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Analytic Hierarchy Process Approach for Selection of Ship Propulsion System – Case Study

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Abstract: *The selection of appropriate propulsion system is one of the most critical decisions in the design and development of a successful ship production environment. During such decision making process which essentially involves qualitative and quantitative multi-criteria selection, a tradeoff between tangible and intangible factors is essential to select the best amongst the equals. In this case study, the design team was tasked to select suitable propulsion system for a ship under design. The team uses analytical decision making tool, such as Analytic Hierarchy Process (AHP) in this case, to arrive at a informed decision. The team could compare many non-comparable but interlinked parameters like technical parameters, cost, time, vulnerability etc using AHP. The team could also harness the expertise of team within the arrived consensus decision. This study illustrates that the decision arrived through analytical methods tend to be accurate and practical than an intuitive decision.*
Keywords: *Analytic Hierarchy Process (AHP), Propulsion system selection, Multi criteria decision making.*

I. Introduction

The process of ship design begins with an amalgamation of a numerous ideas from all the stakeholders. While the ship designer plays a vital role to translate these into an engineering possibility keeping in mind the compliance to parameters like safety, environment and the role, most of the times, various requirements and characteristics conflict with each other. It is desirable, initially, to place a few rigid constraints on the design as possible. However, there can be incompatibilities because some characteristics have a variety of interdependencies with other characteristics and so only by careful analysis it is possible to determine the full implications of setting a requirement i.e. essential condition. This paper explores the variety of interactions that occur between elements of propulsion system and outlines few of the consequences of trade off.

In this case study, an attempt is also made to highlight major imponderables that could arise during the design process, selection process and the possible implications of certain actions using a broadly defined model. The case of Multi Criteria Decision Making (MCDM) of 'selection of propulsion plant' is unique in nature and a suitable analytic method is required to facilitate the designer to select the best option which can meet all the Staff Requirements (SR). The Analytic Hierarchy Process (AHP)[1] is one such tool which suits this MCDM process involving several decision makers with different conflicting objectives to arrive at a consensus decision.

In this case study, a design team has been tasked to select an appropriate propulsion system for a medium cargo ship of following key SR :-

(a) Principal particulars: - Length Overall: 150-160m, Beam Max: 14-15m, Mean Draft: 5.0m, Standard Displacement: around 8000 Ton, Nominal Speed : 25 knots, Endurance: 5500 Nautical Miles(minimum). Helicopter capability : Capability for landing only of weight of 11 T (Max).
(b) All machinery and systems selections to meet Safety of Life at Sea (SOLAS) conventions and regulations issued by International Maritime Organisation(IMO).
(c) Use of 'all electrical system' (electric ship) has been ruled out due to various constraints.

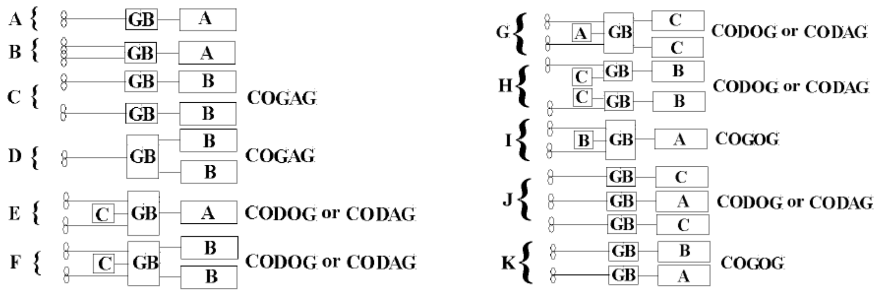
Ship propulsion system criteria

The performance requirements of a ship during the design phase guides the type and combination of the propulsion arrangement selected. There will be certain criteria/characteristics associated with a particular propulsion system which helps refining the available choices for the associated systems and to an extent also the type of hull. The important criteria/characteristics considered for the ship under design table are:-

(a) Fuel consumption (FC)
(b) Weight (W)
(c) Space (S)
(d) Cost (C)
(e) Availability, Reliability and Maintainability (ARM)
(f) Vulnerability (V)
(g) Risk (R)

(h) Manning (M)

Considering the key SR, it is possible to propose a number of options of propulsion aggregate that could satisfy the operational requirements as depicted in Fig 1.



Assumption: Engine A- High MW GT, Engine B- Low MW GT & Engine C- Diesels

Fig 1: Options available for possible propulsion systems

(adopted from Propulsion system criteria, M Plumb)

The design team examined the key characteristics[2], which play vital role in propulsion plant and ship's operations. They are:-

(a) Fuel stowage/ Consumption (FC).The fuel stowage (and so the weight and space occupied by it) is often based on the required endurance of the ship. The endurance can be translated in both range and number of days at sea before refueling. The range has a dual component i.e. the distance 'X' nautical miles and the speed at 'Y' knots. High propulsion system efficiency at Y knots will minimize the fuel stowage requirement. This is an operational advantage and can offer cost advantage as there is reduced demand of fuelling operations. The life cycle cost of a ship also will be affected by the quantity of fuel consumed.

(b) Weight (W). It is advantageous to have the lightest possible equipment so as to reduce the overall dead weight of the ship. Lighter the weight, more the speed and endurance for a chosen propulsion system.

(c) Space (S). The total volume or a deck area occupied when all components of the propulsion package i.e. the main equipment, the auxiliary equipment, the support services, ducting, maintenance envelope and removal spaces necessary can be clubbed as space requirement. If machinery occupies a large space, that can affect the ship's size, role and costs.

(d) Cost factor (C).Costs have many facets and so when cost restrictions are placed on a design it may not always be clear what the full implications will be. It is a complex issue and has many interactions within warship design process. This criterion is currently considered by the company to be very important. All costs that occur prior to the ship going to sea are clubbed and considered under this heading.

(e) Availability, reliability, maintainability (ARM). Availability(A) and Reliability(R) are important features of ship propulsion system. Ideally, A & R both be as close as possible to 100%. Maintainability (M) is linked to A and R because of the interdependency between them. High maintenance loads can affect crew size and life cycle costs; there is constant effort to reduce the maintenance factor.

(f) Vulnerability (V).An assessment of the vulnerability of a propulsion system itself is a matter of judgment of the circumstances the ship may have to face during life cycle. A ship designed to minimise vulnerability to one factor, may, during its life, become vulnerable to some other.

(g) Risk (R). Risk can be in many forms. There could be a risk that one or more aspect of the anticipated performance will not be met within the anticipated cost or programme time. Alternately risk can be a non fulfillment of order in full or part. Thus the type of risk and what can be traded-off must be established.

(h) Manning (M).Equipment that will result in increased manning will have implications on ship size and cost. Skill levels of manpower are also a factor.

(i) Signature and shock (SS).Different noise sources in a ship produce different characteristics patterns. Also, the reduction in radar cross-section and Infra-Red radiations emitted by the hot-parts are also desirable. To protect equipment from shock forces, the equipment needs to be designed to withstand the specified shock loads.

Based on extensive research and consultations, the team concluded that the combination of propulsion systems are good options and four such combination emerge. They are Combination of Gas or Gas turbine system (COGOG), Combination of Diesel engines and Gas turbine system (CODAG), Combination of Gas turbine and Gas turbine system (COGAG) and Combination of Diesel engines or Gas turbine system (CODOG). The team applies analytical tool like, Analytic Hierarchy Process (AHP) to determine the best available choice.

AHP- Objective Judgement

When an objective judgment is to be made when incomparable factors are involved, a method needs to be established of assessing how well each factor will perform in relation other. Some characteristics can be converted to a numerical basis for e.g. lowest fuel consumption can be put as a top choice. Other characteristics for e.g. risk, do not readily lend themselves for conversion into numerical values. Though difficult, it is more meaningful if some rules can be established for each of the factors and a marking system devised so that options can be examined (Fig 2) against the rules and a number is generated to indicate quantitatively how well each option satisfies the requirement.

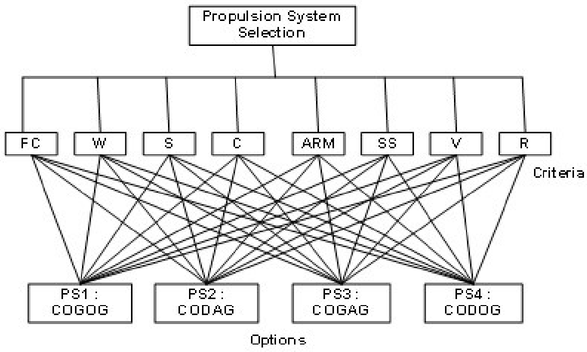


Fig 2: Selection Criteria and Options

Having decided on the criteria for selection and options available to choose from, the team collated and analyzed the information on criteria, options and feedback-form. The team chose five independent experts, handed them with detailed write-up and asked them to rate the criteria individually on the scale of 1 to 9 in comparisons to each other on a set of questions. In order to identify relative criteria, the members of were asked to rate each factor using table of relative importance shown in table 1.

Table. 1 Scale of relative importance

	Definition	Explanation
1	Equal importance	Two activities contribute equally
3	Weak importance of one over another	Experience & judgment slightly favour one over another
5	Essential or strong importance	Strongly favour one over another
7	Very strong and demonstrated	Strongly favoured and its dominance demonstrated in practice
9	Absolute importance	Evidence favouring one over another is of the highest possible order
2,4,6,8	Intermediate values between adjacent scale values	

Merit Numbers and Weighing Of Criteria

In practice, AHP has two basic applications namely, first, assign weights to a set of predetermined elements and make decision out of several scenarios or alternatives and secondly, prioritize elements in order to identify the key elements. Not all factors are going to be equally important in a design e.g. in a space critical in some ship and fuel consumption in other. Weighing factor will depend on judgments by the experts' committee involved. The members independently assigned the merit numbers to each factors. Thereafter, the committee sat together and discussed each rating and arrived at consolidated ratings value. When any difference arose, the easiest way come to conclusion was by calculating the weighted average of all numerical assessments. Higher the weighted average, better the choice. The weighted average of all the experts would indicate the numerical assessment of the option. The judgmental matrices were then formulated based on the feedback report of the experts committee by using the consolidated ratings obtained from the expert committee for each of the criteria.

Solving the current case

Judgmental matrix for the eight evaluation criteria. The matrix is drawn by comparing pair-wise one characteristic against the other. The ratings are written down row-wise. For e.g. in first row 'C' is compared with C, W, S…and relative merit of C is written down. C is 1/3 of W, implying that 'weak importance of one over other'. (Hence W will be 3/1 of C, as reflected in column). Similarly W to R is 9/1, implying absolute importance of W over R.

Calculate the Weighted Average. The weighted Average is calculated using following steps:-
(a) Calculate sum of all cells column-wise.
(b) Divide values of in cell by their respective column total (a).
(c) Then add (b) values row-wise.
(d) Next find the Avg of (c). This value is weighed avg of criteria (row-wise). The sum of all total weighted avg would be One.

Check for Consistency. The consistency checks are undertaken to confirm whether the ratings are consistent and in order. If the consistency index (CI) is less than 0.1 (10%), then the ratings can be treated as consistent. The ratings may be changed and CI can be rechecked. CI is the Eigen value of the matrix. The CI for problem in hand is 0.08. Hence, the ratings are consistent.

When the relative rating of the criteria is found be consistent, the pair-wise comparisons are to be undertaken w.r.t. the options available. As we have 8 criteria and 4 options (PS1, PS2, PS3 & PS4), the expert committee would have rated options available by considering each criteria. Then, build eight 4X4 matrices i.e. one each matrix for each criteria. The averaged weights and CI for each of the matrices is to be computed.

(a) Pair-wise comparison for fuel consumption (FC)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1	3	5	5	0.523667	0.01
PS2	0.333	1	5	3	0.262871	
PS3	0.2	0.2	1	0.2	0.060935	
PS4	0.2	0.333	5	1	0.152527	

(b) Pair-wise comparison for Weight (W)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	0.333	5.000	0.200	0.199	0.05
PS2	3.003	1.000	0.333	0.333	0.169	
PS3	0.200	3.003	1.000	0.333	0.179	
PS4	5.000	3.003	3.003	1.000	0.453	

(c) Pair-wise comparison for Space (S)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	3.000	1.000	5.000	0.358	0.01
PS2	0.333	1.000	0.142	0.500	0.077	
PS3	1.000	7.042	1.000	7.000	0.473	
PS4	0.200	2.000	0.143	1.000	0.092	

(d) Pair-wise comparison for IPC (IPC)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	2.000	0.500	3.000	0.303	0.01
PS2	0.500	1.000	2.000	3.000	0.303	
PS3	2.000	0.500	1.000	3.000	0.303	
PS4	0.333	0.333	0.333	1.000	0.090	

(e) Pair-wise comparison for ARM (ARM)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	0.500	0.330	3.000	0.195	0.01
PS2	2.000	1.000	2.000	2.000	0.371	
PS3	3.030	0.500	1.000	3.000	0.321	
PS4	0.333	0.500	0.333	1.000	0.114	

(f) Pair-wise comparison for Signature & Shock (SS)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	0.330	3.000	3.000	0.275	0.01
PS2	3.030	1.000	2.000	3.000	0.420	
PS3	0.333	0.500	1.000	5.000	0.220	
PS4	0.333	0.333	0.200	1.000	0.085	

(g) Pair-wise comparison for Vulnerability (V)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	3.000	0.200	5.000	0.290	0.05
PS2	0.333	1.000	0.140	0.333	0.051	
PS3	5.000	7.143	1.000	0.333	0.388	
PS4	0.200	3.003	3.003	1.000	0.271	

(h) Pair-wise comparison for Risk (R)

	PS1	PS2	PS3	PS4	Wt Avg	CI
PS1	1.000	0.333	1.000	0.200	0.103	0.01
PS2	3.003	1.000	5.000	1.000	0.397	
PS3	1.000	0.200	1.000	0.333	0.103	
PS4	5.000	1.000	3.003	1.000	0.397	

Decision Matrix

The decision making matrix is formed by combining all above results. The alternatives are arranged in rows and criteria in columns.

Wt	*0.255*	*0.281*	*0.060*	*0.109*	*0.143*	*0.065*	*0.029*	*0.054*
Criteria	**FC**	**W**	**S**	**IPC**	**ARM**	**SS**	**V**	**R**
PS1	0.524	0.199	0.358	0.303	0.195	0.275	0.290	0.103
PS2	0.263	0.169	0.077	0.303	0.371	0.420	0.051	0.397
PS3	0.060	0.179	0.473	0.303	0.321	0.220	0.388	0.103
PS4	0.152	0.453	0.092	0.090	0.114	0.085	0.271	0.397

The overall rating of each of the Propulsion Integrate Options is calculated as shown. For PS1 = 0.524*0.255+0.199*0.281+…..+0.103*0.054. The overall ratings of all options are :-

(a) For PS1 = 0.303
(b) For PS2 = 0.255
(c) For PS3 = 0.204
(d) For PS4 = 0.232

The option, PS1 i.e. COGOG arrangement emerges to be the best suited propulsion system for the illustrated example. This choice is likely to satisfy maximum of criteria than any other options.

II. Conclusions

The AHP is assisting the decision makers to arrive at a consultative and objective decision. In MCDM models, it is not possible to identify which criteria is the most important and by how much. The main contribution of this illustration is, therefore, the identification of most critical parameter and setting hierarchy of all parameters to select the propulsion system. The most important criteria found out were Weight followed by Fuel Consumption. It is pertinent to remember that the importance (weightage) of the criteria may wary with change in conditions under which the decision to be made. Change in conditions would change the importance of the criteria.

The model demonstrates how to assign the numerical values to intangible parameters. The objective comparison of tangibles and intangibles is thus possible and decision maker could arrive at decision which could be backed up by numbers. The AHP uses expertise of the specialists to individually evaluate the options and then combine their evolutions to provide the optimal decision.

Use of analytical methods like AHP, Fuzzy AHP etc would aid the decision maker to arrive at more objectively and hence are recommended to be used in various applications in the Navy.

References

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