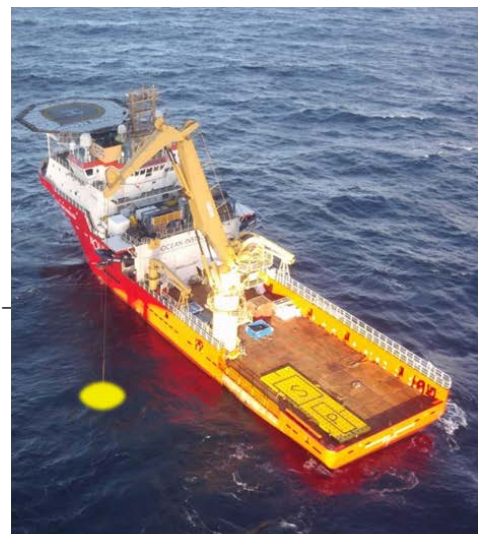
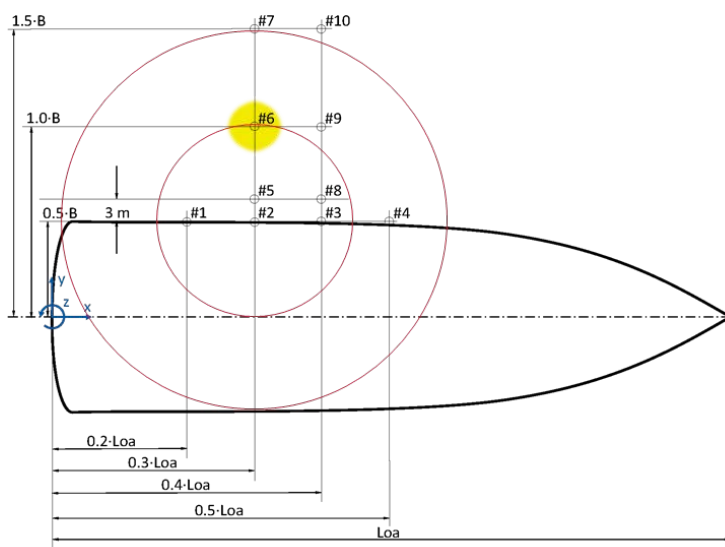


## Meeting Report

1<sup>st</sup> Marine Operations Forum

### PERFORMANCE INDICATORS FOR SUBSEA LIFTING OPERATIONS



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## Introduction

The establishment of the annual Marine Operations Forum is part of the work plan of research area *Vessel Performance* within the Norwegian Centre for Research-based Innovation on Marine Operations (SFI MOVE). The forum shall provide an arena for discussion and information exchange between the stakeholders of the marine and offshore industry and researchers. To ensure a common basis and language when evaluating vessel performance from an academic point of view, feedback and knowledge contribution from experienced players of the marine offshore industry is essential.

The 1<sup>st</sup> forum was held on February 07, 2017 in the premises of the Norwegian University of Science and Technology (NTNU) in Ålesund. 26 participants from 11 different companies were actively participating. The workshop programme was divided into a presentation part and a practical part in order to familiarize everyone with the status of the ongoing research as well as to facilitate experience transfer between the researchers and industrial partners involved in marine operations.

The workshop opened with a welcome address by the center leader Hans Petter Hildre (NTNU) followed by an introduction by the research area leader Florian Sprenger (SINTEF Ocean). The overall objective of the research in the area *Vessel Performance* was summarized and the intended methodology was presented. Further, a list of performance parameters for subsea lifting operations was presented by PhD candidate Martin Gutsch. The proposed parameters were the result of bilateral discussions with the involved industry stakeholders in fall 2016 and was subject for further discussions during the second part of the forum. Finally, Christian Steinebach (SINTEF Ocean) introduced the Analytic Hierarchy Process (AHP), a structured method commonly used for complex decision-making situations that is proposed for weighting of performance parameters.

## Methodology

The current work in research area *Vessel Performance* within *SFI MOVE* focuses on performance evaluation of marine lifting operations over the vessel side, which represent a significant part within subsea construction activities. The central questions addressed in this research area are summarized in Fig. 1. To find answers, the governing performance criteria for offshore operations – from both, technical, logistical and human point of view, have to be identified. Crew experience and field survey work is key to verify the correlation between an academic approach to evaluate vessel performance and the actual operation at sea.

The different parties contributing to the overall performance of a vessel in marine lifting operations typically are ship designers, ship owners, operators, and oil companies. Due to the nature of their business, each of these stakeholders have different viewpoints on operational performance and thus different priorities regarding the outcome of the common research project. The clarification of interests helps all involved parties to work target-oriented towards improved performance.

The proposed procedure to assess vessel performance for offshore work tasks will

- provide ship designers with guidance for performance-driven design of new vessels
- support shipping companies to promote their fleet based on weighted vessel-specific performance parameters and to identify potential for upgrades of existing vessels as well as guidance for the acquisition of new ships
- support marine operators to promote their operational performance and to give guidance for vessel selection
- provide a tool for clients (e.g. oil companies) to compare different available ships and identify a well-suited vessel for a specific campaign (Fig. 2) as well as to give guidance in setting up tenders

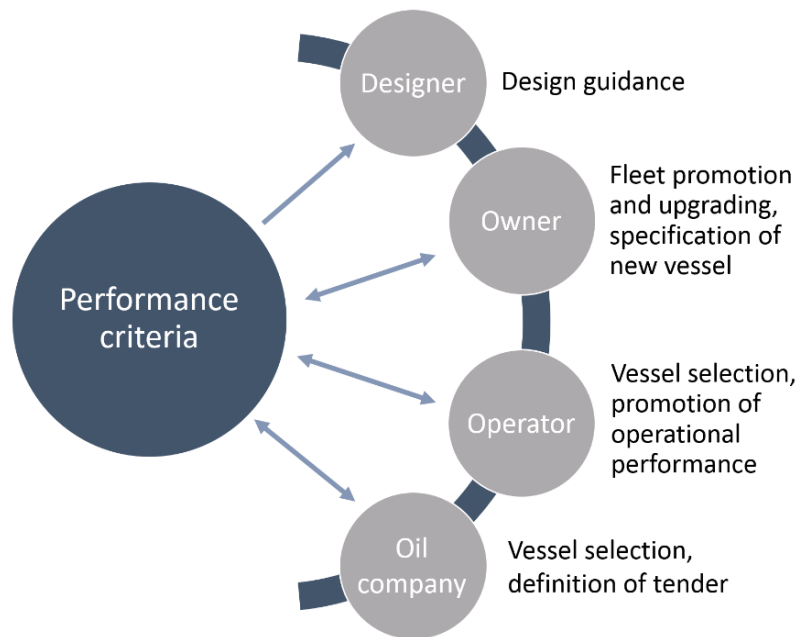
Further, the definition of performance parameters will create important knowledge for the development of simulation tools and on-board support systems for safe operations in less favorable environmental conditions.

What contributes to the performance of a marine operation?

Why are some vessels performing better than others?

Are there alternatives to today's operational limitations?

Fig. 1. Central Questions addressed in RA1



*Fig. 2 Benefits from performance criteria for the involved stakeholders*

Following the proposed methodology, vessel performance is assessed on the base of a given operational scenario which defines certain requirements. This leads to the fact that, in a first step, the number of available ships will be reduced by simple binary evaluations to a relevant fleet of vessels capable to fulfill the required tasks (see Fig. 3). For the considered case of subsea lifting operations over the vessel side, the following parameters would have binary character (note that all parameters that have to be fulfilled by any ship due to regulatory or administrative requirements are not listed):

- availability
- lifting capacity at a defined radius and lifting height
- deployment depth
- DP class
- cargo deck area and capacity

Criteria on the binary decision level are mainly defined by operators and oil companies, e.g. through project tenders or similar specifications. Ship owners, designers and operators will provide input data describing vessel design parameters.

On the next level (performance based level, see Fig. 3), relevant specifications are subject to further evaluations in the vessel selection process, based on more distinguishable functions, such as

- crane tip motion behavior
- freeboard
- 2<sup>nd</sup> crane
- level of task-related experience (track record of vessel and crew)

- further availability of support systems

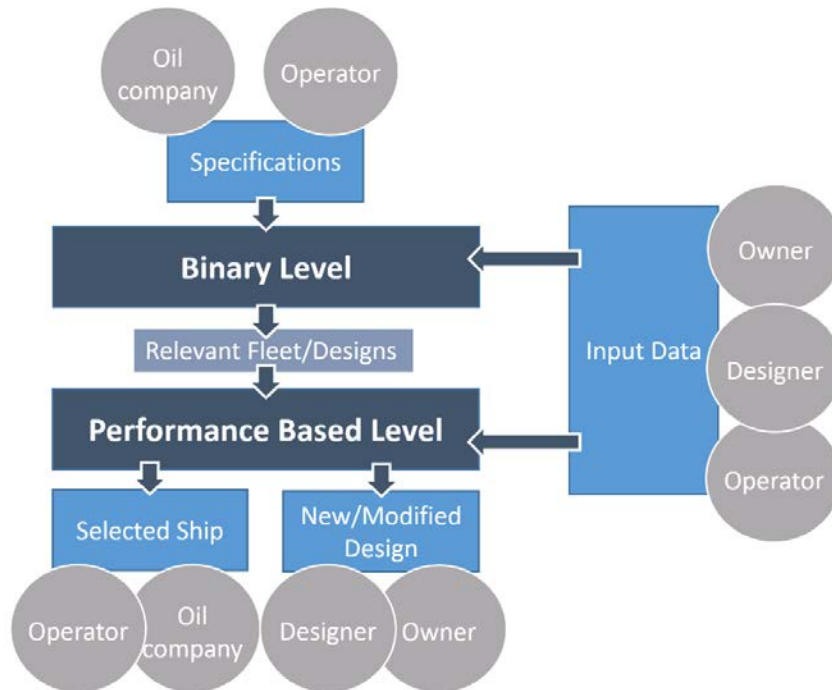


Fig. 3. Methodology for vessel performance evaluations

As the outcome of the assessment on the performance based level, operators or oil companies might select a suitable ship for lease or a specific task, while ship designers and owners might select a new vessel design or receive guidance for modification of designs or existing ships as illustrated in Fig. 2.

## Performance parameters

In order to assess overall performance of a vessel for a certain marine operation (including technical, communication, and human aspects), the research in SFI MOVE aims to contribute to the establishment of a set of operation based criteria and key parameters, describing and quantifying the ability of an offshore work vessel to perform its predefined work tasks effectively.

A proposal of possible performance parameters was electronically distributed in the course of the workshop preparations. An updated version of this list is presented in Tab. 1.

Tab. 1 List of performance parameters including input from workshop

Lifting Operability	Versatility	Safe Work Space	Handling Efficiency	Crew Welfare	Environmental Performance
Vessel response behaviour	Transit speed	Safety priority, routine procedures	No slewing obstructions / limitations	Experience transfer, courses	SEEMP (Vessel emissions)
Motion resonance ratio	ROV (weather limitation for recovery)	Freeboard (possibly increased by solid side walls)	Removable side walls or handrails	Task related simulator training	Weather routing
Lifting capacity* (safe working load, SWL)	Available cargo deck area*	Protection of deck crew and escape areas	Flexible arrangement of tigger winches / sheaves / skidding rails	Food (variety)	Lean DP (fuel consumption in DP)
Required deployment depth*	2 <sup>nd</sup> crane (SWL, AHC + CT with seamless shift)	Noise in work spaces	Extra lifting capacity	Single-bed cabins	Reduced service speed (policy)
Reach of required SWL as function of radius*	Towing winch (capacity, wire length, passive heave comp.)	Free view from crane cabin	Mechanical, non-welded sea fastenings (clamps)	Cabin noise	
Required lifting height H as function of radius*	Rails / skidding / deck handling	DP class 2 or 3*	Skidding rails, module handling tools, alternatives to crane lifting	Availability of internet and Wi-Fi	
Automatic heave compensation (AHC) and constant tension (CT) with seamless shift	Special handling equipment	Avoid working at height	Additional roll damping system	Working hours	
			Decision Support Systems (DSS)	Low Motion Sickness Incidence (MSI)	
			Lift preparations and alongside lifting trials during mobilization		
			Material selection for rigging items		

\*Item may be treated as binary function for pre-selection of suitable vessels for the intended campaign

The areas influencing the overall operational performance cover more than just design-related issues. Among the most critical criteria are human factors as well as vessel motion behavior, technical performance of on-board equipment, and environmental aspects. The selected parameters listed in Tab. 1 are interlinked and will influence the overall performance of a marine lifting operation.

In order to establish a feasible user-friendly procedure for the assessment of operational performance, simplified approaches based on commonly available input data are required. While such an approach increases practical usability, limitations regarding accuracy are expected. As an example, the performance parameter 'vessel response behavior', a key factor in promoting all-year safe and efficient subsea operations, can be evaluated either in-depth by a detailed numerical simulation with full physical input or approximated by the use of a database of vessel responses for representative ships. Those two approaches are illustrated in Fig. 4. An innovative approach to quantify operational ranges in a broader sense than usually is proposed in SFI MOVE through the newly introduced, so called Integrated Operability Factor (IOF) [1].

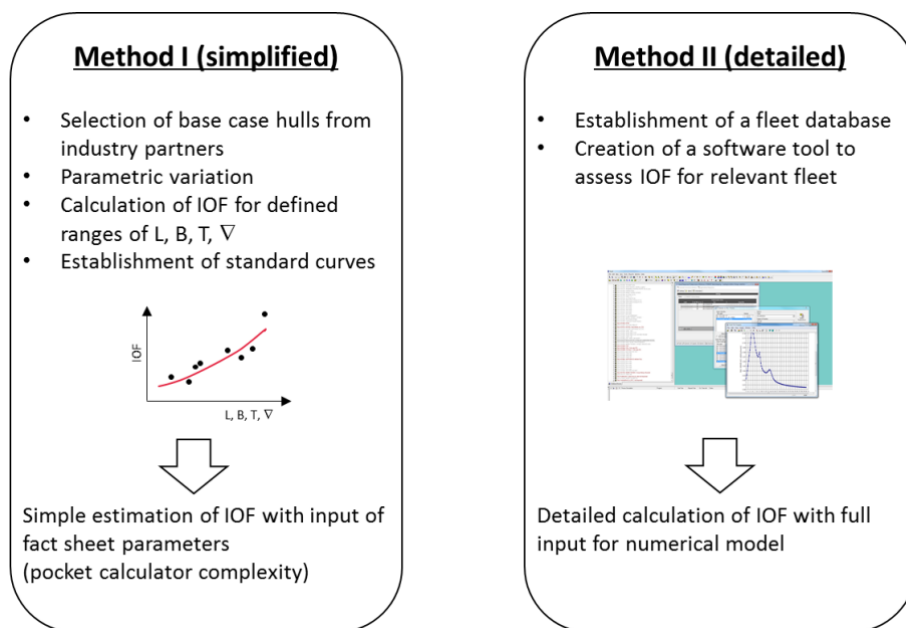


Fig. 4 Schematic illustration of the two-level approach to quantify vessel responses in terms of the IOF

Similar to the commonly used percentage operability, the IOF represents a measure of the vessel responses related to a given limiting criteria, a sea area and season and allows the evaluation of operability under the given conditions.

For operational planning, the information of the absolute operability for a defined limitation criterion is important. However, in order to compare the operational performance of different vessel designs, the assessment of vessel motions over a range of sea states (defined through the spectral formulation and the range of peak periods), is proposed. Unlike for the traditional assessment of percentage operability, not only one operational limit is considered, but the respective limiting criterion is gradually increased from zero to a maximum value and at each step the percentage operability is determined. The IOF is then the ratio of the area under the obtained curve and the area of the square that would represent 100% operability at all limitation criteria steps. Consequently, the IOF gives a broader view on vessel performance since it is easier to distinguish between a good and a better vessel by comparing the operational performance also for stricter limitation criteria. The IOF can be regarded as a *quality index* for vessel behavior in waves with respect to a selected motion criterion, season and sea area.

## Making the Decision

### Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a technique and tool used for multi-criteria decision making. It was developed by Thomas Saaty [2] in the 1970s and has been widely used for complex decision makings. See [3] and [4] for further information and examples.

AHP weighs options according to their importance. But, instead of putting the burden of defining all relative weights on the decision maker, it simplifies the process to pair-wise comparisons. Pair-wise comparisons are usually easier to make than ranking of several alternatives. AHP then derives the resulting weights from the pair-wise comparisons.

To model a problem with the AHP, a hierarchy representing the problem and the pairwise comparisons to establish relations within the structure is required. In the discrete case these comparisons lead to dominance matrices, from which ratio scales are derived in the form of principal eigenvectors. The matrices are positive and reciprocal, e.g.  $a(i,j) = 1/a(j,i)$ .

Pair-wise comparisons use the fundamental scale as shown in Tab. 2.

Tab. 2. Pair-wise weighting intensities used in AHP methodology

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	One element is moderately preferred over the other
5	Strong importance	One element is strongly preferred
7	Very strong importance	An element contributes very much to the objective or, one element is very strongly preferred over the other
9	Extremely strong importance	Highest possible intensity

Intensities in-between (2, 4, 6, 8) may also be used to express finer granularity, as well as decimal values when numerically obtained values are used. The weights are obtained by solving for the principal eigenvector of the matrix and then normalizing the result.

Another advantage of the method is the possibility to obtain a measure of consistency from the comparisons, which is not possible with a simple 'weighted-sum' technique. For example, saying A is more important than B and B is more important than C, implies that A must also be more important than C. AHP will detect the inconsistency, when C had been assigned a higher importance than A.

The Consistency Index (C.I.) of a matrix of comparisons is given by

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



The consistency ratio (C.R.) is obtained by comparing the C.I. with the appropriate number from the following set:

N	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.491

Each number is an averaged random consistency index (R.I.) derived from a sample of size 500, of a randomly generated reciprocal matrix using the scale 1/9, 1/8, ..., 1/2, 1, 2, ..., 8, 9 to see if it is about 0.1 or less. In case this number exceeds 0.1, further studies and/or a revision of the judgment is recommended (Ref [6]).

AHP facilitates the comparison of both, objective and subjective evaluation criteria. As an example, using AHP, the importance of vessel motion behavior (which can be expressed through a number, either IOF or percentage operability) can be compared to the importance of Safe Work Space (which is either given or not, but cannot be expressed through a number).

The literature contains a number of examples, e.g. Dalalah [5] used the AHP method to select the best suited crane for an operation based on capabilities, environment, etc.

### Simplified example: Selection of a vessel for a specific marine operation

The simple example below bases the decision on the criteria operability, safe work space, versatility and environmental performance. The pairwise comparison of the 4 criteria leads to 6 pairs ( $n \cdot (n-1)/2$ ). The numbers indicate the relative importance of each criteria.

Operability	1	vs.	Safe Work Space	4
Operability	1	vs.	Environmental performance	3
Operability	3	vs.	Versatility	1
Safe Work Space	3	vs.	Environment	1
Safe Work Space	6	vs.	Versatility	1
Environmental performance	3	vs.	Versatility	1

The pairwise comparison can be shown in a matrix of scores:

	Operability	Safe Work Space	Environmental Performance	Versatility
Operability	1	1/4	1/3	3
Safe Work Space	4	1	3	6
Environmental Performance	3	1/3	1	3
Versatility	1/3	1/6	1/3	1

As a result of the pairwise comparison a ranking showing the importance of each criterion can be calculated:

Operability	13.6%
Safe Work Space	54.3%
Environment Performance	25.2%
Versatility	7.0%

In order to select a vessel, based on the above weights, one has to establish scores for each of the vessels for each of the 4 criteria.

In this project, AHP has been used to develop a method for vessel selection for marine operations. First results of applying the tool are discussed below.

## Discussion of Results

The individual work for the workshop participants focused on two parts

- a critical review of the list of proposed performance parameters and
- an experience-based weighting of pre-selected parameters using the pair-wise comparison according to the AHP method.

	Ves reso beh	Mot reso ratio	Roll damping	DP class	Lifting capac	Crane reach	Max depl depth	AHC and CT	
Ves reso beh	1.0000	0.5000	1.0000	0.3333	0.5000	1.0000	0.5000	0.5000	
Mot reso ratio	2.0000	1.0000	2.0000	0.3333	0.5000	1.0000	0.5000	0.5000	
Roll damping	1.0000	0.5000	1.0000	0.3333	0.3333	1.0000	0.3333	0.2000	
DP class	3.0000	3.0000	3.0000	1.0000	0.5000	2.0000	1.0000	1.0000	
Lifting capac	2.0000	2.0000	3.0000	2.0000	1.0000	2.0000	1.0000	1.0000	
Crane reach	1.0000	1.0000	1.0000	0.5000	0.5000	1.0000	2.0000	3.0303	
Max depl depth	2.0000	2.0000	3.0000	1.0000	1.0000	0.5000	1.0000	1.0000	
AHC and CT	2.0000	2.0000	5.0000	1.0000	1.0000	0.3300	1.0000	1.0000	
sum	14.0000	12.0000	19.0000	6.5000	5.3333	8.8300	7.3333	8.2303	
									Weights
Ves reso beh	0.071	0.042	0.053	0.051	0.094	0.113	0.068	0.061	0.069
Mot reso ratio	0.143	0.083	0.105	0.051	0.094	0.113	0.068	0.061	0.090
Roll damping	0.071	0.042	0.053	0.051	0.063	0.113	0.045	0.024	0.058
DP class	0.214	0.250	0.158	0.154	0.094	0.227	0.136	0.122	0.169
Lifting capac	0.143	0.167	0.158	0.308	0.188	0.227	0.136	0.122	0.181
Crane reach	0.071	0.083	0.053	0.077	0.094	0.113	0.273	0.368	0.142
Max depl depth	0.143	0.167	0.158	0.154	0.188	0.057	0.136	0.122	0.140
AHC and CT	0.143	0.167	0.263	0.154	0.188	0.037	0.136	0.122	0.151

Fig. 5 Example of the weighting of selected criteria according to the AHP method

The following comments and additions to the proposed list of performance parameters were provided by the participants of the forum

- The limitation for ROV operation indicates the highest achievable limit for crane operation, which means operating ROVs is crucial for crane operations
- The position-keeping ability (initially stated as DP class) differentiates between DP capability, DP redundancy, and environmental regularity number (ERN)
- Automatic overload protection system (AOPS) typically is a classification demand (e.g. DNV GL, ABS, EN 13852-1) and therefore available on every offshore vessel
- Safe workspace includes
  - handling of deck equipment (HSE)
- Handling Efficiency includes
  - efficient mobilization and demobilization
    - minimum time consumption at quay side
    - on-loading and off-loading systems
    - time used for welding of sea fastenings
  - handling material (steel wire vs. fiber material)
- Environmental Performance includes
  - hybrid electric systems
- Economic Performance includes
  - CAPEX (capital related expenses)
  - OPEX (operational related expenses)
  - VOYEX (voyage/transit related expenses, [7])

All input provided by the participants was used to revise the list of performance parameters as shown in Tab. 1. In this context, it has been decided that for the vessel selection process all economic considerations shall be treated separately within a subsequent cost-benefit-analysis (where all listed performance criteria stand on the benefit side) instead of being an integrated part of the performance evaluations.

As a second task, the participants were requested to weight the importance of given parameters based on their own experience according to the AHP method. The weighting was performed for the main category groups:

- Lifting Operability
- Versatility
- Safe Work Space
- Handling Efficiency
- Crew Welfare
- Environmental Performance

For each group, up to seven parameters were proposed. The participants were requested to weight the parameters pairwise as exemplarily shown in Fig. 5. In total, 13 participants submitted their sheets.

The results are presented in Fig. 6, Fig. 7, and Fig. 8. For each item the mean value is shown together with the standard deviation, smallest (minimum) and highest (maximum) value, obtained from the results. Additionally, the results were analyzed in groups according to the category of stakeholder each participant is employed at. This differentiation was made in order to investigate if participants working for an operator (Oceaneering), client (Statoil), designer (Vard, Rolls-Royce, Ulstein), classification society (DNV), or crane manufacturer (NOV) are weighting performance parameters differently. It must be mentioned that due to low number of participants the, the statistical significance is limited. This applies in particular to the evaluation of results in separate stakeholder groups.

Looking at the results from all participants together, a wide scatter of weights for the performance parameters indicates a broad range of views on the priorities, which is expressed through high standard deviation values.

The analysis of the Main Categories (Fig. 6) and Safe Work Space (Fig. 7) indicate an increased awareness regarding the importance of economic and safety related issues (such as Safe Work Space, Handling Safety and Safety Priority). Further, lifting capacity, AHC and CT, flexible arrangement of tugger wires, cabin noise, single bed cabins, low motion sickness incidents (MSI) as well as the availability of ROVs and a 2<sup>nd</sup> crane are regarded as important (Fig. 7 and Fig. 8). The lowest importance was assigned to the Environmental Performance of a vessel (Fig. 6), in which the fuel consumption in DP mode (Lean DP) was ranked with the highest priority (Fig. 8). As a further result, some of the proposed parameters have been ranked to have a low impact on vessel performance by all participants. Among these are: motion resonance ratio, additional roll damping, diving equipment, freeboard, noise in work space, flat deck, non-welded sea fastenings, low motion interruption incidents (MII), leisure activities, utilization of battery power and the fuel type. In case of some of the

parameters, such as freeboard, flat deck and MII, it can be concluded they are of importance, but commonly available on sufficient level on modern ships.

The next steps of work within RA1 (Vessel Performance) encompass the reduction of the list of performance parameters to a number of measurable major items which can be quantified according to the properties of a specific vessel and summarized into one key performance measure, expressing the performance capability of the considered vessel.

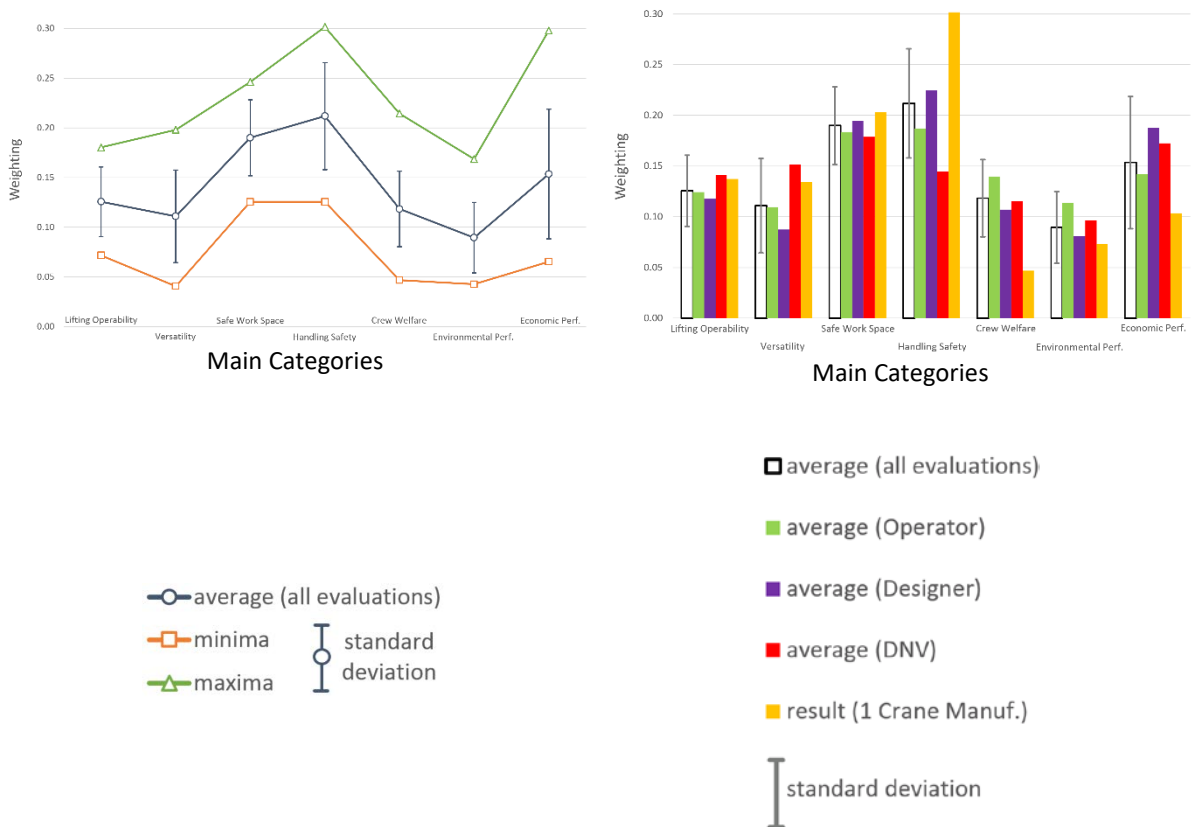


Fig. 6 Weighting of Main Categories

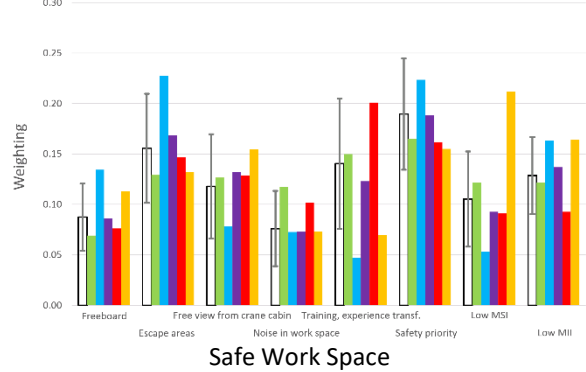
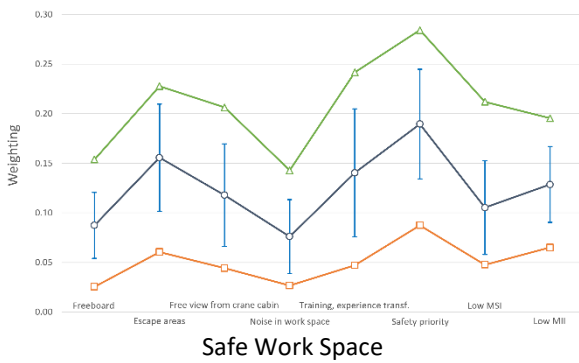
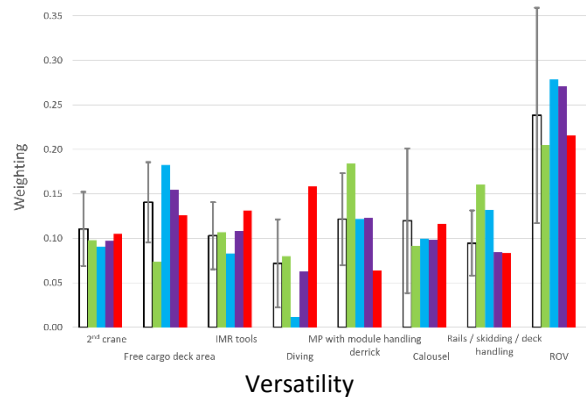
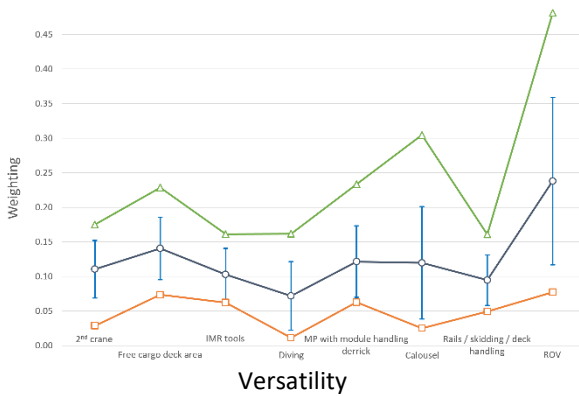
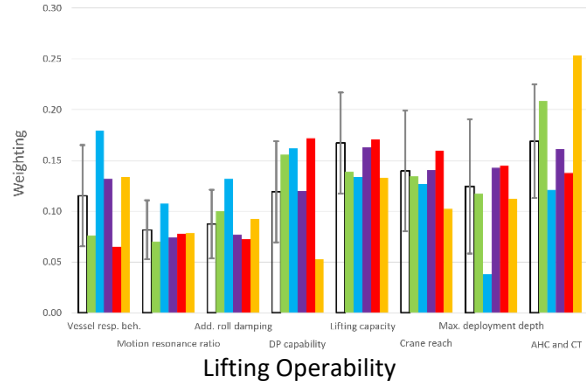
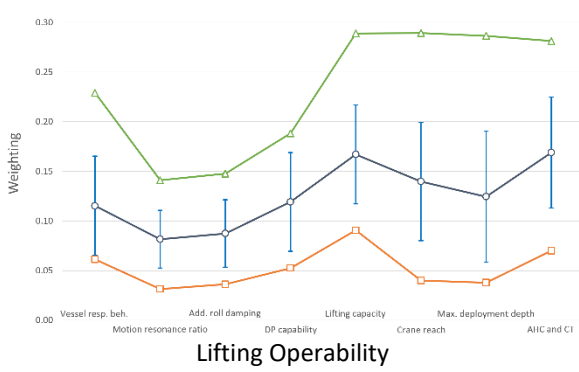


Fig. 7 Weighting of Lifting Operability, Versatility, Safe Work Space

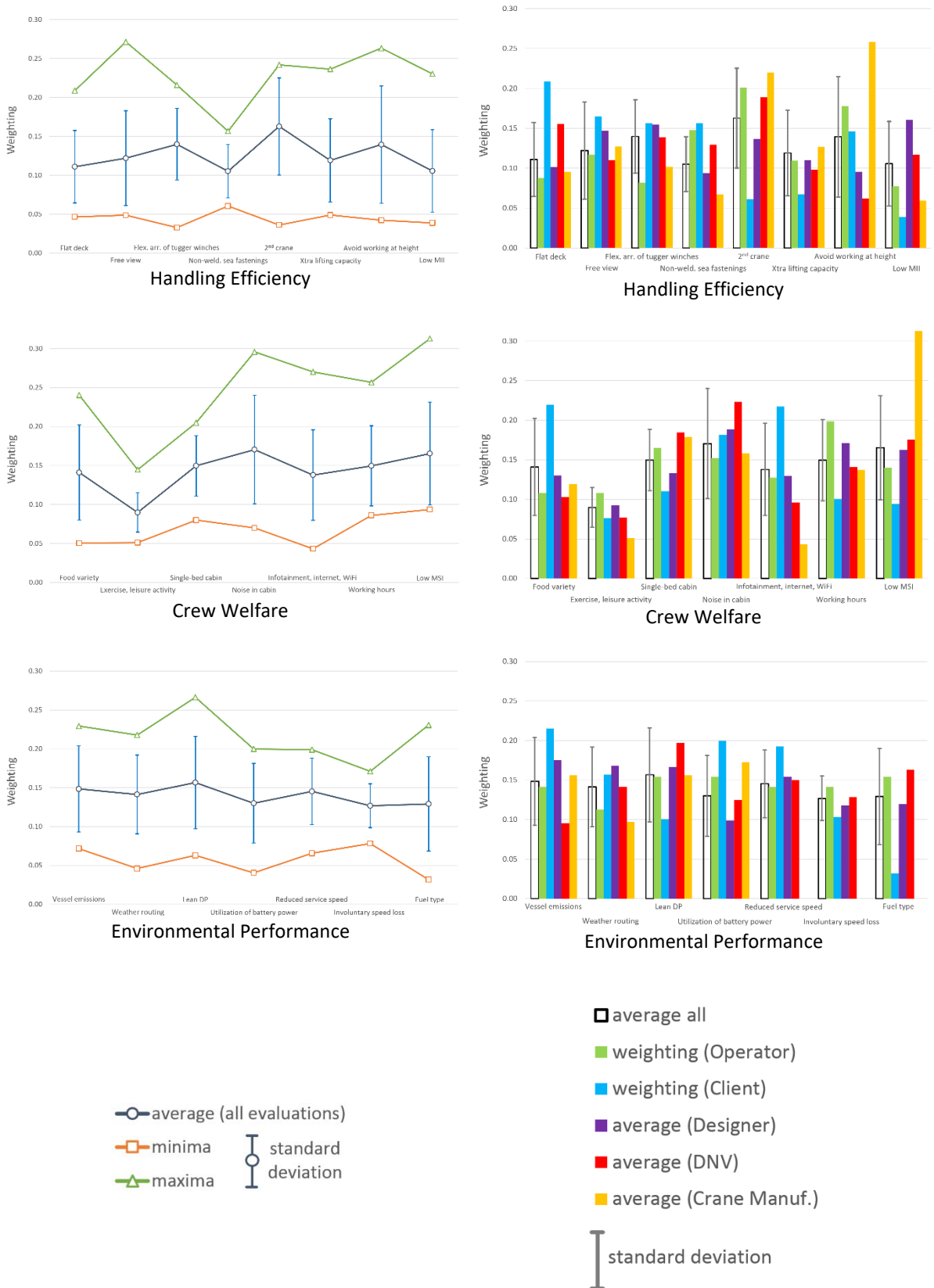


Fig. 8 Weighting of Handling Efficiency, Crew Welfare, and Environmental Performance

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