidates above are shown in Table 9.

Table 9. Propulsion system candidate characteristics

Spec	SP$_{12}$	SP$_{23}$	SP$_{31}$	SP$_{41}$
Rpm (1/s)	688.85	679.28	687.39	710.60
Speed (m/s)	5.229	5.425	5.218	5.394
SFOC (g/kW-H)	198	232	204	213
Space (mm)	1415x910x1075	1600x736x1096	1408x 850x1197	1216x750x1015
Weigth(Kg)	995	895	922	945

Table 10 displays the pair-wise comparison matrix level 1 (criteria) on a rating scale of 1-9 by considering the assessment criteria of some researchers in selecting the ship propulsion system in Table 10. The calculation results show that the highest priority vector value (Eigenvalue) is 0.412 for the SFOC assessment, then the priority vectors for the evaluation of noise level (0.251), ship speed (0.147), RAM (0.087), engine weight (0.060), and, engine space (0.042).

Table 10. Comparison pair matrix for level 1

	SFOC	Noise	Weight	Space	Speed	RAM	Priority vector
SFOC	1	2	7	7	3	5	0.412
Noise	0.5	1	5	5	2	3	0.251
Weight	0.143	0.2	1	3	0.333	0.5	0.060
Space	0.143	0.2	0.333	1	0.333	0.5	0.042
Speed	0.333	0.5	3	3	1	2	0.147
RAM	0.2	0.333	2	2	0,5	1	0.087
Maximum Lambda value=6.104; CI=0.021; RI=1.24; R=0.017							

Table 11. Definition of propulsion system criteria

Criteria	Definition
SFOC	Select the engine with minimum fuel consumption (Kg/kw-H) [1, 4, 15].
Noise	Select the engine with the lowest noise level or the motor with the lowest rpm [16].
Weight	Select the engine with a minimum weight capacity [1, 15].
Space	Select the engine with minimum dimensions (LxBxH) [1, 15].
Speed	Select the engine with maximum speed or power [1, 18].
RAM	Select the engine with reliable reliability, easy to get spare parts, and easy to maintain [15, 17, 18]

Table 12a-12f also displays a pair-wise comparison matrix at level 2 (alternative) with a rating scale of 1-9. The calculation results show that the highest priority vector for the SFOC assessment is 0.500 in SP_{12}, as the comparison pair matrix is in Table 12a. Next, the highest priority vector for the evaluation of the noise level (noise) is 0.564, the weight of the machine is 0.564, the space availability is 0.52, and the speed of the ship is 0.564 for SP_{23}, as shown in the comparison matrix in Table 12b-12e. Furthermore, the RAM priority vector is 0.553 for SP_{32} compared to the comparison pair matrix in Table 12f.

Table 13 shows the comparison matrix of the priority vectors of the motor selection criteria against four alternative propulsion systems (SP). The calculation results show that SP_{23} (Yanmar 6CH-HHTEC engine versus propeller type of A.30X34) has the highest percentage of 31.7%, then SP_3 (Deutz BF06M1013MC engine versus propeller type of B.30X28) is 26.6%, SP_{12} (Yuchai YC6A170C engine versus propeller type of B.30X28) by 26.4%, and SP_{42} (Volvo D7ATA engine versus propeller type of B.30X28) by 15.3%. The high percentage of SP_{23} is because the propulsion system has a minimal noise level, dimensions, and engine weight but has maximum power.

Table 12a. Comparison pair matrix for SFOC

	SP_{12}	SP_{23}	SP_{32}	SP_{42}	Priority vector
SP_{12}	1	5	3	3	0.500
SP_{23}	0.2	1	0.2	0.333	0.066
SP_{32}	0.333	5	1	3	0.288
SP_{42}	0.333	3	0.333	1	0.147
Maximum Lambda value=4.232; CI=0.077; RI=0.9; CR=0.086					

Table 12b. Comparison pair matrix for noise

	SP_{12}	SP_{23}	SP_{32}	SP_{42}	Priority vector
SP_{12}	1	0.2	0.333	3	0.118
SP_{23}	5	1	3	7	0.564
SP_{32}	3	0.333	1	5	0.263
SP_{42}	0.333	0.143	0.2	1	0.055
Maximum Lambda value=4.119; CI=0.040; RI=0.9; CR=0.044					

Table 12c. Comparison pair matrix for weight

	SP_{12}	SP_{23}	SP_{32}	SP_{42}	Priority vector
SP_{12}	1	0.143	0.2	0.333	0.055
SP_{23}	7	1	3	5	0.564
SP_{32}	5	0.333	1	3	0.263
SP_{42}	3	0.2	0.333	1	0.118
Maximum Lambda value=4.119; CI=0.040; RI=0.9; CR=0.044					

Table 12d. Comparison pair matrix for space

	SP_1	SP_2	SP_3	SP_4	Priority vector
SP_{12}	1	0.2	0.333	0.333	0.078
SP_{23}	5	1	3	3	0.520
SP_{32}	3	0.333	1	1	0.201

SP_{42}	3	0.333	1	1	0.201
Maximum Lambda value=4.046; CI=0.015; RI=0.9; CR=0.017					

Table 12e. Comparison pair matrix for speed

	SP_{12}	SP_{23}	SP_{32}	SP_{42}	Priority vector
SP_{12}	1	0.2	3	0.333	0.118
SP_{23}	5	1	7	3	0.564
SP_{32}	0.333	0.143	1	0.2	0.055
SP_{42}	3	0.333	5	1	0.263
Maximum Lambda value=4.119; CI=0.040; RI=0.9; CR=0.044					

Table 12f. Comparison pair matrix for RAM

	SP_{12}	SP_{23}	SP_{32}	SP_{42}	Priority vector
SP_{12}	1	0.333	0.143	0.143	0.050
SP_{23}	3	1	0.2	0.333	0.116
SP_{32}	7	5	1	3	0.553
SP_{42}	3	0.333	0.333	1	0.281
Maximum Lambda value=4.160; CI=0.053; RI=0.9; CR=0.059					

Table 13. Pair Matrix comparison between alternatives and criteria

Priority vector	0.412	0.251	0.060	0.042	0.147	0.087
	FC	NOISE	WEIGHT	SPACE	SPEED	RAM
SP_{12}	0.500	0.118	0.055	0.078	0.118	0.050
SP_{23}	0.066	0.564	0.564	0.520	0.564	0.116
SP_{32}	0.288	0.263	0.263	0.201	0.055	0.553
SP_{42}	0.147	0.055	0.118	0.201	0.263	0.281
Ranking/Score: SP_{12}=26.4%; SP_{23}=31.7%; SP_{32}=26.6%; SP_{42}=15.3%						

4. Conclusion

The selection of the optimum propulsion system for fishing vessels 30 GT (case study KM Inka Mina 759) has been analyzed through engine-propeller matching procedures and the AHP (Analytic Hierarchy Process) method. Based on the engine-propeller matching strategy, it is concluded that there are four candidates for the propulsion system that has the best speed power (optimum propulsion efficiency) and can be used on the KM Inka Mina 759 fishing vessel, namely; i) propulsion system with Yuchai YC6A170C motor versus propeller type B30X28 (SP_{12}) with the optimal percentage of 93% rpm; ii) a propulsion system with a Yanmar 6CH-HHTE3 motor versus a propeller-type A30X34 (SP_{23}) with a percentage of 98% rpm; iii) a propulsion system with a Deutz BF06M1013MC motor versus a B30X28 (SP_{32}) propeller with a percentage of 92% rpm and; iv) propulsion system versus Volvo D7ATA motor and propeller type B30X28 (SP_{42}) with a percentage of 97% rpm. Furthermore, the suitability level for propellers and diesel engines is based on the criteria for selecting fishing machines: fuel consumption noise, weight, required engine room space, ship speed, and RAM (reliability, availability, maintainability). The best results are obtained in a row as follows SP_{23} = 31.7 %, SP_{32} = 27.5%, SP_{12} = 26.4 % and SP_{42} = 15.3.5 %. The high percentage of SP_{23} selection is because the propulsion system has a minimum noise level, dimensions, and engine weight but has maximum power

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