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Maintenance policy selection for ships: finding the most important criteria and considerations

A.J.M. Goossens[a,*], R.J.I. Basten[b]

[a] University of Twente, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, The Netherlands
[b] Eindhoven University of Technology, School of Industrial Engineering, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands

Abstract

Maintenance of technical capital assets is gaining increasing attention, as maintenance is an important contributor to reach the intended life-time of these expensive assets. This paper focusses on maintenance policy selection (MPS) for ships using the Analytic Hierarchy Process. It builds on earlier research where we have investigated MPS specifically for naval ships. Here, we aim to generalize our findings on naval ships towards ships in general, and to elicit the most important criteria for ship MPS. We propose an improved hierarchy of criteria that we use during six workshops at six different companies to investigate MPS. We conclude that it is possible to obtain meaningful outcomes using a single hierarchy of criteria at multiple companies considering various ship types. The workshops reveal that *crew safety* is the most important criterion when selecting a maintenance policy, followed by *reliability* and *availability*—surprisingly, *costs minimization* is only moderately important. Furthermore, the workshops reveal that softer criteria, such as *experience with maintenance* and *planability*, must be included in the MPS process. Finally, we see that, for ship MPS, failure-based maintenance is never preferred, and that there is no clear preference for either time/use-based maintenance or condition-based maintenance.

Keywords:
Maintenance, maintenance policy selection, ship, analytic hierarchy process

1. Introduction

How to maintain technical capital assets is a question gaining increasing attention and relevance [1], as maintenance is an important contributor to reach the intended life-time of these expensive assets. Maintenance can be defined as all activities which aim to keep a system in or restore it to the condition deemed necessary for it to function as intended [2, 3]. By technical capital assets we mean capital intensive, technologically advanced systems that have a designed life-time of at least 25 years, such as trains, ships and aeroplanes.

Based on [3, 4], we define a maintenance policy as a policy that dictates which parameter (for example, elapsed time or amount of use) triggers a maintenance action. Selecting the right maintenance policy is an important decision in maintenance decision making. In practice, current selection methods do not always fit companies well and current, mostly quantitative, maintenance optimization and decision models have low applicability. Hence, the need for tailored maintenance models and concepts is raised in the literature [1, 5]. Several authors argue that practical studies are under-represented, strongly encouraging efforts to close this gap between theory and practice [1, 6, 7].

We look at maintenance policy selection through the use of the Analytic Hierarchy Process (AHP), a multiple criteria decision making (MCDM) method in which the decision problem is structured in a hierarchic way, developed by Thomas Saaty in the 1970s [8].

The first study using the AHP specifically for maintenance policy selection was published in the year 2000 [9]. Since then, more case studies followed [10–15]. The use of the AHP for maintenance decision making emerges in the second half of the 1990s [16–18], when it was recognized that many maintenance decisions can be modelled as MCDM problems [16, 19] and the AHP already found its way in other engineering applications [20]. The AHP structures the decision problem into a decision hierarchy, and uses a series of pairwise comparisons to weigh the criteria and score the alternatives. These comparisons lead to the final preferences of the alternatives, presented as fractions totalling to 1. For the pairwise comparisons, a ratio scale from 1 – 9 is used to indicate how many times more important or dominant one element (criterion or alternative) is over another: 1 to indicate an equal importance, 2 – 9 to indicate a higher importance. Their reciprocals are used to indicate a lower importance. A more extensive explanation on the AHP and its use can be found in [21, 22].

In our earlier research [23], we have investigated maintenance policy selection (MPS) for naval ships, where we developed a hierarchy of criteria usable with the AHP based on both interviews in practice and the relevant literature. We then conducted a series of three workshops in the naval sector: at the owner, the shipbuilder and an original equipment manufacturer of naval ships in the Netherlands. We concluded that the AHP is well suited for maintenance policy selection and that it provides

*Corresponding author; *tel:* +31 53 4891043
Email addresses: a.j.m.goossens@utwente.nl (A.J.M. Goossens), r.j.i.basten@tue.nl (R.J.I. Basten)

a structured and detailed approach for MPS.

Building on this previous research, the current paper focusses on maintenance policy selection (MPS) for ships in general and contributes in three ways.

- We construct a new hierarchy of criteria, taking into account the evaluations of the naval hierarchy by the participants of the three workshops in [23]. We have not encountered the use of such feedback in the literature so far. We use this hierarchy at six new workshops at six different companies that consider various ship types.
- With the six workshops, we aim to further generalize the previous findings towards ships in general. During these workshops the participants go through the AHP using the new hierarchy of criteria and afterwards evaluate the workshop. These evaluations provide insight in applicability and generalization of our AHP-based MPS method: can a single hierarchy of criteria be used at various companies for various ship types and provide meaningful outcomes?
- We conclude on the most important criteria and considerations for ship MPS. During these workshops we inherently elicit the preferences of all the participants on both the weights of the criteria and the scoring of the maintenance policy per criteria. These preferences give insight in what is—and what is not—found important in practice when selecting a maintenance policy.

The paper is structured as follows. In Section 2, we explain how we use the feedback to construct the new hierarchy of criteria and then present this hierarchy. In Section 3, the MPS workshops are explained. The workshops generate two types of results: the quantitative outcomes of the criteria weights and policy preferences and the participants' qualitative evaluation of the workshops. These results are discussed in Section 4. Lastly, the conclusions on the three main points of this paper are drawn in Section 5, along with giving recommendations for further research.

2. The hierarchy of criteria

Constructing the hierarchy of criteria, we build upon the earlier version of the hierarchy that was used for naval ships (presented in [23]). The initial criteria for this hierarchy are drawn from eighth interviews in industry, presented in Table 1, and case studies in literature that use the AHP for MPS [9–15]. Of the list of 187 criteria (see Appendix A), the 46 criteria that were mentioned three times or more in total were used to construct the naval hierarchy.

For the construction of the new hierarchy, we take several steps. Most importantly, taking into account the evaluations of the naval hierarchy by the participants of the three workshops in [23], remove the criteria that received very low weights (i.e., were seen as not important) and we merge criteria that were considered overlapping. Furthermore, to reduce the size of the hierarchy, and thus reduce the number of pairwise comparisons and the time needed to do these comparisons, the criteria that are mentioned four times or more in total in the original list of 187 are used as the starting point (see Appendix A). The initial amount of criteria used for constructing the hierarchy is brought down from 46 to 24 by this step only. The new hierarchy of criteria is presented in Figure 1 and is discussed top-down, per level in the hierarchy in the following subsections.

2.1. *The complete hierarchy*

The goal of the decision hierarchy is to select the best maintenance policy. We maintain the general structure for the hierarchy, because it was found to be clear and understandable. The hierarchy starts with a division into *goals* and *fit*. Beneath these two top level criteria, the hierarchy is structured into six second level sub-criteria and 21 lowest level criteria.

2.2. *The first level of criteria:* goals *and* fit

The division into *goals* and *fit* was well-received. Therefore, we keep this top-level division in the hierarchy. *Goals* focusses on the maintenance goals of the company, while *fit* considers how well the maintenance and maintenance process fits to the company.

2.3. *The sub-criteria*

To bring more balance in the hierarchy, the difference in number of sub-criteria beneath *goals* and *fit* is brought down by reducing the amount of criteria beneath *fit* from six to four. The number of sub-criteria beneath *goals* remains two. The resulting sub-criteria are as follows.

- Beneat *goals*:
  - *KPIs (Key Performance Indicators)*: measurable reasons for doing maintenance; and
  - *desirables*: reasons for doing maintenance that cannot be easily measured or quantified.
- Beneat *fit*:
  - *fit to operations*: the operational aspects to consider;
  - *fit to relations*: the internal and external relations of the company;
  - *fit to spare parts*: the spare parts and the presence commonality; and
  - *fit to tasks*: the influences on performing maintenance tasks.

2.4. *The lowest level criteria*

To continue bringing balance in the hierarchy, all lowest level criteria are clustered in similar size groups of three or four criteria. *Costs minimization* is included as KPI; in [23], it was deliberately chosen not to focus on costs, to not get distracted from the focus on the goals and fit. However, during the naval evaluations all participants stated a costs criterion should be included. Furthermore, all criteria concerning the mission are merged into one: *mission profile*. Lastly, we do not incorporate *rules and regulations* and *warranty periods*, as they do not offer

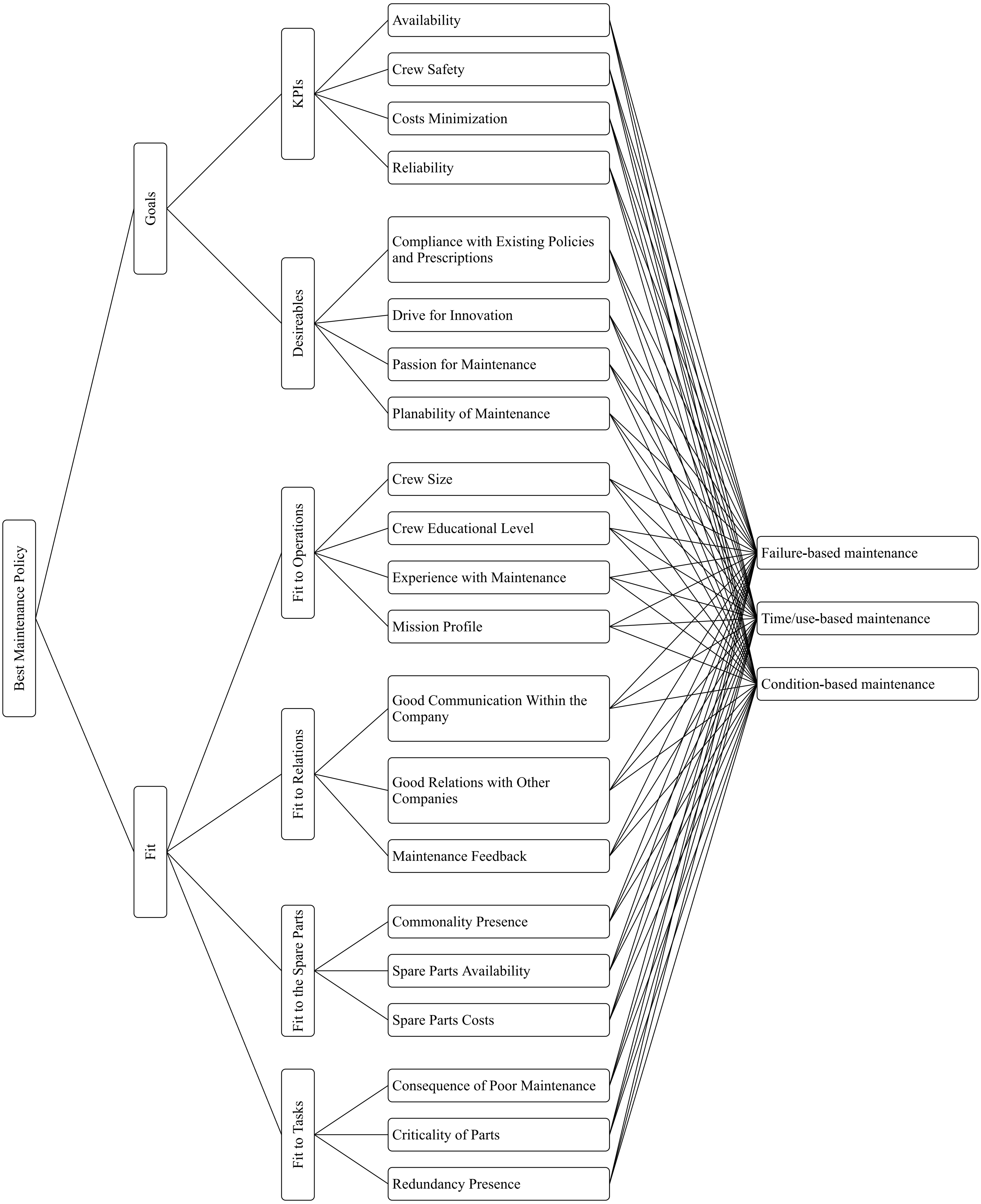

Figure 1: The hierarchy of criteria

Table 1: Interviewed company and interviewee roles, from [23].

Company role	Company	Interviewee role
Damen Schelde Naval Shipbuilding	Naval specific shipbuilder	ILS provider
Imtech Marine	General maritime maintainer	Maintainer
Lloyd's Register EMEA	General maritime classification society	Regulator
Thales	Naval specific OEM	Designer, ILS provider
Royal Netherlands Navy	Vessel owner and operator	User, maintainer, regulator

Table 2: Workshop, company, ship sector and case overview.

Company	Company role	Ship sector	Participants	Company case
Alewijnse	Maintainer	Various	2	General cargo ship
Damen Shipyards Gorinchem	Shipbuilder	Tugs	3	Tug product group
Fugro Marine Services	Maintainer	Research vessels	3	System on research vessels
KNRM	Owner & operator	High speed service crafts	6	Class of RHIB[a]
Loodswezen	Owner & operator	High speed service crafts	3	Fleet of pilot tenders and SWATHs[b]
SmitLamnalco	Owner & operator	Tugs	4	Class of tug

[a] Rigid-hulled Inflatable Boat [b] Small Waterplane Area Twin Hull

a choice, they are fixed. Instead, to allow for deviation from these fixed rules, we incorporate the criterion *drive for innovation*.

Overall, a reduction from 29 to 21 criteria in the lowest level of criteria in the hierarchy is obtained. The definitions of the criteria, as used during the workshops, are listed in Appendix B.

2.5. The alternatives: the maintenance policies

As mentioned in Section 1, we define a maintenance policy as a policy that dictates which parameter (for example, elapsed time or amount of use) triggers a maintenance action. In [23], three policies are used as alternatives and during the evaluation these three were well received by the participants. Therefore, we keep the three policies:

- *failure-based maintenance*: corrective maintenance, where a failure triggers the maintenance;
- *time/use-based maintenance*: planable maintenance, where either the elapsed time or the amount of use triggers the maintenance; and
- *condition-based maintenance*, where a measured condition triggers the maintenance.

3. The maintenance policy selection workshops

To put the hierarchy to practice, we organize six workshops at six different ship companies. For an overview of these companies, see Table 2. During these workshops a maintenance policy is selected for a system chosen by the participants: the company case. The workshops take about three to four hours per workshop and all six structured identically:

1. an introductory presentation;
2. a fictitious example case;
3. the selection and the discussion of the company case;
4. discussion of the results; and
5. evaluation of the workshop.

During the introductory presentation (1) the planning of the workshop and the nature of our research are presented. To get the participants acquainted with the AHP, they are guided through a fictitious example case (2) about the purchase of a new car. At the start of the company case (3), the participants are handed a copy of the hierarchy (Figure 1) and a list of definitions of the criteria (see Appendix B). The company case is then chosen by the participants (see the final column of Table 2), which can be any system of interest with no limitations on, for example, type of system or level in the system.

Doing the company case, the participants are asked to individually and manually fill out the pairwise comparisons, starting with the scoring of the alternatives and followed by the weighing of the criteria. When all participants are finished, the geometric mean is used to synthesize the inputs given by the participants and calculate the group's aggregated scores and weights [21, 22]:

$$\bar{a}^g = \sqrt[n]{a_1 \cdot a_2 \cdots a_n} = \left(\prod_{i=1}^{n} a_i \right)^{1/n}$$

where a_i is the score or weight per pairwise comparison, given by participant i, with $i \in \{1, \ldots, n\}$ and n being the number of participants present at the session. The geometric standard deviation of the inputs is used to investigate where the participants agree and disagree most within the pairwise comparisons.

Using these calculations, the following results are discussed with the participants (4): the final scoring of the alternatives, the results of the aggregated pairwise comparisons, a sensitivity analysis for the top level criterion *goals* compared to *fit*, and the pairwise comparisons where the participants disagree most.

To evaluate the workshop (5), each participant receives an evaluation form (see Appendix C) to fill out. This evaluation form consists of 16 questions divided into three categories: the session, the hierarchy of criteria, and the decision.

4. Results of the workshops

The results are split into three categories: the criteria and hierarchy, the decision and the workshop itself. Within these categories, the workshops yield results in two ways: for the first two categories the quantitative outcomes of the criteria weights and policy preferences, and for all three categories the qualitative evaluations by the participants.

4.1. The criteria and hierarchy

By the weighing of the criteria and the scoring of the alternatives, the workshops inherently elicit the preferences of the 21 participants in total. Figure 2 presents the average importances of the lowest level criteria, presented in the so-called ideal form for which all weights are divided by the largest one [21]. Looking at the criteria per cluster of sub-criteria, we notice the following.

- KPIs
  The top three criteria are all *KPIs*. *Crew safety* is by far the most important criterion, over three times more important than *reliability*, the second most important criterion, and *availability*, the third most important one. The fourth *KPI*, *cost minimization*, remarkably ranks only 12th.

- Desirables
  Planability and *compliance with existing policies* rank 5th and 6th, but *drive for innovation* and *passion for maintenance* rank 14th and 16th.

- Fit to operations
  Ranking 4th, *experience with maintenance* is the most important criterion after three of the *KPIs*. Ranking 7th, *crew educational level* is of remarkably higher importance than *crew size*, ranking 19th. *Mission profile* sits right in the centre with rank 10.

- Fit to relations
  The three criteria from *fit to relations* are of notably low importance. *Maintenance feedback*, *good communication within the company* and *good relations with other companies* rank 17th, 20th and 21st respectively.

- Fit to the spare parts
  Only *spare parts availability* seems to be of moderate importance, being ranked 8th. *Commonality presence* and especially *spare parts costs* are of low importance.

- Fit to tasks
  The three criteria under *fit to tasks* are roughly in the middle, *redundancy presence* ranking 9th, *consequences of poor maintenance* ranking 11th and *criticality of parts* ranking 13th.

The evaluation of the hierarchy of criteria by the participants is meant to determine if the hierarchy is clear and understandable, and if any criteria are lacking or redundant. The evaluations reveal that all but two participants find the hierarchy of criteria clear and understandable. Out of these two, one participant disagreed and reckons he lacks prior knowledge. The other did not fully understand the division into *goals* and *fit*. Besides this one participant, the groupings and divisions made in the hierarchy are also clear to the participants and the participants had no further comments on this.

On the criteria, most participants do not miss any criteria or alternatives and find the hierarchy complete. This is an improvement compared to the naval hierarchy in [23], where considerately more and more coherent remarks were made. Comments on the current hierarchy are quite minor, as only three participants state that mandatory maintenance by class surveys and rules and regulations should be included. As for the alternatives, one participant would like to include opportunity-based maintenance and another participant would include load-based maintenance. The participants of one company share the feeling that the hierarchy could be made more specific to their company by changing a few criteria.

Concluding, the new hierarchy is better received than the naval hierarchy in [23] it is based on. This shows that taking the feedback from practice into account improves the hierarchy. The comments the participants do make are minor and seem quite specific to the interest of that participant. Only the lack of mandatory maintenance by class surveys and rules and regulations is mentioned by multiple (3 out of 21) participants. Whether this justifies adding the criterion to the hierarchy needs further consideration.

Eliciting the participants' preferences, we expected the *KPIs availability* and *reliability* to obtain the highest global importances. Surprisingly, this is not the case, as *crew safety* obtains the highest global importance—not only of the *KPIs*, but of all the criteria. We also did not expect the low global importance of *cost minimization*, as it was specifically added to the hierarchy because of the evaluations of the naval workshops. It appears that a costs aspect is too important to leave out of the hierarchy. In other words, a costs aspect is needed to fully portray the MPS problem. However, when included, it obtains only a moderate importance. Lastly, besides the *KPIs*, all (but one) clusters of sub-criteria appear to play a role in ship MPS, especially *fit to operations* and *desirables*, providing the half of the top ten criteria. This reveals that these qualitative criteria play an important role for ship MPS and cannot be excluded from the decision. The exception is *fit to relations*, of which all criteria obtain notably low global weights. Apparently, considering the relations with other companies is not that important for ship MPS.

4.2. The decision

The final policy preference per case is shown in Table 3. It reveals that failure-based maintenance is never the preferred alternative. In three cases time/use-based maintenance is the preferred alternative, in the other three cases condition-based maintenance is preferred. The differences between time/use-based maintenance and condition-based maintenance are small in each case, and no single maintenance policy can be regarded as overall best.

When the average policy scores are considered (see Figure 2), the underlying rationales for the preferences become apparent. There is no criterion for which failure-based maintenance is, on average, the preferred policy. Time/use-based maintenance

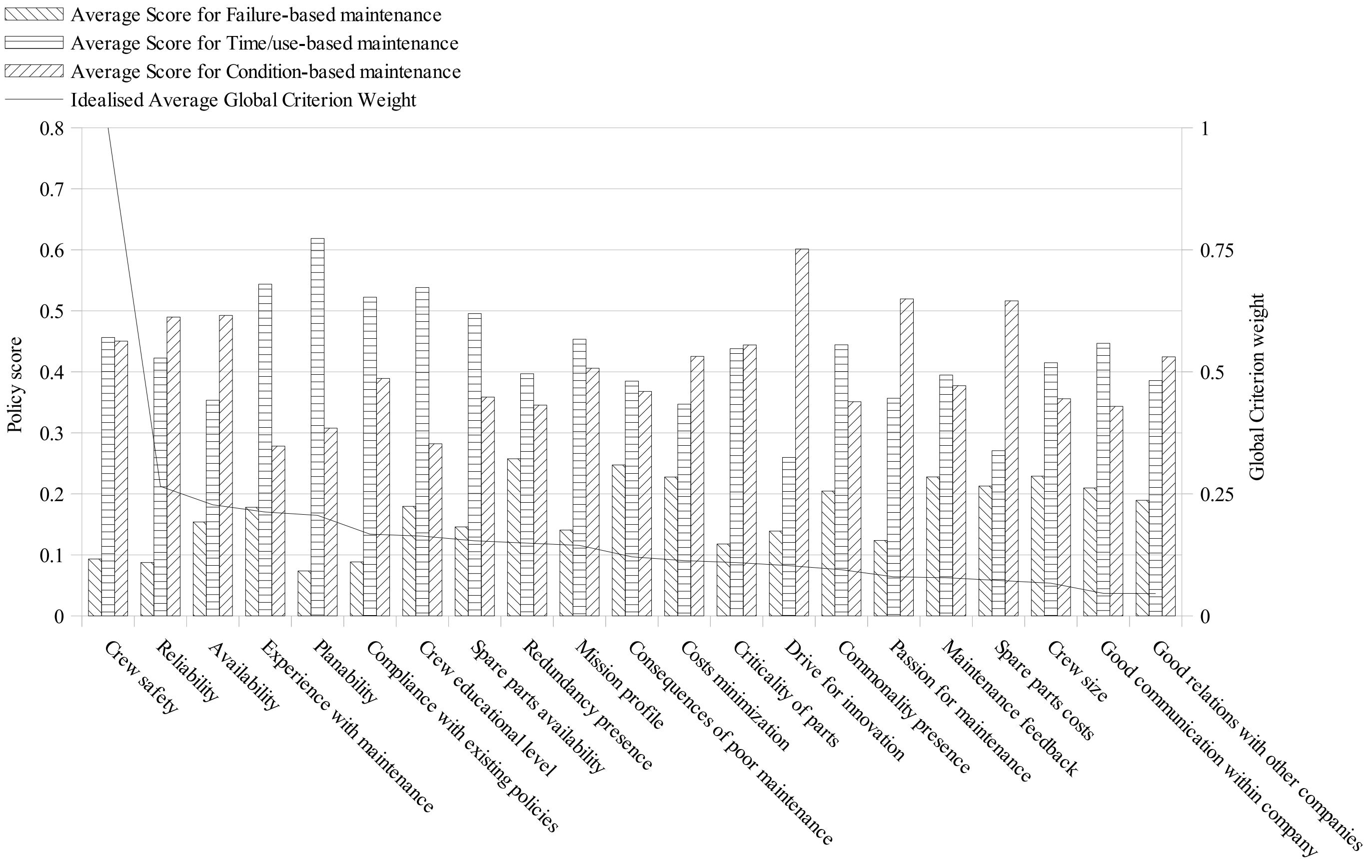

Figure 2: Idealised average global weights of the lowest level criteria and their average policy scores.

and condition-based maintenance take turn at being most preferred. The top five most important criteria are exemplary: for *crew safety* time/use-based maintenance and condition-based maintenance score almost equal. For *reliability* and *availability* condition-based maintenance is preferred, while for *experience with maintenance* and *planability* time/use-based maintenance is preferred.

However small, the largest differences between time/use-based maintenance and condition-based maintenance are seen at Fugro Marine Services and Loodswezen, that both prefer time/use-based maintenance. At the former case, this is because time/use-based maintenance receives equal or higher scores than condition-based maintenance for a remarkably high number of criteria: all but three. This overall preference for time/use-based maintenance might be explained by the combination of a highly redundant system configuration in combination with a project-based work approach. At the latter case, a comparatively high importance of *planability* strengthens the preference for time/use-based maintenance. An explanation for the emphasis on *planability* could be that because the company has its own maintenance facility where the space and resources are limited, maintenance time needs to be planned carefully and well in advance.

In the evaluation of the final decision, the questions focus on the final maintenance policy selected during the session, insight gained during the session and the level in the system for which a policy was selected. For the final policy selected, most participants would have chosen for the same maintenance policy as indicated by the AHP. Some participants expect a different order of preference and one participant would have liked to see a larger difference between the final preferences. Adding to that, all but two participants indicate that they now better understand the selection process and the decision made. The two who do not, state that the choice matched the idea already in their minds. On the level in the system for which a maintenance policy should be selected by a session like this, all but one participants agree that it would work best for high levels. While the disagreeing participant suggests every level, the others range from component-level to fleet-level, where some participants propose a selection based on criticality.

Concluding, it appears that failure-based maintenance is never an option, and that the main consideration is between time/use-based maintenance and condition-based maintenance. Using the AHP creates insight in this consideration and provides a plausible final preferred policy, useful for high levels in the system.

4.3. The workshop

The workshops themselves are evaluated by all participants. The evaluation consists of questions about the workshop in general, its usefulness and the groups with which the sessions

Table 3: The final preference of the alternative maintenance policies per case.

Company	Company case	Final policy preference Failure-based	 Time/use-based	 Condition-based
Alewijnse	General cargo ship	0.190	**0.423**	0.387
Damen Shipyards Gorinchem	Tug product group	0.107	0.430	**0.463**
Fugro Marine Services	System on research vessels	0.131	**0.523**	0.345
KNRM	Class of RHIB	0.131	0.416	**0.454**
Loodswezen	Fleet of pilot tenders and SWATHs	0.092	**0.490**	0.417
SmitLamnalco	Class of tug	0.131	0.434	**0.435**

are held. The outcomes of the evaluations of the workshops are in line with those in [23].

In general, all participants show a positive attitude towards the workshop. They find the workshop interesting, instructive and clarifying. Also, all participants liked doing the workshop. The participants indicate that the workshop offers a new perspective on maintenance and provides insight and knowledge. Furthermore, it facilitates a structured discussion on maintenance within the group, eliciting and aligning the opinions in the group. On the time needed to do such a workshop, three to four hours seems the right amount of time. Although one participant labelled the workshop as intensive and one recognizes that workshops like this take time to do well, only two participants explicitly state the workshop is too short. The other participants state that the duration is fine. Reflecting on the group, the participants indicate that the groups should be diverse. Participants in already diverse groups value this diversity, participants in less diverse groups state the need for diversity. Lastly, all but one participant would do a similar session again, either for other systems or sub-systems of their case. The one participant who would not do such a session again does not see a need for it, as he sees the session as a confirmation of the current approach.

5. Conclusions

This paper aims to generalize the AHP-based MPS method, along with the hierarchy of criteria, from earlier research with a naval application towards application for ships in general, and to investigate the most important criteria for ship MPS. Based on the six workshops in industry, we conclude that we have successfully been able to generalize the AHP-based MPS approach:

- by taking the feedback from practice into account, the hierarchy of criteria improved;
- it is possible to use the same hierarchy of criteria at multiple companies and obtain meaningful outcomes;
- the use and value lie not so much in the actual selection of a policy, but in facilitating a structured discussion on maintenance and its policies;
- the proposed method appears to work best when high levels in the system are considered, even up to fleet level.

By doing the workshops, we have inherently elicited the preferences of the participants. This reveals importances of the criteria. In other words, it reveals what practitioners find important when considering maintenance policy selection:

- *crew safety* is the most important criterion when selecting a maintenance policy, followed by *reliability* and *availability*;
- softer, qualitative criteria play an important role, as *experience with maintenance* and *planability* complete the top five criteria. These criteria must not be precluded;
- *cost minimization* plays only a moderate role. Nevertheless, to fully portray the MPS problem, a costs criterion needs to be included;
- for the final preferred maintenance policy, the actual consideration is between time/use-based maintenance and condition-based maintenance.

For the research, various ship types have been analysed during the workshops. These ship types only cover a part of all ship types [24, 25]. Therefore, an expansion towards more ship types is recommended. Also, we recommend broadening the investigation of the applicability of the AHP for MPS towards other industries. We suggest the maritime oil and gas industry, where floating production, storage and offloading (FPSO) vessels could act as a starting point, considering their ship-like nature. Another option would be a move towards land-based moving assets such as trains, the land-based equivalents of ferries. Within these industries, further study on, and the elicitation of, the most important criteria for MPS can shine more light on industry practice and increase practical relevance.

Considering the maintenance policies, we notice that condition-based maintenance is receiving an increasing amount of attention in the literature [26, 27] and has become a trending topic in practice. In light of our findings, we encourage the devotion of equal attention to time/use-based maintenance.

Furthermore, the process can still be improved by a refinement of the hierarchy based on the workshop evaluations. Especially the inclusion of mandatory maintenance by class surveys and rules and regulations needs consideration. Accordingly, we recommend others who use the AHP to incorporate feedback from practice to improve the hierarchy.

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Appendix A. List of criteria

The list of criteria obtained from both the interviews and literature is presented in Table A.1, along with the total times mentioned. Only the criteria that were mentioned three times or more are shown; a line is drawn to indicate the criteria that are mentioned four times or more, and have thus been considered during the hierarchy formation.

Table A.1: The list of criteria

Criteria	Times mentioned
Costs (minimization)	11
Availability	8
Maintenance or failure feedback	7
Experience (with maintenance)	7
Reliability (mission and operational)	7
Spare parts availability	6
Mission duration/time on sea	6
Good relations with other companies and institutions	6
Earlier/old/already existing prescriptions	6
Criticality	6
Rules and regulations	5
Redundancy presence	5
Planability	5
Mission/operation/use profile	5
Crew safety	5
Consequences of bad maintenance or failures	5
Warranty periods	4
Taking responsibility	4
Spare parts costs	4
Passion for maintenance, preference for minimal or maximal maintenance	4
Good communication with 2^{nd} parties	4
Crew size	4
Crew educational level	4
Commonality presence	4
Usefulness of monitoring data	3
Training costs	3
Spare parts amount	3
Risk during mission or operation	3
Requirements of 2^{nd} parties	3
Reachability of parts	3
Production loss (MTBF, MTTR, downtime)	3
Mission readiness	3
Mission location	3
Maintenance location (on board or on shore)	3
Knowledge	3
Insight in system	3
Influence on and control over customers and their demands	3
Amount of faith in existing policies and prescriptions	3
Drive for innovation or change	3
Costs of change of policy (investment required)	3
Commercial interests	3
Austerity measures (imposed/required)	3
Amount of outsourcing	3
Amount of available funding/budget	3
Age of vessel (and remaining useful life)	3
Added quality	3

Appendix B. List of definitions as used during the sessions

The definitions of the criteria incorporated in the hierarchy, handed to the participants during the workshops.

- *Failure-based maintenance*: corrective maintenance where failures triggers the maintenance actions
- *Time/use-based maintenance*: planable maintenance where elapsed time or amount of use triggers the maintenance actions
- *Condition-based maintenance*: where a measured condition triggers the maintenance actions
- *Availability*: the total availability of the system
- *Costs minimization*: the minimization of financial costs made
- *Crew Safety*: the safety of the crew
- *Reliability*: the total reliability of the system
- *Compliance with existing maintenance policies and prescriptions*: the desire to keep doing current maintenance practices
- *Drive for innovation*: the desire to innovate
- *Passion for maintenance*: the desire to do good and responsible maintenance
- *Planability of maintenance*: how well the maintenance can be planned
- *Crew size*: the amount of crew members
- *Crew educational level*: the educational level of the crew
- *Experience with maintenance*: the experience the company has with doing maintenance
- *Mission profile*: the profile of the mission, think of: location, duration, intensity and risk
- *Good communication within the company*: the communication between different divisions within the company
- *Good relations with other companies*: the relations with related companies
- *Maintenance feedback*: feedback of maintenance actions and results throughout the company and supply chain, and vice versa
- *Commonality presence*: the presence of commonality within the system
- *Spare parts availability*: the spare parts readily available where maintenance is needed
- *Spare parts costs*: the financial costs of the spare parts
- *Consequences of bad maintenance*: what happens if maintenance is done incorrectly, maintenance induced failures
- *Criticality of parts*: the criticality of the parts in the system
- *Redundancy presence*: the presence of redundancy within the system

Appendix C. Evaluation form questions

The evaluation form is originally in Dutch, the translated version is shown below.

1. The session
   (a) What did you think of the session?
   (b) Did you find it useful? Why?
   (c) Did you enjoy it? Why?
   (d) What do you think of the duration of the session?
   (e) Would you want to do a similar session again? Why?
   (f) If so, when and how many times would you want to this?
   (g) What did you think of the group? Think, for example, about the number of people and the various functions they have.
   (h) Do you have any suggestions for improvement?
2. The hierarchy of criteria
   (a) Do you think the hierarchy is clear and understandable? Why?
   (b) What to you think of the clusters/divisions/categories made?
   (c) Are any criteria lacking? If so, which?
   (d) Are any criteria redundant? If so, which?
3. The decision
   (a) During the session one of the policies ended up being most favourable. Would you have chosen for the same policy? Why?
   (b) Do you feel you better understand the way the decision was made?
   (c) For which level in the system would you ideally want to select a maintenance policy using such a session?
4. Do you have any other remarks?

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