MAIN ENGINE SELECTION OPTIMIZATION ANALYSIS OF THE SHIP CARAKA JAYA III BASED ON ENGINEERING AND ECONOMY COSIDERATIONS

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Abstract

Caraka Jaya III, as sister ships, built in Indonesia in the era 1990, devided into three building phases. Each phase had the different main engine. Especially for the second phase used the MAN B&W 5S26MC as main engine. After several years later, some of the engines were going to have the problems, especially for the pistons and its rings. The selected engine was not the only one that should be used. In accordance with selection the engine, the optimization procrdure offer best solution as compromise.
Selecting the main engine is a complicated and time consuming task. The application of Analytic Hierarchy Process (AHP), one of the Multi Criteria Decision Making (MCDM), would promise a powerful tool for main engine selection as well as usual engineering design process. To select the candidate of the main engine it needs more criteria to obtain satisfactory solution. The criteria therefore are developed as pair wise coparison matrix leading to the mathematic solution. Analysis procedure is devided into three levels, namely, (1) criteria, (2) sub-criteria and (3) alternative of the selected engine. A consistency ratio needed as the acceptance criteria to check the solution of the pair wise comparison matrix.
The final result obtained from multiplication of all matrixs on analysis, namely, SKL Diesel 8VD29/24AL- 0.149; MaK 9M20 – 0.190; Wartsila 9L20 – 0.088; Wartsila 6SW28 – 0.121; NIIGATA 8PA5L – 0.098; MAN B&W 5S26MC-0.354. According to the result, optimation solution will be MAN B&W 5S26MC or MaK 9M20.

Key words: Caraka Jaya Ship, Main Engine Selection, Criteria, Decision Making

INTRODUCTION

Background

The global economy is more interlink than ever before. Functioning Maritime Trade plays a decisive role here, as more than 90% of global goods traffic is handled by sea. Couple with the necessity to use more and more efficient ships (drastic doubling to tripling of fuel costs nowadays), the call for state-for-the-art ships will remain at a very high level. Efficient propulsion engineering on board of these modern ships is absolutely.

Today, the primary source of propeller power is the diesel engine and the power requirement and rate of revolution very much depend on the ship's hull form and the propeller design. Therefore, in order to arrive at a solution that is as optimal as possible, some general knowledge are essential as to the pricipal ship and diesel engine parameters that influance the propulsion system.

Fuel efficiency and friendliness are high on the list of requirements for ship propulsion engine from today's shipping and shipbuilding industries. Thus maritime trades must be comitted to creating better technology in these areas that will benefit both the customers and environment.

Caraka Jaya III built in Indonesia in the era 1990, devided into three building phases. The first phase used MAN B&W 4L35MC. The engine had slow maneuver on operational condition and caused a high vibration. The second phase used MAN B&W 5S26MC. These engines were used as an evaluation from the previous phase, because of the reason that already describes. But the solution was finish yet, the previous problems, that the maneuver was still slow and there was a new problem, the broken rings of pistons were quite often that effect maintenance schedule and more operational cost. In a construction manner, Caraka Jaya Vessels were not only using available engine, but also there was several alternatives to use an other engine, as long as the alternative that taken have characteristics and variables that closed to the engine that already used, to keep the expected ship performance.

Problems Forming

On the main engine selection for a ship, the designer is always considering several factors, especially technical and economical factors. The problems that appear are, how they make decision to choose an alternative with a lot of criteria, which is between each other has various importance level.

In other side, the solution that already decided must have the best compromise, with considering all criteria according to the importance level.

Problem Limitation

To get a more optimal result the reseach needed much more supporting variables. More including variables make the chosen criteria get a better result but need a longer survey and supporting data.

Because of that, with several considerations about the data availability, the reseach has limitation for the measurement variables that are, engine characteristics, dimensions, fuel consumptions, fuel costs and maintenances. Engine reliability data is not included on analysis. In other side, the ship that used as reseach object is Caraka Jaya III Phase II, that the engine is MAN B&W 5S26MC using as main engine.

Objective

The reseach objective is:

Making main engine selection guidance for a ship with more than one alternative engines.

The benefit from this reseach are:

- ✓ Giving a description about technical and economical aspect for severals engines on main engine selection.
- ✓ It is used to solve main engine selection for a new ship.

METHODOLOGY

Optimization problems with ordinary criteria can not solve with optimization model which only has one objective function. That why the optimization matter for the problem with multi criteria, must use decision theory with multi criteria or usually call Multi Criteria Decision Making (MCDM).

Thomas L.Saaty, from University of Pittsburgh, has developed the Analytic Hierarchy Process (AHP). AHP is used to solve complicated problems, which are data and statistical informations from the problem are very limited, or more quantitative, based on perception, experience and intuition.

Judgement that includes a lot of participant will give a lot of opinions. AHP only need one participant for one comparison matrix. According Saaty, solution for the problem is using geometric mean as an assist instrument to make average opinion result with formulation:

$$a_{ij} = (Z_1, Z_2, Z_3 .... Zn)^{1/n} \quad .... \; 1$$

$$i = 1,2,3, ...n$$

where:

a_{ij} – comparison avarage value between Ai and Aj for n participant

Zi – comparison value between criteria Ai and Aj for participant i.

The load that look for is inside vector W = (w_1, w_2, w_3 .... w_n), which value wn declare subcriteria relative load on hierarchy.

Based on pair wise comparison matrix, value a_{ij} is declare on vector W as follows:

$a_{ij} = wi/wj$

$a_{ij} \cdot wj/wi = 1$

where: i,j = 1,2,3 ....n

$$\sum_{j=1}^{n} a_{ij} \frac{w_j}{w_i} = n$$

$$\sum_{j=1}^{n} a_{ij} \cdot w_j = n \cdot w_i, \qquad \dots\dots\dots 2$$

where: i = 1,2,3 .... n, that is equivalent with formulation:

$$A\,W = n\,W, \qquad \dots\dots\dots\dots\dots 3$$

In matrix form which formulation will be like on the next formulation.

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix}$$

Variable n is able to change with vector λ, with the result is:

$$A\,W = \lambda\,W, \qquad \dots\dots\dots\dots\dots 4$$

where λ = (λ1, λ2, λ3, ... λn) which is eigenvalue.

RESULTS AND DISCUSSION

Selection Variables

Variables which are often to use and influence the main engine selection are engine total weight, engine total space, original cost, maintenance and repairing time, and maneuver ability.

To be able to make selection process for getting favorable solution which is compromise result, so the chosen variables are as follows:

a) Load characteristics (w_1)
a.1.Nominal load (w_{11})
a.2. Engine margin (w_{12})
a.3. Driver type (w_{13})

b) Specific fuel oil consumptions (w_2)
b.1. 100% fuel consumption (w_{21})
b.2. 85% (w_{22})
b.3. 75% (w_{23})
b.4. 50% (w_{24})

c) Engine performances (w_3)
c.1. Power (w_{31})
c.2. BMEP (w_{32})
c.3. 100% RPM (w_{33})
c.4. Minimum RPM (w_{34})

d) Engine dimensions (w_4)
d.1. Length (w_{41})
d.2. Width (w_{42})
d.3. Height (w_{43})
d.4. Weight (w_{44})

e) Costs (w_5)
e.1. Fuel consumption (w_{51})
e.2. Maintenance (w_{52})
e.3. Spare part availability (w_{53})

Main Engine Candidates

From the previous description, the ships Caraka Jaya III Phase II using main engine MAN B&W 5S26MC, the MCR power is 2050 BHP with propeller speed 207 rpm.

With using the ship and engines data approach, several engines are choosing as candidates or alternatives. Where the chosen engine performances are equal with the existing engine.

Table 1. Engine alternatives

Merk	Continuous output		Speed, rpm		BSFC, g/kWh
	kW	BHP	Max	Min	
SKL VD29 /24AL	1550	2107	1000	300	185.8
MaK 9M20	1530	2080	1000	300	189
Wartsila 9L20	1485	2019	1000	500	192
Wartsila 6SW26	1560	2121	720	300	190
Niigata 8PA5L	1498	2037	900	300	203
MAN B&W 5S26MC	1508	2050	207	155	177

Analysis Framework Hierarchy

Arranging decision making process framework in a step does decision making through the AHP methods by step hierarchy structure, which will make the mathematical solution easier.

Further, the decision making hierarchy structure is forming to be:

Stage one : Decision making objective, which is appropriate main engine selection.
Stage two : Determining choosing criteria, which are load characteristic, engine performance, fuel consumption, engine dimension and cost.
Stage three : Sub elements of the stage two are su criteria such as already describe on the previous table.
Stage four : Chosen engine alternatives are: SKL, MaK, Wartsila, Niigata, MAN B&W.

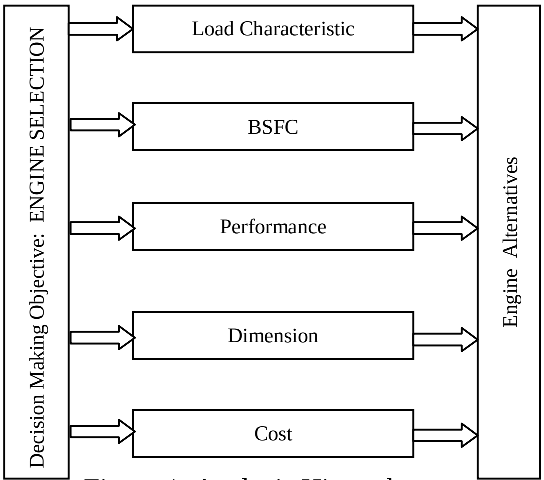


Figure 1. Analysis Hierarchy

Mathematical Solution

With the load that already decided before, then the mathematical solution with using matrix can be done.

Solution with making *pair wise comparison matrix* first, from each existing criterion.

The amount of choosing criteria from the stage 1 analysis process n = 5, that are:

- ✓ Load factor (w_1)
- ✓ Engine performance (w_2)
- ✓ Specific fuel oil consumption (w_3)
- ✓ Engine dimension (w_4)
- ✓ Cost (w_5)

Further, the next calculation process can be done through the matrix solution.

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \frac{w_1}{w_4} & \frac{w_1}{w_5} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} & \frac{w_2}{w_4} & \frac{w_2}{w_5} \\ \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} & \frac{w_3}{w_4} & \frac{w_3}{w_5} \\ \frac{w_4}{w_1} & \frac{w_4}{w_2} & \frac{w_4}{w_3} & \frac{w_4}{w_4} & \frac{w_4}{w_5} \end{bmatrix} = \begin{bmatrix} a \\ b \\ c \\ d \\ e \end{bmatrix}$$

Table 2. Major Criteria Matrix

Major Criteria	w_1	w_2	w_3	w_4	w_5
w_1	1	1	3	3	5
w_2	1	1	3	3	5
w_3	1/3	1/3	1	1	3
w_4	1/3	1/3	1	1	3
w_5	1/5	1/5	1/3	1/3	1

To make the Eigenvector component then the formulation is as follows:

$$\sqrt[5]{\frac{w_1}{w_1}+\frac{w_1}{w_2}+\frac{w_1}{w_3}+\frac{w_1}{w_4}+\frac{w_1}{w_5}} = a$$

$$\sqrt[5]{\frac{w_2}{w_1}+\frac{w_2}{w_2}+\frac{w_2}{w_3}+\frac{w_2}{w_4}+\frac{w_2}{w_5}} = b$$

$$\sqrt[5]{\frac{w_3}{w_1}+\frac{w_3}{w_2}+\frac{w_3}{w_3}+\frac{w_3}{w_4}+\frac{w_3}{w_5}} = c$$

$$\sqrt[5]{\frac{w_4}{w_1}+\frac{w_4}{w_2}+\frac{w_4}{w_3}+\frac{w_4}{w_4}+\frac{w_4}{w_5}} = d$$

$$\sqrt[5]{\frac{w_5}{w_1}+\frac{w_5}{w_2}+\frac{w_5}{w_3}+\frac{w_5}{w_4}+\frac{w_5}{w_5}} = e$$

Then the mathematical solution for Eigenvector value on stage 1 is $[a, b, c]$ from Eigenvector value sigma,

$$\sum = a + b + c + d + e$$

a = b = 1.67027; c = d = 1.4147; e = 1.156256 and Σ = 7.32619.

The priority vector is from the previous result:

$$x_1 = \frac{a}{\Sigma}$$
$$x_2 = \frac{b}{\Sigma}$$
$$x_3 = \frac{c}{\Sigma}$$
$$x_4 = \frac{d}{\Sigma}$$
$$x_5 = \frac{e}{\Sigma}$$

$$[x_1, x_2, x_3, x_4, x_5] = \begin{bmatrix} 0.22798; 0.22798; \\ 0.1931; 0.1931; 0.15782 \end{bmatrix}$$

The next is the matrix multiplication with priority alternatives of value λ

$$\lambda\text{max} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5$$

λ = 2.40366 + 2.40366 + 1.01164 + 1.01164 + 0.37774

λ = 7.20834

The next is determining consistency index (CI):

$$CI = \frac{\lambda - n}{n - 1}$$

From the CI value then determining of the random consistency value (RC):

$$RC = \frac{CI}{RI}$$

RC = 0.01

Where random index value (RI) = 1.12, is the value for matrix with ordo n = 5.

If RC value ≤ 0.1, then the solution with matrix is satisfied, so the solution for stage 1 to determine major criteria is acceptable. The next solution is for stage 2, with the same method for the stage 1.

Determining of The Engine

After all matrix calculations are done, the next is to make decision about engine selection, apply matrix multiplication from every existed solution stage. Matrix multiplication that is done namely Eigen vector matrix multiplication. If eigenvector matrix from the solution of stage 1 declare with V_1, and the solution of stage 2 declare with V_2, and the solution of stage 3 declare with V_3, therefore matrix multiplication is done with the next formulation:

$$V^1 = V_1 + V_2$$
$$P = V^1 + V_3$$

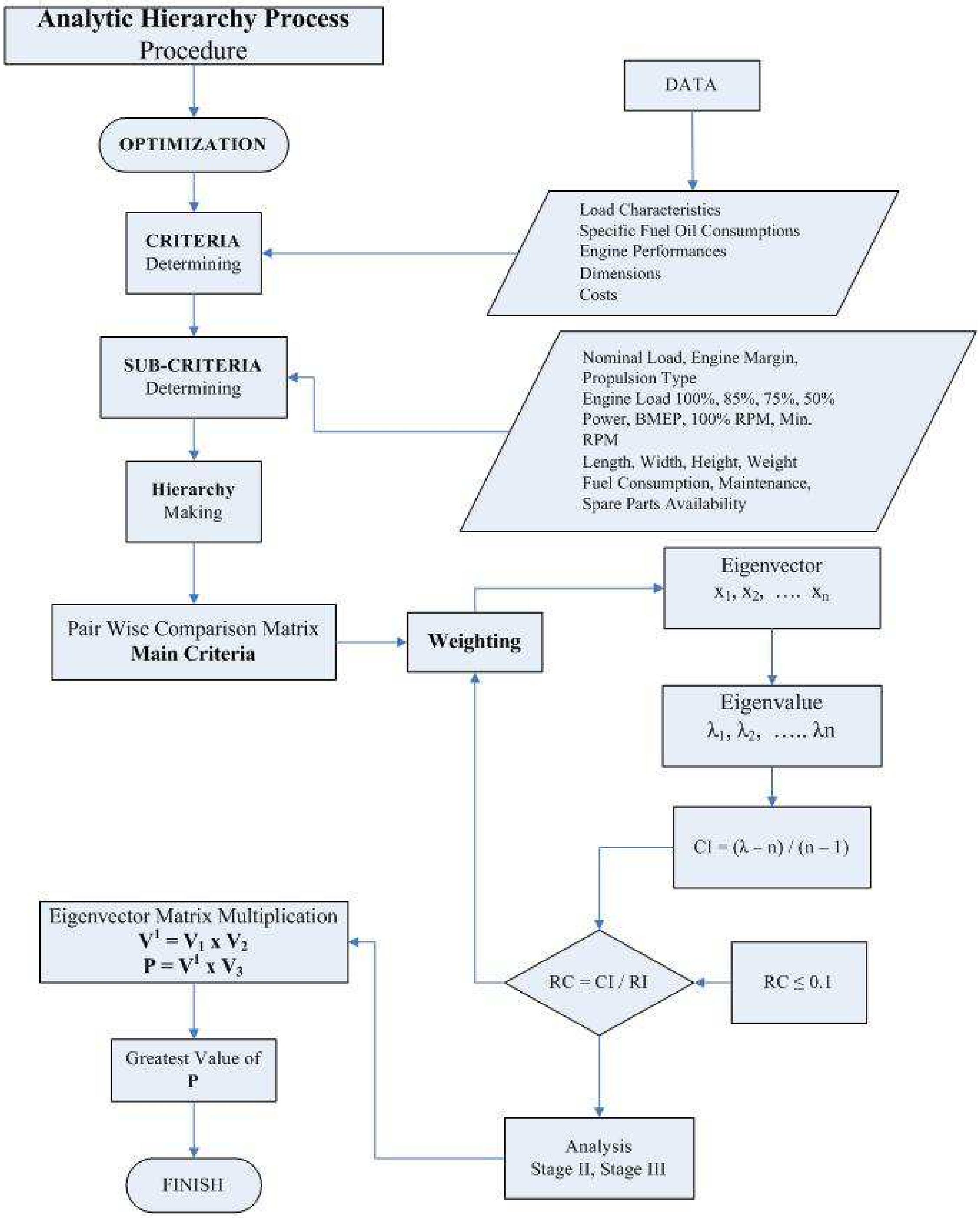
Where, P is Eigenvector from the choice. The largest P value is the choice that is taken.

That's why the matrix that needed is quite a lot, therefore, the calculation for the solution process is done with using application program ***Expert Coice version 9.0***. This program is developed to solve the AHP problem easier and faster. The final result from the AHP with Expert Choice version 9.0 is as follows:

Table 3. AHP Analysis Final Result

Engine Types	Results
SKL VD29/24AL	0.149
MaK 9M20	0.190
Wartsila 9L20	0.088
Wartsila 6SW26	0.121
Niigata 8PA5L	0.098
MAN B&W 5S26MC	0.354

Therefore, the choice is MAN B&W 5S26MC because it has the largest Eigenvector value that is:0.354. If the choice priority on the ship maneuver, therefore, the second alternative is MaK 9M20, with Eigenvector value is 0.190.



MULTI CRITERIA DECISION MAKING
ANALYTICAL HIERARCHY PROCESS

CONCLUSION

Main engine selection on a ship is a very important stage because the decision which made will cause consequences in operational.
There are several engines that could be the choice candidate, but the designer need to do an accurate selection for the major variables that will influence on the decision making. In other side the decision is not only with intuition or experiment, but also need to follow analysis procedure.

Several decision making techniques are scientific reliable method.
Analytic Hierarchy Process is one of decision making techiques that offer mathematical solution procedure using matrix. Eigenvector matrix is a final solution form from this method, with taking the largest value as a choice.

To get optimum final result that is the best compromise solution, it’s suggested to involve more criteria and subcriteria.

From the harbor tool and infrastructure condition in Indonesia, ship with a tonnage like Caraka Jaya III is better using four stroke medium speed diesel engine as main engine, that is able to make good maneuver in small harbor.

REFERENCES

[1]. Harrington, Roy L., 1992, *Marine Engineering*, The Society of Naval Architects and Marine Engineers, Jersey City.
[2]. Illies K., 1984, *Handbuch der Schiffsbetriebsteknik*, Vieweg, Braunschweig.
[3]. MaK, 1994, *Project Guide M20*, Krupp MaK, Kiel.
[4]. MAN B&W, *Basic Principles of Ship Propulsion*, Copenhagen.
[5]. MAN B&W, 1987, *Project Guide Two Stroke Engine S26MC*, Copenhagen
[6]. Saaty T.L., 1980, *The Analytic Hierarchy Process*, Mc Graw-Hill, New York.