A decision support model for selecting between alternative fishing vessel designs

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The scope of this paper deals with the decision-making process concerning selection of a stern trawler design from among several available alternative designs. A decision support model based on the analytical hierarchy process (AHP) was used to assist in the decision. This paper describes how the stern trawler design selection problem is modeled as a multiple objective decision making (MODM) problem. A model is built with goal, objectives defining main criteria involved in the selection process such as economic, technical or safety criteria and sub-objectives under the defined main criteria for which data are known or subjective judgments can be made. The goal, objectives, sub-objectives and alternatives are arranged in a hierarchy Pairwise comparisons are made between the different objectives and between the different sub-objectives for a case study involving several alternative stern trawler designs, showing the methodology and its application. The alternatives are evaluated and compared and the results are discussed.

ان من نطاق هذا البحث كيفية التعامل مع عملية اتخاذ القرار فيما يختص باختيار تصميم لاحدى مراكب الصيد من نوع الجر الخلفى من بين عدة تصميمات مختلفة ومتاحة. لقد تم استخدام نموذج دعم قرار مبنى على طريقة التسلسل الطبقى التحليلية للمعاونة فى اتخاذ القرار. هذا البحث يصف كيفية نمذجة مسألة اختيار تصميم لسفينة صيد من نوع الجر الخلفى باستخدام نموذج اتخاذ قرار ذى غايات متعددة. ان النموذج موضح بالهدف، والغايات التى تعرف المعايير الاساسية الخاصة بعملية الاختيار مثل المعايير الاقتصادية والتقنية ومعايير الامان والغايات التحتية المعرفة والتى تأتى بعد الغايات الاساسية وتعرف لها بيانات أو التى يمكن ان تتخذ لها تقديرات شخصية. فى هذا البحث، تم ترتيب الهدف، والغايات والغايات التحتية والاختيارات فى تسلسل طبقى. وقد تم عمل مقارنات زوجية بين الغايات المختلفة وبعضها وبين الغايات التحتية وبعضها لدراسة حالة تتضمن عدة اختيارات لتصميمات سفن صيد من نوع الجر الخلفى تبين الطريقة وكيفية تطبيقها. وقد تم ايضا عمل تقديرات للا ختيارات المختلفة ومقارنتها وتمت مناقشة النتائج.

Keywords: Fishing vessel design, Decision support, Analytic hierarchy process, Utility functions, Data ratings

1. Introduction

Selecting from among several alternative engineering designs, in general, and in particular between alternative ship designs is a task that involves evaluating and comparing the acceptable alternatives in order to reach a decision on which alternative is considered to be the " best" alternative for the desired service. " Best" design is largely dependent on the preferences of the decision-maker who is the person responsible for making the selection. The selection or decision making process involves more than one criterion. Some of these criteria may be difficult to quantify and sometimes conflict. Such multiple criteria problems need methods classified as Multiple Objective Decision Making (MODM) methods. Many such methods were developed over the last thirty years or so [1,2], and have been successfully used in various engineering and non-engineering fields such as business manage ment, medicine, etc.

Ship design is a field which covers multi-disciplines and in which the designer must balance between these different disciplines to reach his goal. The main dimensions of a ship such as length L, breadth B, draught T, depth D, block coefficient C_B, freeboard FB, etc decide many of the ship's characteristics, e.g. stability, hold capacity, power requirements, and even economic efficiency [3]. A ship design must meet a number of objectives that should be set at their most desirable level [4]. When setting these objectives, one should arrange them in their order of importance. For some types of ships, weight is a critical objective, while for other types volume, deck area, linear dimensions, stability, or tonnage may be the critical objectives. Acquisition cost and operating economy are critical objectives to which the ship owner attaches a high level of importance. Designs prepared by shipyards for a competitive tender almost always give priority to acquisition or first cost.

The main objectives or criteria for fishing vessels relate to the type of fishing they are intended for, such as, bottom stern trawling for demersal fish species, mid-water stern trawling for pelagic fish species, beam trawling for flatfish and shellfish, purse seining for pelagic species, longlining, etc. The different types of fishing vessels and methods are described in [5] and [6]. Other criteria include the range or time spent away from the port where the catch is to be unloaded, stability, fishing equipment, deck arrangement, environmental friendliness, economics, etc. In this study, a complete model is developed defining the criteria that are to be considered in the selection of fishing vessels of the stern trawler type. This model may be used by prospective ship owners intending to purchase such a vessel, when faced with the problem of having to select between alternative designs, e.g. tender offer.

The ship owner becomes a decision maker needing efficient tools to enable him to solve the decision problem since multiple conflicting criteria must be considered. One such tool is the Analytic Hierarchy Process (AHP), developed by T.L. Saaty [7]. Reference [8] was the first to introduce the method to marine design selection.

2. The analytic hierarchy process

The AHP was developed by Thomas Saaty [7] to help individuals and groups to systematically identify the "best" from among several alternatives. A rational or best choice is that which achieves some multiple objectives set by the decision maker(s). AHP allows decision makers to model a complex problem in a hierarchical structure having a goal, then objectives (criteria), then sub-objectives and finally alternatives, see fig. 1. AHP enables the inclusion of both objective and subjective considerations in the decision process [9].

2.1. Decision formulation

The process starts by the development of the decision hierarchy. This hierarchy represents the decomposition of a complex decision problem from high level objectives or criteria to lower level criteria. The objectives on a particular level are not equally important but should be of the same order of magnitude. This can be done by grouping criteria having the same order of magnitude together, e.g. economic criteria, performance criteria, etc. Once the hierarchy has been developed, the different criteria must be weighed relative to each other.

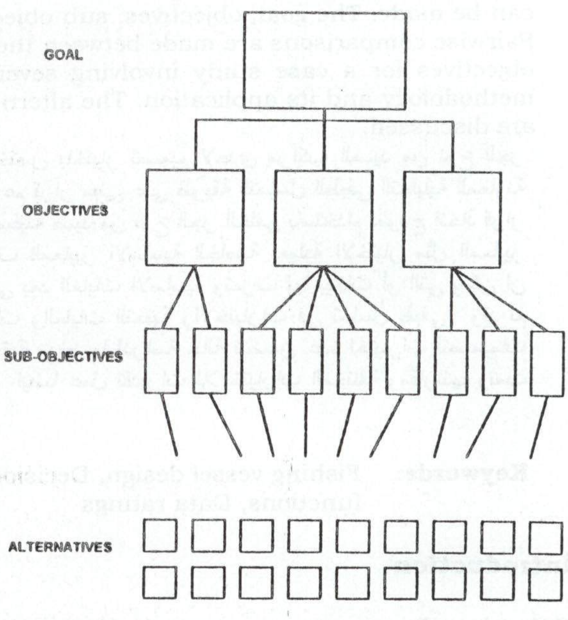

Fig. 1. A decision hierarchy.

2.2. Relative weighing

Related same level criteria in the hierarchy are compared and evaluated using a series of pairwise comparisons that take the form of matrices. The values assigned are from a numerical ratio scale defined in [7]. This ratio scale consists of predetermined numbers measuring the pairwise relative importance between same level criteria from the viewpoint of their contribution to the higher level criterion under which they are classified.

Table 1 presents the numerical ratio scale proposed in [7] for indicating the relative importance between criteria. This is a subjective procedure which depends largely on the decision maker's preferences and previous experience.

Table 1
Relative importance scale for pairwise comparisons

Value	Definition
1	Equal importance of criteria
3	Moderate importance of one criterion over the other
5	Essential or strong importance of one criterion over the other
7	Very strong importance of one criterion over the other
9	Extreme importance of one criterion over the other
2,4,6,8	Intermediate values

If data are available for some or all of the lowest level objectives, which are designated as the covering objectives, ratings or utility functions may be introduced to give them scores against each objective, for the different alternatives. The strength of AHP lies in its ability to handle simultaneously subjective judgments and data.

2.3. Problem solving

Several matrices are formed from the pairwise comparisons. To establish weights assigned to the criteria at one level with respect to the higher level criterion (say w_1 , w_2, w_3 , ..., w_n), mathematical techniques are applied. If the pairwise comparison matrix is expressed as follows:

$$\mathbf{A} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} & \dots & \frac{w_2}{w_n} \\ \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} & \dots & \frac{w_3}{w_n} \\ \dots & \dots & \dots & \dots & \dots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_3} & \dots & \frac{w_n}{w_n} \end{bmatrix}.$$

Finding the vector of weights $\mathbf{w}$, involves solving the following eigenvalue problem:

$$\mathbf{A} \cdot \mathbf{w} = \lambda \cdot \mathbf{w}$$

Matrix **A** has one non-zero eigenvalue λ_{max} , which is of magnitude n. The corresponding eigenvector is $\mathbf{w}$. The above is based on a consistent set of weights.

2.4. Measuring consistency

The decision maker's matrix of relative weights **A** is said to be consistent if:

$$a_{ik} \cdot a_{kj} = a_{ij} \quad \text{for all i, j.}$$

This is difficult to realize since the decision maker may not always be consistent in his judgments of the relative importance of the criteria. Saaty [7] defined a Consistency Index (CI) provided by:

$$CI = \frac{\lambda_{max} - n}{n - 1}.$$

The ratio of the consistency index (CI) to an average consistency index for random comparisons for a matrix of the same size, also known as the Random Index (RI) is defined as the Consistency Ratio (CR):

$$CR = \frac{CI}{RI}.$$

A consistency ratio of 1 indicates that the judgments are made at random and is actually an indicator of inconsistency.

3. Stern trawler selection: development of a hierarchical decision model

A prospective ship owner planning to buy a fishing vessel is faced with a complex decision problem. The fishing vessel in question will be required to fish in specific fishing grounds and will target some specified fish species. The first decision he will have to make concerns the type of fishing vessel and the required fishing method. The decision maker (ship owner) must decide whether he wants a custom designed vessel, a stock hull or a used vessel [10]. He may call out a tender and receive several offers in response. Each alternative offer includes a set of drawings, detailed technical specifications and pricing.

The next decision becomes complex since it involves several criteria or measures of merit.

In this study, a decision support model is developed with the assumption that the required type of vessel has already been decided upon: a stern trawler. The decision maker's goal is to select between alternative stern trawler designs. Main objectives governing the decision are identified in their order of importance: economic criteria; technical criteria; safety criteria; operational criteria; RMA- reliability, maintainability, and availability; human factors; and environmental criteria.

Fig. 2 shows the proposed model as a hierarchy with nodes shown as circles. Refs. [10-13] cover the design and economics of fishing vessels.

3.1. Economic criteria

The following economic sub-objectives are identified: acquisition cost, profitability, economic life of vessel and estimated yearly fuel consumption. The first, acquisition cost is known in a selection problem. Profitability is measured by the Internal Rate of Return (IRR) obtained from an economic analysis in which yearly operating costs and revenues must be estimated to obtain a net cash flow. IRR is the interest rate for which the Net Present Value (NPV) of the cash flows over the economic life of the vessel is zero. Taxes, inflation and effect of obtaining part of the acquisition cost through a bank loan must be included in the analysis. The economic life of fishing vessels is considered to be 25 years for new builds and can be calculated for used vessels according to their age. Ref. [14] contains a complete overview of ship design economics. The last economic sub-objective is the yearly all-purpose fuel consumption.

3.2. Technical criteria

These include size measured by the length overall (LOA), the construction material, whether the trawler is a single decker or has a shelter deck which is the modern trend. The fish hold volume must be equal to or larger than that required by the owner. Brake horsepower, free-running speed and towing speed must satisfy owner requirements. Two types of main engines are usually used on board stern trawlers: medium speed diesel engines (MSDE) or high speed diesel Engines (HSDE). The MSDE is usually preferred since it uses heavy fuel oil (HFO) and consumes less fuel than the HSDE, which uses the more expensive Diesel Oil (DO). Finally, the type of propeller is considered: fixed pitch, controllable pitch in fixed nozzle or controllable pitch in steering nozzle.

3.3. Safety criteria

The safety of a fishing vessel must comply with the requirements of reference [15]. The metacentric height (GM), FreeBoard (FB) and Bow Height (HB) must be larger than minima specified in [15]. Fire safety, life-saving appliances, navigation and communications equipment, and crew safety must also be in accordance with [15].

3.4. Operational criteria

The sub-objectives include the range, catch rate, arrangement of the deck with respect to winches, equipment, nets, and working space; whether there are one or two rigs, availability of fishing equipment such as nets and ropes, availability of fish detection equipment such as sonars and echo sounders or satellite connection. The sub-objectives also include: handling and stowage of catch, whether whole or scaled and gutted, stowed in boxes, on shelves or in tanks; and finally the method of fish preservation: in ice, chilled or frozen.

3.5. Reliability, maintainability and availability

Reliability is the probability of non-failure of the ship, propulsion plant and all systems on board. Maintainability includes frequency of preventive maintenance, cost of maintenance, spare parts requirements, downtime for maintenance, etc. Availability of the fishing vessel and systems is also included.

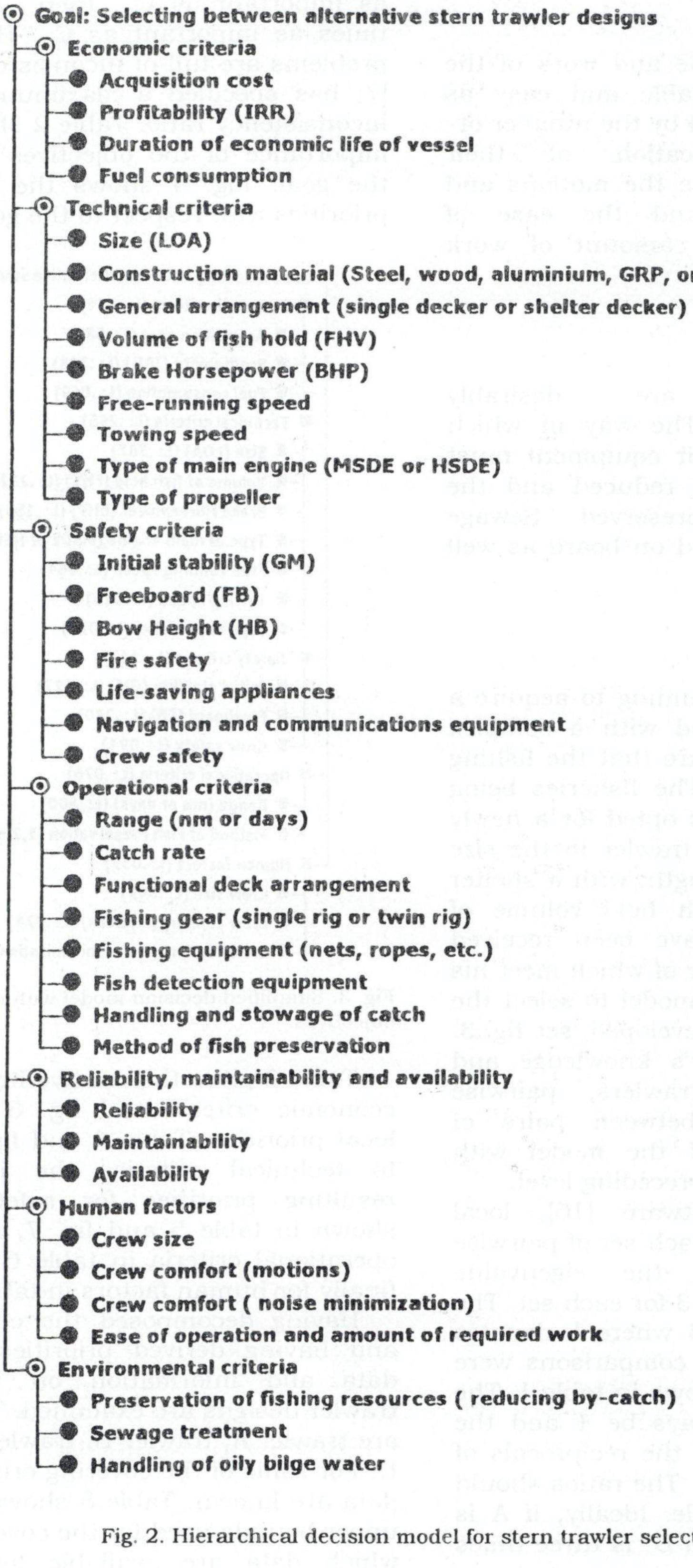

Fig. 2. Hierarchical decision model for stern trawler selection.

3.6. Human factors

This involves making life and work of the crew onboard as comfortable and easy as possible. This is determined by the number of crew needed, the location of their accommodations and hence the motions and noise they experience and the ease of operating the vessel and amount of work required by them.

3.7. Environmental criteria

Fishing vessels are desirably environmentally friendly. The way in which they are operated and their equipment must be such that by-catch is reduced and the fishing resources are preserved. Sewage should preferably be treated on board as well as oily bilge water.

4. Case study

A prospective buyer intending to acquire a new fishing vessel is faced with a complex task. He wants to make sure that the fishing vessel fits his objectives. The fisheries being already determined, he has opted for a newly built steel, twin rig, stern trawler in the size range of 20m to 30m in length; with a shelter deck and a minimum fish hold volume of $100m^3$. Different offers have been received from several shipyards, four of which meet his requirements. A simplified model to select the "best" of the four offers is developed, see fig. 3. Based on the ship owner's knowledge and experience with stern trawlers, pairwise comparisons are made between pairs of objectives at one level of the model with respect to the immediately preceding level.

Using AHP based software [16], local priorities are derived from each set of pairwise comparisons by solving the eigenvalue problem described in sec. 2.3 for each set. The results are shown in fig. 3 where L denotes local priority. The pairwise comparisons were made based on the scale shown in table 1. The diagonal elements will always be 1 and the lower triangle elements are the reciprocals of the upper triangle elements. The ratios should be as consistent as possible. Ideally, if A is twice as important as B and B is three times as important as C ; then A should be six times as important as C . However, real-life problems are full of inconsistencies and Saaty [7] has specified a maximum of 0.1 for the inconsistency ratio. Table 2 shows the relative importance of the objectives with respect to the goal. Fig. 4 shows the calculated local priorities with respect to the goal.

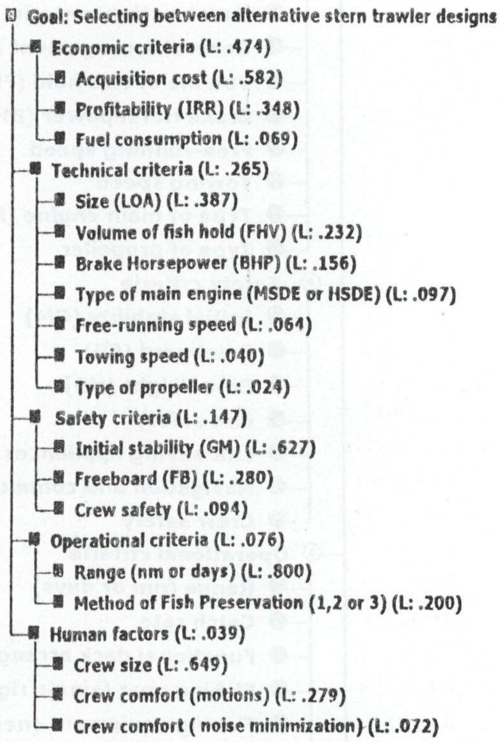

Fig. 3. Simplified decision model with objectives and sub-objectives.

Table 3 gives the relative importance of the economic criteria and fig. 5 the calculated local priorities. Table 4 and fig. 6 correspond to technical criteria. the judgments and resulting priorities for safety criteria are shown in table 5 and fig. 7, respectively; for operational criteria in table 6 and fig. 8 and finally for human factors in table 7 and fig. 9.

Having decomposed the complex problem and having derived priorities, the available data and information on the alternative trawler designs are examined. The alternatives are trawler A, trawler B, trawler C and trawler D. For some of the covering criteria, numerical data are known. Table 8 shows the lower and upper bounds used for the covering criteria for which data are available for the different alternatives. The minimum GM is specified as 0.35m and the minimum freeboard is determined from a minimum of 12.5 degrees inclination for deck immersion [15]. Table 9 shows the actual data for the four alternatives.

To compare between alternatives with known data, linear decreasing or increasing utility functions are used to translate data into values between zero and one, in order to give the alternatives scores. Fig. 10 shows the used utility function for profitability (IRR). This is an increasing function since for IRR, the larger the better.

Table 2
Relative importance of objectives with respect to goal

	Economic	Technical	Safety	Operational	Human factor
Economic	1	3	4	5	7
Technical	1/3	1	3	4	6
Safety	1/4	1/3	1	3	5
Operational	1/5	1/4	1/3	1	3
Human factor	1/7	1/4	1/5	1/3	1

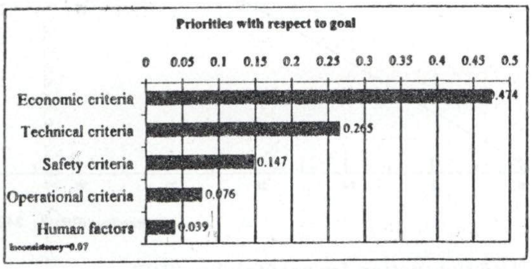

Fig. 4. Priorities with respect to goal.

Table 3
Relative importance of economic criteria

	Acq. cost	IRR	Fuel consumption
Acq. Cost	1	2	6
IRR	1/2	1	5
Fuel consumption	1/6	1/5	1

Table 4
Relative importance of technical criteria

	Size (LOA)	FHV	B.HP.	Type of ME	Free-running speed	Towing speed	Type of prop.
Size (LOA)		3	4	5	5	6	7
FHV			3	4	4	5	7
B.HP.				3	4	4	6
Type of ME					3	4	5
Free-running speed						3	5
Towing speed							4
Type of prop.							

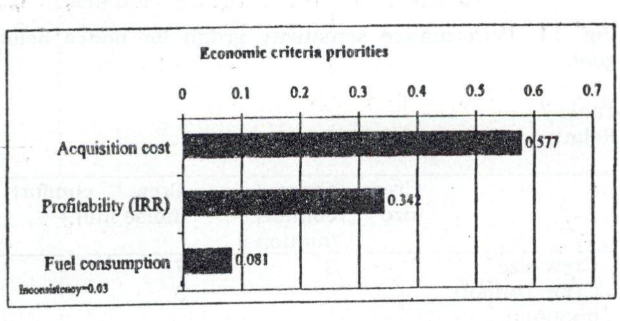

Fig. 5. Priorities with respect to economic criteria.

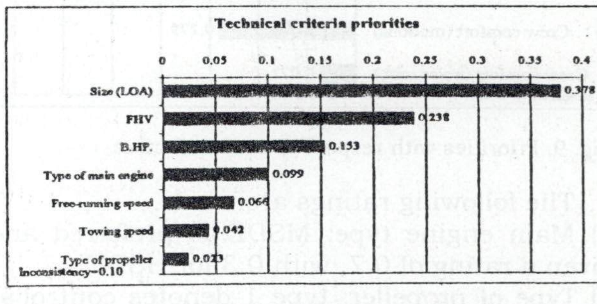

Fig. 6. Priorities with respect to technical criteria.

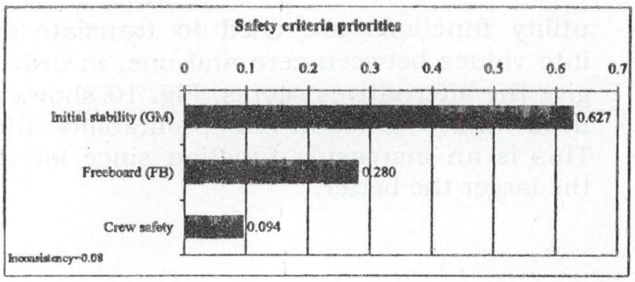

Fig. 7. Priorities with respect to safety criteria .

Table 5
Relative importance of safety criteria

	Initial stability	Freeboard	Crew safety
Initial stability		3	5
Freeboard			4
Crew safety			

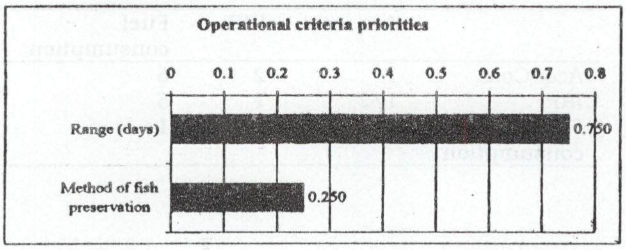

Fig. 8. Priorities with respect to operational criteria.

Table 6
Relative importance of operational criteria

	Range	Method of fish preservation
Range		3
Method of fish preservation		

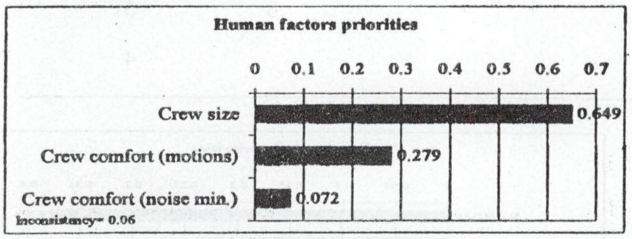

Fig. 9. Priorities with respect to human factors.

The following ratings are used:

a) Main engine type: MSDE is preferred and given a rating of 0.7, with 0.3 for HSDE.

b) Type of propeller: type 1 denotes controllable pitch propeller (CPP) with steering nozzle, with a rating of 0.65; and type 2 denotes CPP with fixed nozzle, with a rating of 0.35.

c) Crew safety: acceptable with a rating of 0.15, high level with a rating of 0.35 and very high level with a rating of 0.5.

d) Method of fish preservation: frozen (1) with a rating of 0.36, chilled (2) also with a rating of 0.36 and in ice (3) with a rating of 0.28.

e) Crew comfort (motions and noise minimization): bad with a rating of 0.1, acceptable with a rating of 0.3 and good with a rating of 0.6.

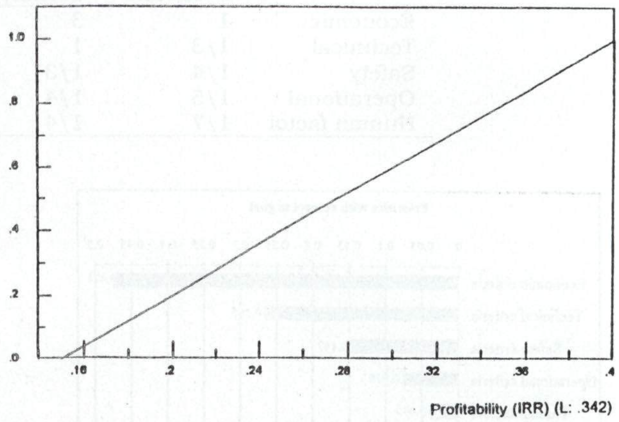

Fig. 10. Utility function for profitability (IRR).

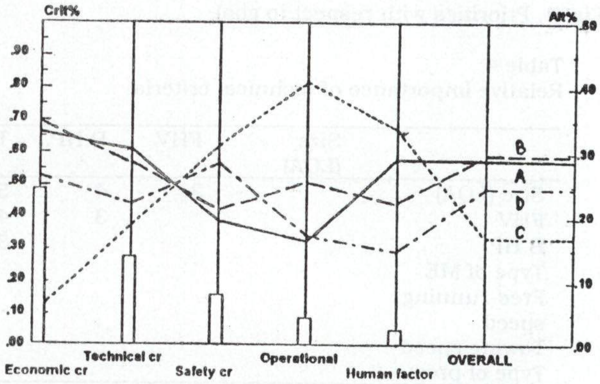

Fig. 11. Performance sensitivity graph for nodes below goal.

Table 7
Relative importance of human factors

	Crew size	Crew comfort (motions)	Crew comfort (noise min.)
Crew size		3	7
Crew comfort (motions)			5
Crew comfort (noise min.)			

Table 8
Lower and upper bounds for covering criteria

		Low	High
Economic criteria			
	Acquisition cost	$1,000,000	$3,000,000
	Profitability (IRR)	0.15	0.4
	Fuel consumption	900 tonnes/yr	1500 tonnes/yr
Technical criteria			
	Size (LOA)	20m	30m
	FHV/ Req. FHV	1	1.7
	B.HP.	700	1500
	Free-running speed	8 knts	11 knts
	Towing speed	3 knts	4.5 knts
Safety criteria			
	GM/min. GM	1	4
	FB/min. FB	1	3
Operational criteria			
	Range	5 days	15 days
Human factors			
	Crew size	4	10

Table 9
Given data for alternatives

Alternative	DECR Economic criteria Acquisition cost (0.577)	INCR Economic criteria Profitability (IRR) (0.342)	DECR Economic criteria Fuel consumption (0.081)
Trawler A	$1,600,000.00	0.24	1200 tonnes /yr
Trawler B	$1,800,000.00	0.27	950 tonnes /yr
Trawler C	$3,000,000.00	0.20	1400 tonnes /yr
Trawler D	$2,000,000.00	0.25	1500 tonnes /yr

Alternative	DECR Technical criteria Size (LOA) (0.378)	INCR Technical criteria FHV /Req. FHV (0.238)	INCR Technical criteria B.HP. (0.153)	RATINGS Technical criteria M.E. Type (0.099)	INCR Technical criteria Free-running speed (0.066)	INCR Technical criteria Towing speed (0.042)	RATINGS Technical criteria Type of propeller (0.023)
Trawler A	23.95 m	1.3	985	HSDE	10.5 knts	4 knts	1
Trawler B	27.00 m	1.7	976	MSDE	9.5 knts	3.5 knts	1
Trawler C	29.00 m	1.1	1349	MSDE	10 knts	3.5 knts	1
Trawler D	27.40 m	1.2	1340	HSDE	10.5 knts	3.5 knts	2

Alternative	INCR Safety criteria GM/ MIN. GM (0.627)	INCR Safety criteria FB/ MIN. FB (0.280)	RATINGS Safety criteria Crew safety (0.094)
Trawler A	2.28	2.5	V.H. Level
Trawler B	2.57	2.6	H. Level
Trawler C	3.66	3.66	H. Level
Trawler D	3.29	3.29	H. Level

Alternative	INCR Operational criteria Range (0.750)	Ratings Operational criteria Method of fish preservation (0.250)
Trawler A	7 days	2
Trawler B	10 days	2
Trawler C	15 days	1
Trawler D	8 days	3

Alternative	INCR Human factors Crew size (0.649)	RATINGS Human factors Crew comfort (motions) (0.279)	RATINGS Human factors Crew comfort (noise min.) (0.072)
Trawler A	9	Acceptable	Bad
Trawler B	6	Good	Acceptable
Trawler C	10	Acceptable	Bad
Trawler D	4	Good	Good

The obtained global priorities, relative to the goal for the four alternatives are:

$$G: \begin{bmatrix} \text{Trawler A} \\ \text{Trawler B} \\ \text{Trawler C} \\ \text{Trawler D} \end{bmatrix} = \begin{bmatrix} 0.288 \\ 0.297 \\ 0.169 \\ 0.246 \end{bmatrix}.$$

A performance sensitivity graph fig. 11 shows how well each alternative performs with respect to each of the major objectives. The importance of the objectives is depicted by vertical bars. The performance of each alternative with respect to each of the objectives is depicted by the intersection of their line segments with the vertical line at each of the objectives. The overall performance of an alternative is depicted by the intersection of the alternative's line segment with the "overall" vertical line at the right of the graph.

5. Conclusions

From this study, the following conclusions can be drawn:

1) The use of Multicriteria Decision Making (MCDM) methods is spreading and rapidly becoming the preferred technique for engineering design selection problems.
2) Ship design selection is a process involving many criteria, some of which are conflicting. A systematic decision making approach must be adopted to take all the different aspects of the design into consideration.
3) Decision support models in the same context as the one presented may be developed for different ship types taking into account the objectives and requirements pertaining to each type.
4) The analytic hierarchy process (AHP) is a very efficient method for use in the ship design selection problem, in general, and in the fishing vessel selection problem, in particular, as shown.
5) The decision making process must include both data and subjective judgments.

References

[1] R. L. Keeney, and H. Raiffa, " Decisions with Multiple Objectives: Preferences and Value Tradeoffs," Cambridge University Press (1993).

[2] P. Vincke, "MultiCriteria Decision-Aid," John Wiley & Sons (1992).

[3] H. Schneekluth and V. Bertram, "Ship Design for Efficiency and Economy," Butterworth-Heinemann, Second Edition (1998).

[4] D. G. M. Watson, "Practical Ship Design," Elsevier Ocean Engineering Book Series, Vol. 1 (1998).

[5] J. Fyson, "Design of Small Fishing Vessels," FAO Fishing News Books (1988).

[6] J.C. Sainsbury, "Commercial Fishing Methods: An Introduction to Vessels and Gears," FAO Fishing News Books (1996).

[7] T. L. Saaty, "The Analytic Hierarchy Process," McGraw-Hill, New York (1980).

[8] P. Sen, " Marine Design: The Multiple Criteria Approach," Trans. RINA, Vol. 134, Pt. B, pp.261-276 (1992).

[9] E. H. Forman and M.A. Selly, "Decision by Objectives: How to convince others that you are right", World Scientific, Singapore (2001).

[10] C. Hamlin, "Preliminary Design of Boats and Ships," Cornell Maritime Press, Maryland, USA (1989).

[11] M. A. Shama, "An Integrated Approach for Improving the Economics of Coastal Stern Trawlers," AEJ, Vol. 33 (2), pp. 113-125 (1994).

[12] C. Hamlin, "Systems Engineering in the Fishing Industry," Marine Technology, Vol. 23 (2), pp. 158-164 (1986).

[13] A. Papanikolaou, and E. Kariambos, "Optimization of the Preliminary Design and Cost Evaluation of Fishing Vessels," Schiffstechnik, Ship Technology Research, Vol. 41, pp. 46-52 (1994).

[14] E. C. Hunt, and B. S. Butman, "Marine Engineering Economics and Cost Analysis," Cornell Maritime Press, Maryland, USA (1995).

[15] "Safety of Fishing Vessels," International Maritime Organization, IMO (1995).

[16] User's Manual for Expert Choice 2000, Expert Choice, Inc., Pittsburgh, PA (2000).

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