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USE OF THE AHP METHOD FOR PREFERENCE DETERMINATION IN YACHT DESIGN

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ABSTRACT

A sailing yacht is a human-centred product, the design of which revolves primarily around the wants and desires of the future owner. In most cases, these preferences are not measurable, such as a personal aesthetic feeling, or a need for comfort, speed, safety etc. The aims of this paper are to demonstrate that these preferences can be classified and represented numerically, and to show that they are correlated with the type of yacht owned. As a case study, the owner's preferences for deck equipment are considered. These are determined by pairwise comparisons of the importance rankings for features previously defined by yacht owners, following the analytic hierarchy process (AHP) method. As a result, a quantitative representation of these preferences is established, and they are shown to be correlated with the type of yacht. The findings of the current study show that the yacht owners' preferences can be represented numerically, leading to a utilitarian conclusion that concerns the support and even some degree of automation of the design process.

Keywords: Yacht Design, AHP Method, Yacht User Preferences, Sailing Yacht, Human-Centred Design

INTRODUCTION

As a technical object, a yacht needs to be designed and built to withstand rough sea conditions, to ensure safety and convenience to people on board, and to provide pleasure, or possibly even the perception of luxury resulting from spending time in a unique way. As a recreational vehicle, it needs to meet the expectations of users with a wide range of comfort levels. The achievable speed of a yacht is also a significant feature, since racing forms part of the lifestyle of numerous sailors. Whatever the exact purpose, a yacht can be recognised as a human-centred object. This aspect, although clearly more prominent for a yacht than for other watercraft, is to some extent similar for many types of vessels. The main design objectives may vary depending on the type of vessel, meaning that the optimal solution depends on the specific purpose of the ship. Nevertheless, all ships must be safe at sea, economically efficient, and generally perform well within their scope of application. Although the definitions of these requirements are tailored to the purpose, the main thrust of the designer's efforts remains very similar [1].

The scientific literature in the field of ocean engineering is mainly focused on maritime transport, its impact on the environment, and ways to optimise it, with the goals of safety and health; it therefore includes issues related to improving the efficiency of ships, for example by increasing the speed, capacity, lifespan and human safety while lowering pollution, costs, risks and accidents [2], [3]. The vast majority of research on motor yachts addresses the optimisation of the hull shape and the automation of the design process [4], [5].

For a sailing yacht, the aspects most often studied are its behaviour in waves [6] and the prediction of its speed under sail [7]. Other areas of interest are the aero- and hydrodynamics of the yacht [8], the behaviour of the sails [9], and the performance of the yacht under different sail settings [10]. Existing articles have also considered masts and rigging, for example the overall strength and performance of standing rigging [11], and the optimisation of the rigging structure design process [12]. Although the human factor is considered in several of the research papers mentioned above, the main purpose of the researchers has been to improve the yacht as a technical object.

Yachts are made for people, and designers therefore prefer a human-centred approach. Human comfort on board is discussed in scientific publications in terms of ergonomic guidelines [13], [14] or with regard to the design of the interior and exterior of a yacht [15]. The term „human factor" is considered mainly in association with safety [16], [17], and rarely in relation to the conceptual design of the interior of the yacht [18]. Although the authors of the latter reference discuss the importance of knowing the customer's needs and requirements, this is not suitable for an automated design process and only applies to one-off production. The design process itself has been considered in several articles, ranging from different design approaches and ways of communicating with the customer [19], through design optimisation [20], to the entire approach to yacht design [21] which involves gathering information on the client's preferences in the initial phase of the project. Baranowski in [22], focuses on modifying a sailing yacht to accommodate disabled individuals. This process entails gaining a deep understanding of the requirements of such individuals and implementing tailored solutions on the yacht. However, it must be noted that this scenario is rare and does not extend to the production of yachts on a larger scale.

The design process is related to the selection of the best solution for a given project, although this is usually the "best" only in certain respects, such as cost or a low risk of failure, and the choice may be made using multi-criteria decision-making (MCDM) methods [23]. However, there is a noticeable lack of studies of the selection of deck equipment for a yacht in relation to the preferences of yacht owners, in other words studies that take into account a variety of different aspects of yacht operation, such as comfort, performance, cost, durability, and aesthetics. These are subject to the individual feelings of the owner, and due consideration has not yet been paid to this subject. Deck equipment should also be considered as a link between the sailor and the sail, which can act in both directions.

Questions arise as to whether it is possible to objectively examine and classify the preferences of sailing yacht owners and present them numerically, whether there are any correlations between yachts and their owner's preferences, and whether these correlations could be used in the yacht design process.

To answer these questions, the analytic hierarchy process (AHP) method, a tool that facilitates decision making, is applied in this study. The aim of this method is to make the right decision, rather than to indicate certain preferences or to find any correlations between these and other features. However, one of the steps of this method requires experts to determine the weights of the features affecting the decision-making process. These weights reflect the preferences of the experts. In the case considered here, they will be determined by the owners of sailing yachts through a survey created based on the instructions given by the developer of this method. The opinions of shipowners on the use of their yachts, for example sailing them, operating them and maintaining them in good condition, will be considered here, with deck equipment and rigging forming the main focus of the study.

The ability to determining users' preferences in a measurable, numerical way could significantly speed up the design process. The designer could then rely on these numbers to improve their design. Costs related to the replacement of failed elements, which in shipyard conditions can reach up to 40% of the value of the entire construction [24], would also decrease.

The rest of this paper is organised as follows. In the next section, the AHP method used in the study is explained, and the study preparation process is presented. The subsequent section presents the obtained results and a discussion, while the last section presents the conclusion.

IDENTIFICATION OF THE END-USER'S PREFERENCE PATTERNS

As the central idea behind this research is to identify and quantify the typical patterns of preferences of yacht end-users, the AHP method was adopted, since there are many examples of its use in solving a variety of problems where it is impossible to quantify the decision variables. This method was deemed suitable to determine the subjective ratings provided by owners of yachts.

Analytic hierarchy process

The AHP method is a multi-criteria decision support method (multiple-criteria decision analysis, MCDA) that was proposed by Saaty in the 1970s [25]. Methods of this type are used when the number of decision variables (i.e. the factors influencing the final decision) exceeds human analytical capabilities; in other words, when there are too many variables for the human mind to be able to grasp them all at once, especially if there are contradictory features [26]. The AHP is an effective method for dealing with complex problems of this type [27]. It helps decision makers set priorities between alternatives, sub-criteria and criteria in the decision-making process, and to make the best decision in a given context [23], [28]–[30]. The method is used to structure the problem, starting from the goal to be achieved as a result of making a decision, through the criteria affecting the choice, and ending with the possible options.

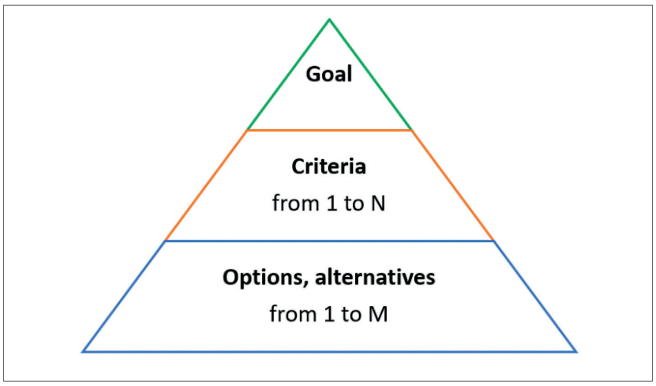

Fig. 1. The AHP hierarchy pyramid

The algorithm for the AHP method consists of several consecutive steps:

1. Determining the decision problem;
2. Developing a decision model using a hierarchical structure;
3. Comparing criteria in pairs using a fundamental scale of comparison;
4. Determining priorities and their interpretation;
5. Dealing with inconsistent answers;
6. Group decision making (aggregation of results);
7. Making a decision;
8. Analysing the effects of the decision;

This process is widely discussed in the scientific literature in relation to many different decision-making problems, including those relevant to the maritime industry, and will not be further explored in this article. For more information, please see the sources.

APPLICATION OF THE AHP METHOD IN THIS STUDY

Experts

The purpose of using the AHP method is to make the right decision, rather than to indicate certain preferences of the experts or to find any correlations between these preferences and other features. This study focuses on the opinions of yacht owners on the use of their yachts, i.e. sailing them, operating them, and maintaining them in good condition. The experts in this study are therefore all owners of sailing yachts who are responsible for their maintenance and are their main end-users.

Decision-making goal

The decision-making goal should be formulated in such a way that the experts' answers reflect their personal preferences in relation to the use of their yachts. If a decision were to be made, it should affect the quality of operation of a yacht from the point of view of the user (yacht owner). Since the direct link between the sailor and the yacht is the deck equipment and rigging, these should be the focus. Thus, the decision-making goal in this case is the selection of the optimal deck equipment for a particular sailing yacht.

Hierarchical structure of a decision problem

Tab. 1. Features of the deck equipment

Criteria	Description
Price of the accessory	Preferred value: low price.
Durability	Resistance, failure-free operation, durability, strength, ease of repair of the equipment. Preferred value: high durability.
Efficiency	Functionality, ease and convenience of use (efficiency is a general characteristic that allows one to say that one element is better than another in terms of use). Preferred value: high efficiency.
Weight of the accessory	Preferred value: low weight.
Aesthetics of the accessory	Colour, shape, attractiveness, matching the appearance of the yacht, overall visual and aesthetic impression of the accessory. Preferred value: high level of aesthetics.

- Decision goal: Selection of the optimal deck equipment for a given sailing yacht.
- Criteria influencing the decision: Based on the author's experience of sailing and professional work in the selection and sale of deck equipment, the criteria in Table 1 were identified.
- Selectable options: Groups of accessories should be identified, such as winches, staysail furlers, masts, standing and running rigging, cleats, jammers, etc. Individual products should then be associated with these groups, and solutions with different parameters should be found (e.g. Winch 1, Winch 2, Winch 3, etc.). Since the purpose of this study was to examine the preferences of users rather than to select equipment, this step was omitted.

The overall hierarchy is shown in the form of a diagram in Fig. 2.

In this case, there is one goal involving five equipment features (N = 5) that influence decision making, and 15 options (M = 15) with different parameters for each feature that classify them higher or lower. The options are not considered here.

Obtaining experts' judgements

To collect the individual judgements from the owners of a wide range of sailing yachts, a survey was created and posted in several social media groups that included yacht owners.

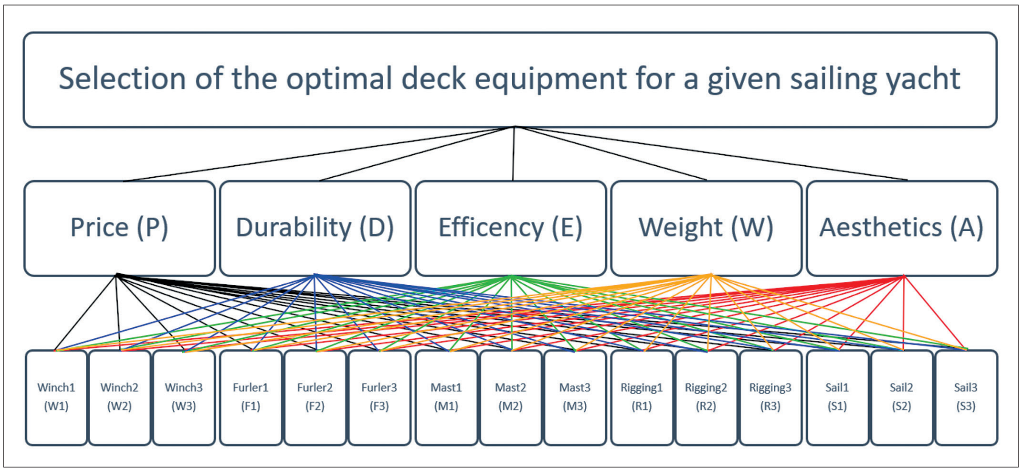

Fig. 2 Hierarchy structure tree of sailing yacht deck equipment applying the AHP method

It was also sent directly to a few yacht owners known to the authors.

The survey asked experts to compare the features listed in Table 1, in pairs. As there were five features, 10 comparisons were needed to cover all possible combinations. The respondents were asked to decide which of the two features was more important than the other, and to what extent, based on a rating scale from one to nine [25]. The scale was limited to odd numbers only (1, 3, 5, 7, 9) to make the comparison easier for the respondents. Furthermore, to check whether the preferences formed some kind of pattern, respondents were asked to provide additional information about the yacht they owned and which formed the subject of the pairwise comparison, such as the brand, hull type, main dimensions and purpose of the yacht. They were also asked to provide brief information on their sailing aspirations and age.

RESULTS

Experts' answers

A total of 48 responses were obtained from the experts, the vast majority of whom were owners of tourist/cruising yachts. The numbers of respondents for each type of yacht are presented in Table 2 below. The judgements are shown in the table in Appendix 1.

Tab. 2. Number of respondents by type of yacht owned

Yacht type owned by the respondent	Number of respondents
Racing/cruising yachts	2
Racing yachts	2
Expedition yachts	5
Seagoing cruising yachts	24
Inland/coastal cruising yachts	15

DETERMINATION OF YACHT OWNERS' PRIORITIES

To establish a priority ranking, each method mentioned in reference [26] was studied, and the outcome with the lowest consistency ratio (CR) value [25] was selected to ensure that the answers did not contradict each other. These priorities were determined for each respondent. Due to the number of responses involved, only a selection of results are shown in Table 3.

Tab. 3. Calculated individual priorities

No	Price	Mass	Efficiency	Durability	Aesthetics	CR
1	33.62%	15.19%	17.69%	26.07%	7.43%	0.1697
2	18.32%	4.76%	13.41%	52.95%	10.56%	0.1605
3	3.61%	14.29%	22.50%	50.89%	8.71%	0.2698
...						
11	16.40%	19.47%	19.47%	25.19%	19.47%	0.0339
12	26.91%	23.20%	8.61%	29.47%	11.80%	0.4303
...						

Verification

According to Saaty [25], a CR of greater than 0.1 indicates inconsistency, and the answer should be rejected. Unfortunately, an overwhelming majority of the answers to our survey were inconsistent (CR > 0.1, highlighted in red in Table 3). To investigate these discrepancies, a control participant with the highest CR was consulted, who reported that the priority weights determined by the AHP method on the basis of his answers were as he expected; in other words, he considered them subjectively correct. He also did not identify any substantive errors in the construction of the questionnaire.

Correcting respondents' answers

As the questionnaire was found to be intelligible and the priority ranking of the results was considered correct, the WAM method [31] was implemented to improve the CR.

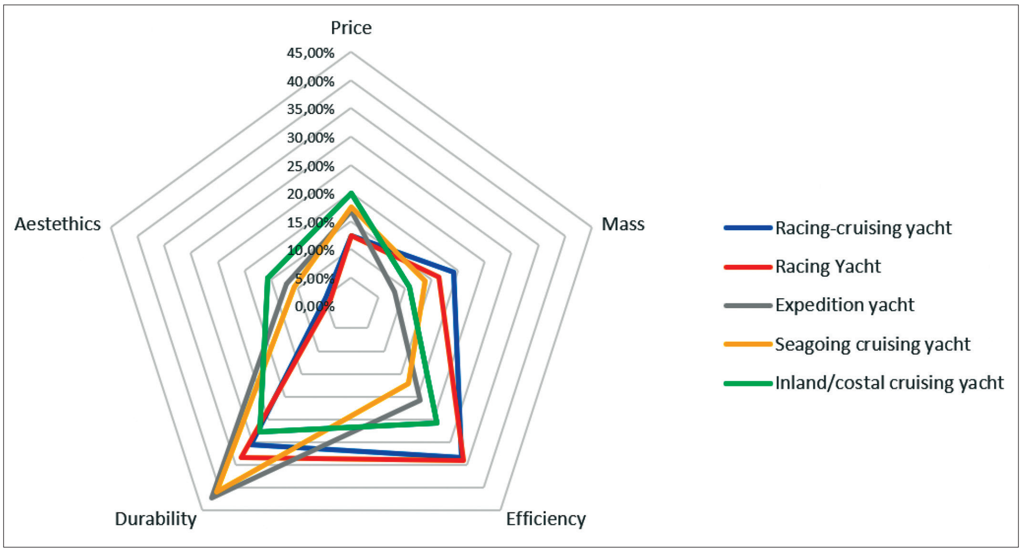

Fig. 3 Yacht owners' preferences, determined based on aggregated consistent individual judgements by yacht type

Tab. 4. Preferences of sailing yacht owners

Yacht type	Price	Mass	Efficiency	Durability	Aesthetics	CR
Racing/cruising yacht	12.45%	19.15%	33.23%	30.43%	4.75%	0.049
Racing yacht	12.41%	16.45%	33.90%	33.45%	3.78%	0.036
Expedition yacht	16.79%	8.03%	20.75%	42.22%	12.21%	0.026
Seagoing cruising yacht	17.46%	13.87%	17.18%	40.81%	10.68%	0.011
Inland/coastal cruising yacht	19.92%	10.90%	25.85%	27.71%	15.62%	0.005

Tab. 5. Preferences of sailing yacht owners aggregated before CR improvement

Yacht type	Price	Mass	Efficiency	Durability	Aesthetics	CR
Racing/cruising yacht	11.93%	17.76%	33.11%	33.03%	4.16%	0.084
Racing yacht	17.60%	15.56%	31.41%	32.24%	3.20%	0.314
Expedition yacht	16.85%	7.80%	20.31%	43.69%	11.35%	0.061
Seagoing cruising yacht	17.39%	13.53%	16.31%	42.34%	10.43%	0.045
Inland/coastal cruising yacht	19.79%	11.01%	25.01%	28.65%	15.53%	0.022

The individual judgements were corrected, and new priorities and CR values were calculated. The new results are shown in the table in Appendix 2.

Group aggregation results

After aggregating the results according to the values specific to each yacht (such as the overall length (LOA), breadth (B), displacement (D), etc.), according to the factors of slenderness, comfort, etc., it was concluded that the purpose of the yacht had the greatest correlation with the priorities. The individual judgements were divided into groups related to the type of yacht owned, and then aggregated using the geometric mean method [32]. As a result, the percentage degree of importance was obtained for each of the features of the deck equipment, depending on the type of yacht. The results are shown in Fig. 3 and Table 4.

In order to explore the impact of improving the respondents' answers on the relevance of the results, inconsistent judgments were also aggregated for comparison. It was found that the aggregation method using the geometric mean had a positive impact on the final CR, which was greater than 0.10 only for the group of racing yachts. The results obtained from this process were very similar to those of the improved answers, as shown in Fig. 4 and Table 5.

DISCUSSION

The use of a nine-point rating scale and a pairwise comparison of features seems to be a good method for determining priorities among yacht owners. The results showed that durability was the most important feature for expedition and seagoing cruising yachts, whereas the efficiency and mass of an accessory were the most important aspects for racing and racing/cruising yachts. The owners of inland/coastal cruising yachts had the most balanced priorities (regardless of the mass of an accessory) and valued aesthetics most highly.

The use of the AHP method imposes certain limitations on the results. The method used to conduct the study, the number of respondents, their questionable proficiency in the

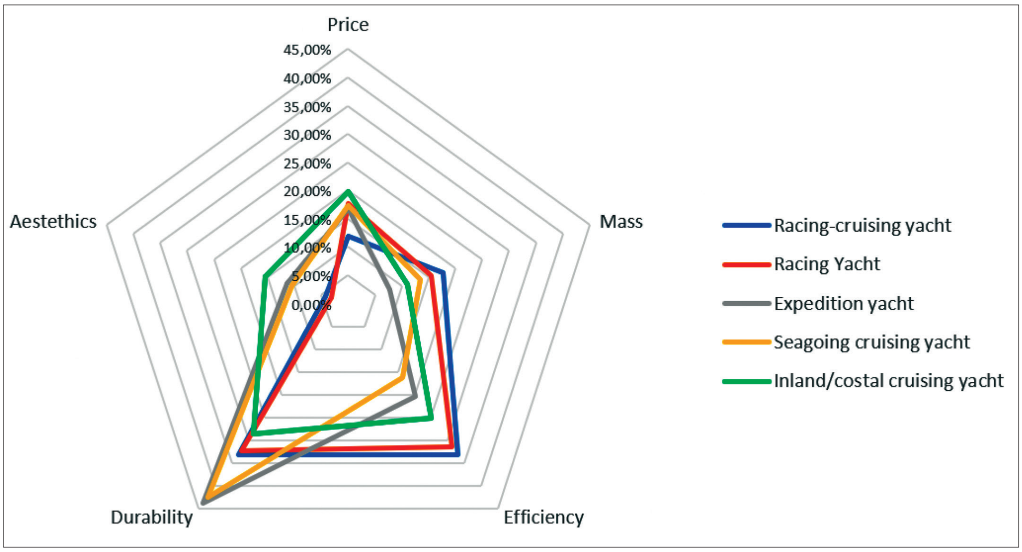

Fig. 4 Yacht owners' preferences determined based on aggregated inconsistent individual judgements by yacht type before CR improvement

field under study and the consistency of the matrix of their answers differ significantly from the recommendations made by the developer of the AHP, which may cast doubt on the results obtained in this work. However, as indicated by the control respondents, the prioritisation of their responses was in line with their expectations, even if the CR was greatly inflated. Furthermore, a comparison showed that the improvements to the CR had a negligible effect on the final results in terms of the priorities. The biggest error was found in the priority of the price reported by racing yacht owners, which reached 5%, whereas the error in the efficiency was 2.5% and the variability in all the other priorities was less than 1%. This error was due to the small number of respondents in this group (two people) and the fact that one of them gave very inconsistent answers.

Most of the inconsistent answers that required correction came from the owners of tourist yachts. Some of them pointed to the extreme advantage of feature 1 over feature 2, feature 2 over feature 3, and feature 3 over feature 1. As if all features were equally important to them. It can therefore be concluded that people engaged in hobby, tourist and recreational sailing do not have extensive expert knowledge of the field of equipment selection, and are not aware of the frequent need to compromise. Much less extreme responses were received from the owners of racing and expedition yachts, although only two responses were received from racing yacht owners, one of which was very inconsistent.

Research has shown that the preferences of yacht owners in terms of equipment vary depending on the purpose of the yacht. The purpose also affects their sailing aspirations; for example, an owner may take advantage of the qualities of an expedition yacht to go on long voyages. This, in turn, affects the owner's experience and expert knowledge.

The results obtained here indicate that the AHP method can be used as a priority setting tool. However, the question to be answered differs from the one that will be posed in the method as a decision problem, meaning that it needs to be very carefully thought out.

CONCLUSION

The aims of this study were to examine, classify and numerically rank the preferences of sailing yacht owners, and to explore whether these preferences depended on the type of yacht owned. The AHP method was applied to the research problem, and it was shown that these preferences were correlated with the purpose of the yacht owned by the respondent. A scheme for the numerical representation of these intangibles was presented, and may be valuable in the yacht design process, as these data are much more comprehensible and can be processed by a computer in this form.

The research results show that a group of people who own similar vessels have similar preferences and expectations towards their yachts and the related equipment. It can therefore be concluded that when designing a new yacht, properly determining the preferences of the future owner will lead to a more precise determination of the yacht's purpose. This, in turn, leads to a more accurate determination of the required nautical qualities, yacht size, equipment etc. When these preferences are expressed as numerical values, they can be used to automate the selection of certain elements, which can significantly improve the design process.

Since a relatively small group of yacht owners was involved in this study, it would be advisable to carry out further work with larger groups. Data collected from a much larger number of respondents might allow their preferences to be classified according to other factors, such as the sailing area or the size of the yacht. The use of these data in the design process is therefore the next step for future work. The classification of equipment components according to the features presented here, and assigning them to particular types of yacht, would be possible avenues to explore.

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