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The shipyard technological level evaluation methodology

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Summary

A competitive advantage over other shipyards is extremely important in the high-stake shipbuilding industry. Typically, a competitiveness analysis of a shipyard measures productivity based on specific parameters, such as tonnes or compensated gross tons produced per consumed working hour. The authors of this paper consider identifying the technological level required to achieve this productivity as essential, including other information relevant for the shipbuilding process. Therefore, a methodology for determining the technological level of shipyards is proposed based on defined criteria and a structured evaluation. The criteria were devised and structured hierarchically. The methodology also offers company management a solution for continuous monitoring for improving shipyard design and production processes.

Keywords: *shipbuilding, technological level, methodology, evaluation, productivity, efficiency, sustainable production*

1. Introduction

In today's highly competitive shipbuilding industry, gaining a competitive advantage over shipyards is important. A competitive and sustainable shipyard demands that management continuously monitor and improve productivity, efficiency and quality while decreasing the overall costs of the production process [1]. Typically, the competitiveness analysis of a shipyard measures productivity based on parameters such as tonnes produced or compensated gross tonnes (CGT) produced per consumed working hours [2-4]. However, there is some criticism of the CGT approach, like its ability to address unnecessary factors in technical works while identifying influential factors and methods for measuring the productivity of the shipbuilding process [5]. The efficiency, costs and quality of processes and product are the most influential factors considered but are not adequately integrated into the CGT approach [6]. Therefore, to conduct shipbuilding productivity measurement, the certain researcher uses methods and tools such as data envelopment analysis (DEA) based on a detailed analysis of several shipyards [7]. DEA is also used in research [8], along with the analytic hierarchy process method (AHP), for similar purposes but more toward performance benchmarking. In the paper [9], AHP is used for shipbuilding process improvement based on efficiency parameters, whereas in the paper [10], the AHP method has been combined with the fuzzy technique for evaluating pipe-cutting technologies. Researchers are researching a systematic and holistic approach based on costs and man-hours, particularly in outfitting [11]. Some examples from research use a mathematical approach to production systems engineering to analyze shipbuilding production lines, as in papers [12-14], or discrete event simulation using modern computer software for modeling, analyzing and improving the shipbuilding production process, [15-17]. Lately, with expanding computer power and the development of data sciences, researchers, as in paper [18], have been using large databases, the Internet of Things and data mining in a data-driven approach to performance evaluation in shipbuilding.

However, this method does not give a complete insight into a shipyard's productivity and competitiveness or provide an ongoing platform for general improvements and quality improvements useable in shipyard management. Therefore, the authors believe it is essential to determine the technological level used in achieving the sought productivity, including information relevant to the entire shipbuilding process, such as documentation, equipment, work areas, human resources and work methodology [19]. Defining the technological level of a shipyard is often achieved using benchmarking methods in comparing it to other shipyards with similar production processes and products or based only on the level of equipment used in the design and production process [20, 21]. This approach may, in certain circumstances, be satisfactory but not optimal for a particular shipyard [17]. Also, this kind of benchmarking analysis depends on the expert's competencies and various assumptions related to statistical quantities, the interpretation of the results and the projection of the shipyard [22]. Some researchers approach the question of productivity by applying specific prediction methods based on mathematical equations stemming from various assumptions and simplifications of real data [23]. Therefore, the authors of this paper provide a methodology for an improved approach to evaluating the technological level of shipyards and provide a solution for continuous process monitoring and improvement.

2. Proposed methodology

The proposed methodology for determining the technological level of a shipyard requires identifying relevant criteria upon which the technological level depends, as researched in [9]. In this paper, these criteria were identified and hierarchically structured for the evaluation procedure. Each criterion was further analyzed in the proposed evaluation process, and appropriate values and grades were assigned to obtain the final grade for each criterion. The suggested methodology also provides management with a solution to monitor and improve the shipyard design and production process continuously.

In the proposed methodology, the identified criteria are divided into three major groups (Fig. 1). The criteria are attributed to the technological level of shipyard production, evaluating the technological level of ship pre-outfitting and amending technical documentation that affect the evaluation of ship production. Assigned grades for each significant criteria group formulate the equation (Equation 1) for the overall grade for the technological level of the shipyard (Gr_{TLS}):

$$Gr_{TLS} = \frac{Gr_{TLP}+Gr_{TLO}+Gr_{TLD}}{3} \tag{1}$$

where Gr_{TLP} is the grade for the technological level of ship production, Gr_{TLO} is the grade for the level of ship pre-outfitting and Gr_{TLD} is the grade for the effect of technical documentation amendments on ship production.

Each of the three criteria is divided into more refined sub-criteria. Hence, the evaluation of the technological level of ship production is divided into workshops for hull fabrication and installation and workshops for fabrication and installation of outfitting elements. Evaluation of hull fabrication and installation workshops relies on sophisticated tools and devices for fabricating hull parts. The share of installed hull structure parts directly on hull subassemblies, panels or blocks is also considered, as well as the share of hull structure parts installed directly on the building berth.

Evaluation of workshops for fabrication and installation of outfitting elements is mainly based on the sophistication of tools and devices used for fabrication and on the share of ship outfitting parts installed in particular outfitting stages. Furthermore, ship outfitting is divided into two - stages: pre-outfitting, otherwise known as advanced outfitting, and on-board outfitting. The authors primarily evaluated the level of outfitting completeness in pre-outfitting stages compared to on-board outfitting, which is always much more resource-consuming.

Concerning the criteria for evaluating the influence of technical documentation amendments on ship production, the primary indicator of the unreliability of technical documentation is the number of revisions in each drawing. If the need to change technical documentation is identified in the design stage, it only affects the cost of technical documentation changes and a possible time extension for completion. However, if the need for technical documentation changes is identified during ship production, the cost of such changes increases, depending on the ship production phase. In the latter case, the authors focused on conducting the evaluation mainly based on four critical points. The first point is the impact of changes on the plan and lead time for ship production. The second point focuses on evaluating the impact of other systems and works not subject to the changes. Next, the third point concerns evaluating the impact ton modifications. Last is evaluating the effect of halting further works. In the following chapters, the suggested methodology is explained in detail.

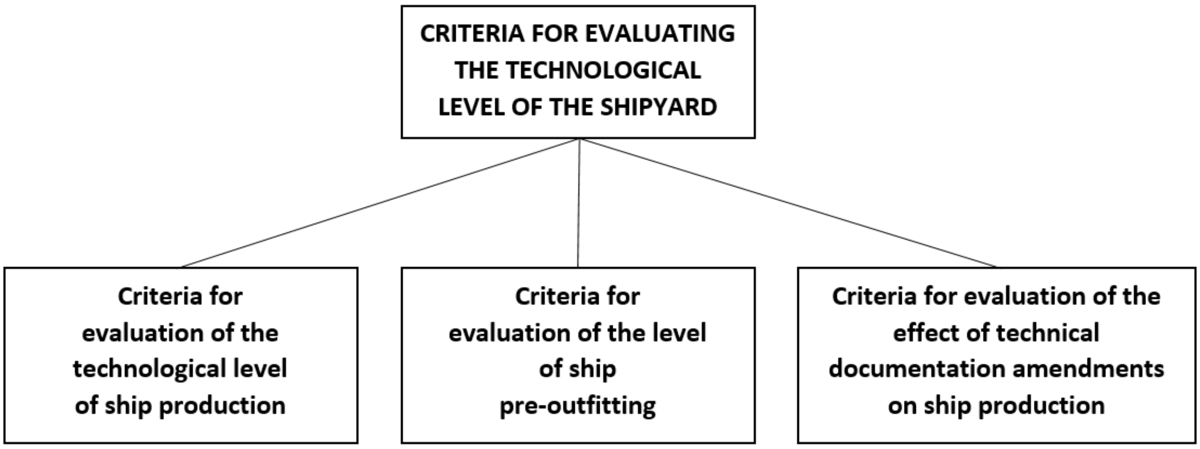

Fig. 1 Breakdown structure of criteria for evaluating the technological level of the shipyard

3. Criteria for evaluating the technological level of ship production

Criteria for evaluating the technological level of ship production are divided into two major groups (Fig. 2):

- Evaluation of the technological level of the shipyard workshops for hull fabrication and installation, which is further evaluated using three criteria
- Evaluation of the technological level of the shipyard workshops for outfitting fabrication and installation, which is further evaluated using two criteria

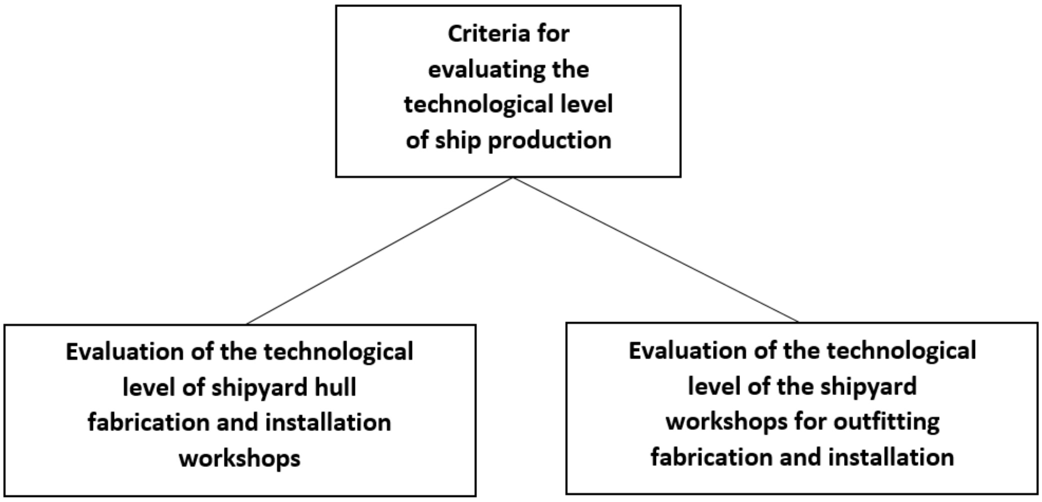

Fig. 2 Breakdown structure of criteria for evaluating the technological level of ship production

The technological level of shipyard hull fabrication and installation workshops is further evaluated using three criteria, as shown in Fig. 3.

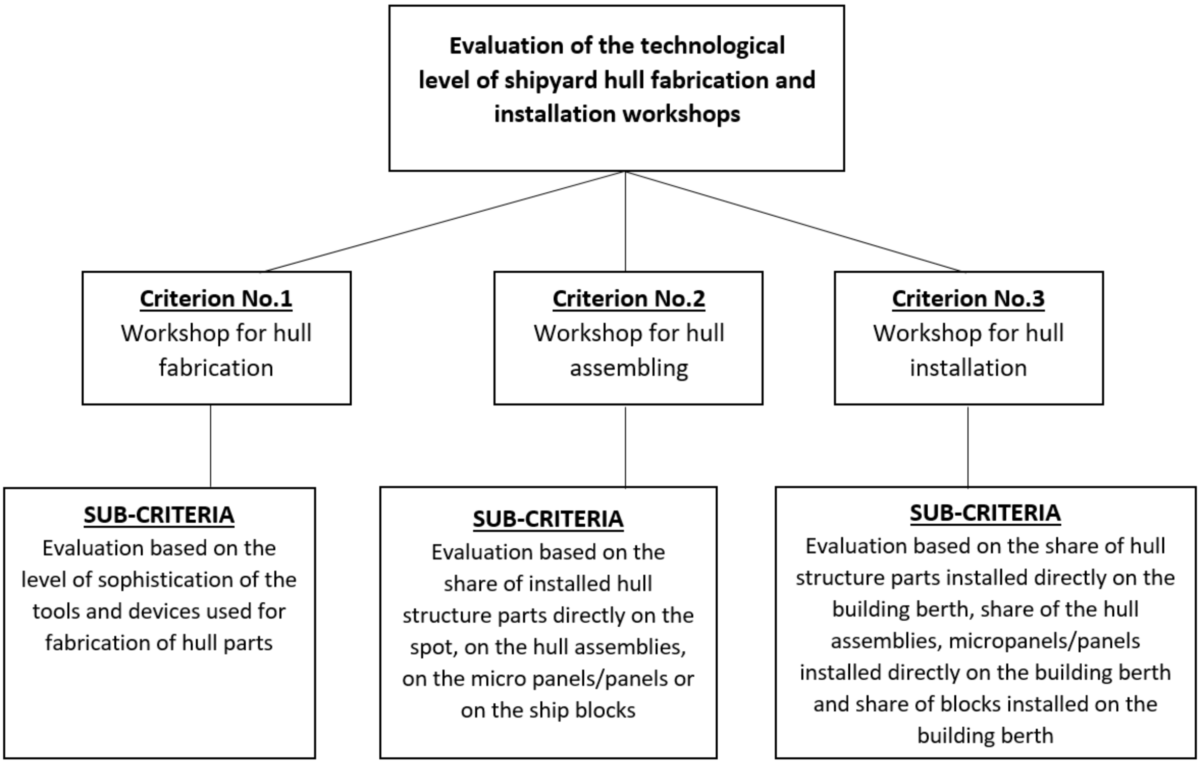

Fig. 3 Evaluation structure breakdown of shipyard hull fabrication and construction workshops at the technological level

Evaluation of the technological level of the shipyard workshops for outfitting fabrication and installation is further evaluated using three criteria, as shown in Fig. 4.

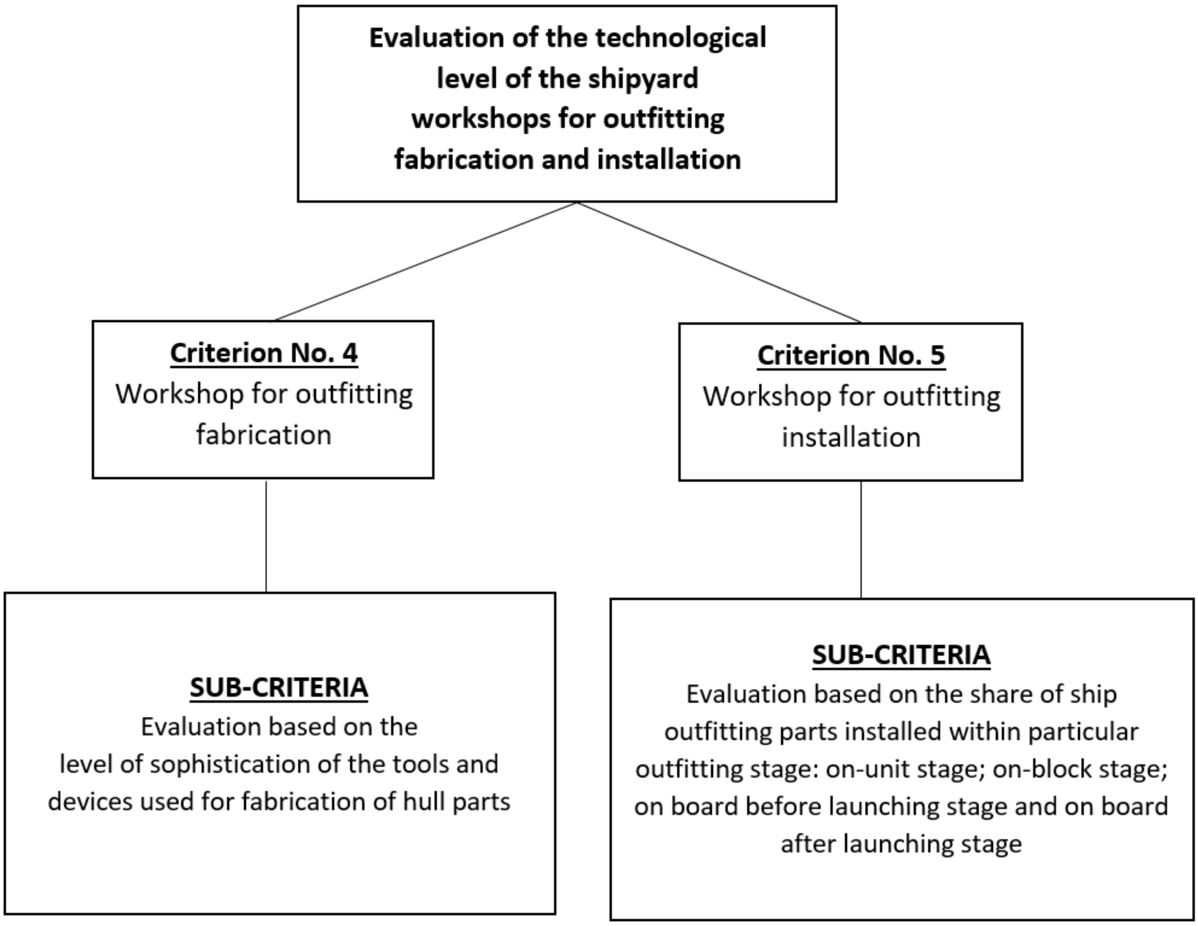

Fig. 4 Breakdown structure of the evaluation of the technological level of shipyard workshops for outfitting fabrication and construction

Evaluation of workshops for hull fabrication is based on the sophistication of tools and devices used to fabricate hull parts (Table 1). The total share hull structure parts fabricated using different types of tools in the workshops is 100%. The level of hull structure parts fabricated using specific tools and devices based on pre-defined sophistication is then estimated. The hull structure parts fabricated with a sophisticated group of tools are not included in the calculation for a group of less sophisticated tools and devices; hence the total sum of fabricated hull structure parts is always equal to 100%. This approach is seen in column B in Table 1, where a grade was assigned for each observed group of tools. The value of the observed group is always equivalent to the difference in total content (the amount of which is 100%) and the sum of values of the remaining group of tools and devices. Each group of tools and devices is evaluated and graded based on the share of parts fabricated for hull structures (column C). The technological level of workshops for hull fabrication is shown in Table 1. Workshops with a higher average grade (Gr_{Hf}) have a higher technological level and sophistication.

Evaluation of the technological level of the workshop for hull assembling is shown in Table 2. It is based on the share of installed hull structure parts directly on the spot or in hull assemblies, micro-panels, panels, and blocks. The hull part embedded in one group cannot be embedded again in another; hence the sum of the share of individual ship hull parts is always equal to 100%. The calculation method for evaluating and grading is based on the same principle described for the workshop for fabricating the ship hull parts. Workshops with a higher average grade (Gr_{Ha}) have a higher technological level and sophistication.

Table 1 Evaluation of the technological level of workshops for hull fabrication

WORKSHOP FOR HULL FABRICATION, CRITERION NO. 1			
x	SHARE OF FABRICATED HULL STRUCTURE PARTS	VALUE *(Hf_x)* [%] from 0 to 100	GRADE *(Gr_x)* 1 to 5
	A	B	C
1	Handheld and portable tool, Hf_1	$Hf_1 = 100 - (Hf_2 + Hf_3)$	1 – from 80 to 100 2 – from 60 to 80 3 – from 30 to 60 4 – from 10 to 30 5 – from 0 to 10
2	Semi-automatic or automatic tools, Hf_2	$Hf_2 = 100 - (Hf_1 + Hf_3)$	1 – from 0 to 10 2 – from 10 to 30 3 – from 30 to 50 4 – from 50 to 80 5 – from 80 to 100
3	Semi-automatic or automatic production lines, Hf_3	$Hf_3 = 100 - (Hf_1 + Hf_2)$	1 – from 0 to 5 2 – from 5 to 20 3 – from 20 to 40 4 – from 40 to 70 5 – from 70 to 100
	TOTAL	100%	$Gr_{Hf} = \frac{Gr_1 + Gr_2 + Gr_3}{3}$

Table 2 Evaluation of the technological level of the workshop for hull assembling

WORKSHOP FOR HULL ASSEMBLING, CRITERION NO. 2			
x	SHARE OF ASSEMBLED HULL STRUCTURE PARTS	VALUE (Ha_x) [%] from 0 to 100	GRADE (Gr_x) 1 to 5
	A	B	C
1	On the spot, Ha_1	$Ha_1 = 100 - (Ha_2 + Ha_3)$	1 – from 40 to 100 2 – from 10 to 40 3 – from 5 to 10 4 – from 0 to 5 5 – 0
2	On hull assemblies, micro-panels and panels, Ha_2	$Ha_2 = 100 - (Ha_1 + Ha_3)$	1 – from 0 to 5 2 – from 5 to 20 3 – from 20 to 40 4 – from 40 to 60 5 – from 60 to 100
3	On blocks, Ha_3	$Ha_3 = 100 - (Ha_1 + Ha_2)$	1 – from 0 to 10 2 – from 10 to 40 3 – from 40 to 70 4 – from 70 to 90 5 – from 90 to 100
	TOTAL	100%	$Gr_{Ha} = \frac{Gr_1 + Gr_2 + Gr_3}{3}$

The evaluation of the technological level of the workshop for hull installation is shown in Table 3. It is based on the share of hull structure parts installed directly on the building berth, the share of hull assemblies, micro-panels or panels installed directly on the building berth and the share of blocks installed on the building berth. Individual hull structure parts installed directly on the building berth can no longer be incorporated into another group. Also, when installed directly on the building berth, hull assembly, micro-panel, or panel cannot be incorporated into the block. Hence, the sum of shares of individually embedded parts of a ship hull equals 100%. The evaluation and grading calculation method is based on the same principle described in the fabrication of ship hull parts. Workshops with a higher average grade have a higher technological level and sophistication.

Table 3 Evaluation of the technological level of the workshop for hull installation

WORKSHOPS FOR HULL INSTALLATION, CRITERION NO. 3			
x	SHARE OF INSTALLATION	VALUE (Hi_x) [%] from 0 to 100	GRADE (Gr_x) 1 to 5
	A	B	C
1	Parts of the hull structure installed directly on the building berth, Hi_1	$Hi_1 = 100 - (Hi_2 + Hi_3)$	1 – from 40 to 100 2 – from 10 to 40 3 – from 5 to 10 4 – from 0 to 5 5 – 0
2	Hull assemblies, micro-panels and panels installed on the building berth, Hi_2	$Hi_2 = 100 - (Hi_1 + Hi_3)$	1 – from 80 to 100 2 – from 50 to 80 3 – from 20 to 50 4 – from 10 to 20 5 – from 0 to 10
3	Blocks erected on the building berth, Hi_3	$Hi_3 = 100 - (Hi_1 + Hi_2)$	1 – from 0 to 5 2 – from 5 to 10 3 – from 10 to 30 4 – from 30 to 60 5 – from 60 to 100
	TOTAL	100%	$Gr_{Hi} = \frac{Gr_1 + Gr_2 + Gr_3}{3}$

Evaluation of workshops for outfitting fabrication is based on the level of sophistication of the tools and devices used for the fabrication of outfitting parts (Table 4). The evaluation and grade values calculation method is based on the same principle described for the workshop fabricating ship hull parts. Workshops with a higher average grade (Gr_{Of})have a higher technological level and sophistication.

Evaluation of the technological level of the workshop for outfitting installation is shown in Table 5. It is based on the share of ship outfitting parts installed on particular outfitting stages: on-unit, on-block, on board up to and upon launch. The outfitting part installed in one group cannot be installed again in another group, hence the sum of the share of all individual outfitting parts is equal to 100%. The calculation method for evaluation and grading values is based on the same principle described for fabrication of ship hull parts. Workshops with a higher average grade (Gr_{Oi}) have a higher technological level and sophistication.

The overall grade for the technological level of ship production is calculated using Equation 2:

$$Gr_{TLP} = \frac{Gr_{Hf}+Gr_{Ha}+Gr_{Hi}+Gr_{Of}+Gr_{Oi}}{5} \quad (2)$$

Table 4 Evaluation of the technological level of the workshop for outfitting fabrication

WORKSHOP FOR OUTFITTING FABRICATION, CRITERION NO. 4			
x	SHARE OF FABRICATED OUTFITTING PARTS	VALUE (Of_x) [%] from 0 to 100	GRADE (Gr_x) 1 to 5
	A	B	C
1	Handheld and portable tool, Of_1	$Of_1 = 100 - (Of_2 + Of_3)$	1 – from 80 to 100 2 – from 60 to 80 3 – from 30 to 60 4 – from 10 to 30 5 – from 0 to 10
2	Semi-automatic or automatic tool, Of_2	$Of_2 = 100 - (Of_1 + Of_3)$	1 – from 0 to 10 2 – from 10 to 30 3 – from 30 to 50 4 – from 50 to 80 5 – from 80 to 100
3	Semi-automatic or automatic production lines, Of_3	$Of_3 = 100 - (Of_1 + Of_2)$	1 – from 0 to 5 2 – from 5 to 20 3 – from 20 to 40 4 – from 40 to 70 5 – from 70 to 100
	TOTAL	100%	$Gr_{Of} = \frac{Gr_1 + Gr_2 + Gr_3}{3}$

Table 5 Evaluation of the technological level of the workshop for outfitting installation

WORKSHOP FOR OUTFITTING INSTALLATION, CRITERION NO. 5			
x	SHARE OF INSTALLED OUTFITTING PARTS	VALUE (Oi_x) [%] from 0 to 100	GRADE (Gr_x) 1 to 5
	A	B	C
1	On-unit outfitting stage, Oi_1	$Oi_1 = 100 - (Oi_2 + Oi_3 + Oi_4)$	1 – 0 2 – from 0 to 5 3 – from 5 to 15 4 – from 15 to 30 5 – from 30 to 100
2	On-block outfitting stage, Oi_2	$Oi_2 = 100 - (Oi_1 + Oi_3 + Oi_4)$	1 – 0 do 5 2 – from 5 to 15 3 – from 15 to 30 4 – from 30 to 60 5 – from 60 to 100
3	On board outfitting up to launching, Oi_3	$Oi_3 = 100 - (Oi_1 + Oi_2 + Oi_4)$	1 – from 70 to 100 2 – from 50 to 70 3 – from 30 to 50 4 – from 15 to 30 5 – from 0 to 15
4	On board outfitting upon launching, Oi_4	$Oi_4 = 100 - (Oi_1 + Oi_2 + Oi_3)$	1 – from 80 to 100 2 – from 60 to 80 3 – from 30 to 60 4 – from 5 to 30 5 – from 0 to 5
	TOTAL	100%	$Gr_{Oi} = \frac{Gr_1+Gr_2+Gr_3+Gr_4}{4}$

4. Criteria for evaluating the level of ship pre-outfitting

The outfitting and equipment supply process is important for ship construction duration and costs in today's shipbuilding, especially for complex ships with high added value. These aspects have been researched by various authors, as given in the references [19], [9], [24] and [25]. Ship outfitting (Fig. 5) is typically divided into two stages: pre-outfitting, or advanced outfitting and on-board outfitting [26].

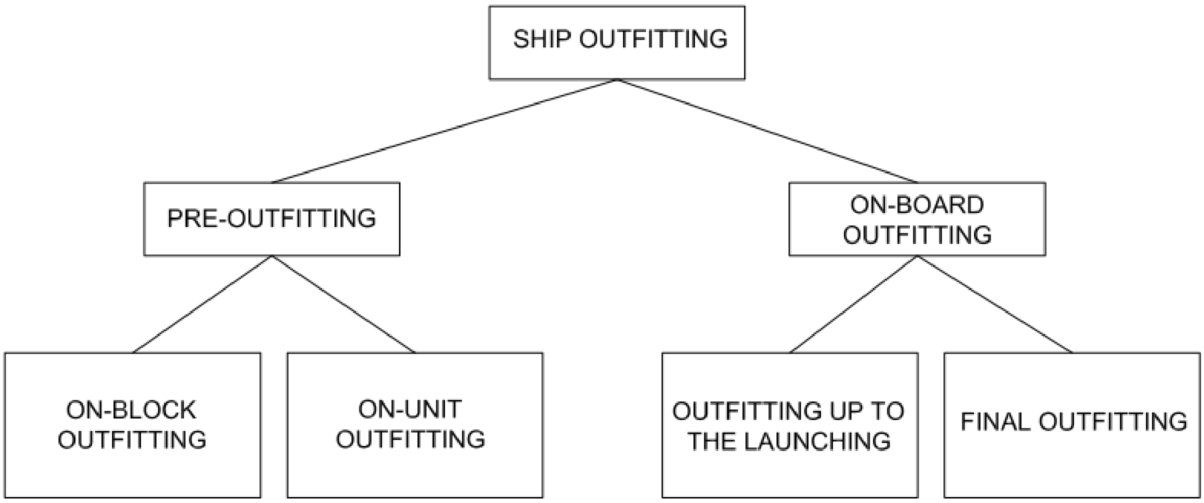

Fig. 5 Breakdown structure of outfitting stages

The pre-outfitting process takes place almost simultaneously with hull construction. It is divided into two independent outfitting stages: on-blocks and on-unit outfitting, otherwise known as modular outfitting. On-board outfitting is divided into two outfitting stages: on-board outfitting up to the launching and final outfitting performed on board after launching.

On-blocks outfitting entails the outfitting of panels, hull assemblies and blocks with equipment parts such as pipelines, cable trays, ducts, pipe penetrations, cables and ducting penetrating the structural parts as well as stairs, ladders, railings, manholes, and hatches.

On-unit outfitting involves assembling ship equipment in workshops as an assembly unit, machinery unit, and structural unit [27]. The assembly unit is made in a workshop and consists of the steel parts of the ship equipment without mechanical or electrical drives. The machinery unit comprises ship equipment constructed using devices and machines arranged as an independent unit on a support and foundation. A machinery unit can be designed as an independent unit of one or more ship systems. If comprising just one ship system, it is called a system machinery unit (e.g., a fuel oil preparing unit). If it includes multiple systems, it is called a module machinery unit. If the machinery unit, except the foundations of machinery and equipment, includes some part of the ship structure, then the unit is called a structural unit.

On-board outfitting begins immediately upon erecting the block on the building berth, and continues with installation of ship equipment up to the launching. The last stage of ship outfitting comprises the final outfitting performed after launching and when the ship equipment subjected to damage is installed (i.e., instruments, equipment for communication, navigation and signals, electronics and computer equipment, lifesaving equipment and all other equipment not installed during the early outfitting stages).

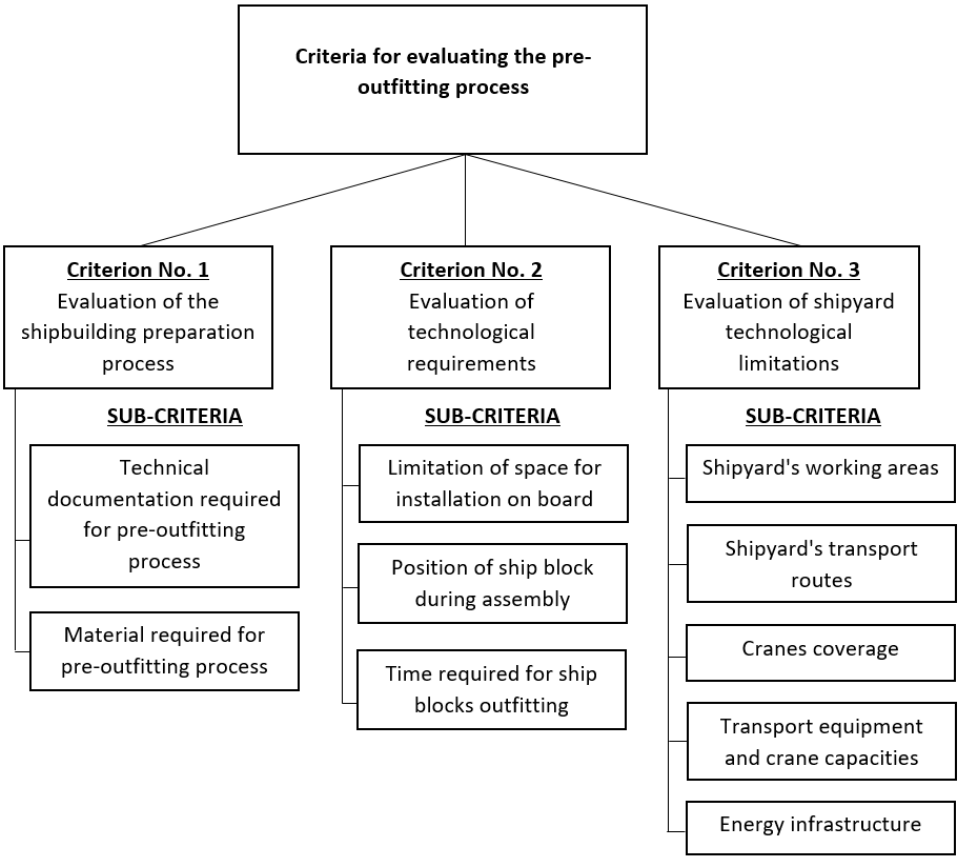

Fig. 6 Breakdown structure of criteria for evaluating the level of ship pre-outfitting

Table 6 Evaluation of the shipbuilding preparation process – Criterion No. 1

SHIPBUILDING PREPARATION PROCESS, CRITERION NO. 1		
No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_x) 1 to 5
1	TECHNICAL DOCUMENTATION REQUIRED FOR THE PRE-OUTFITTING PROCESS	1 - Ship outfitting is carried out using functional technical documentation. 2 - Specific detailed technical documentation for the pre-outfitting process is not provided, except for on-board outfitting. 3 - Detailed technical documentation dedicated to on-board outfitting for preparing the necessary material and scope of the job at the required level of pre-outfitting. 4 - Detailed technical documentation for the pre-outfitting process prepared according to the ship systems is provided. 5 - Detailed technical documentation for the pre-outfitting process prepared according to zone outfitting is provided.
2	MATERIAL REQUIRED FOR THE PRE-OUTFITTING PROCESS	1 - Material preparation is performed using functional technical documentation in the production phase. 2 - Material preparation is performed using functional technical documentation in the preparatory phase. 3 - Material preparation is based on detailed technical documentation prepared for on-board outfitting in the production phase. 4 - Material preparation is based on detailed technical documentation for on-board outfitting in the preparatory phase. 5 - Material preparation is based on detailed technical documentation prepared for pre-outfitting.
		$Gr_{PP} = \frac{Gr_1 + Gr_2}{2}$

Table 7 Evaluation of technological requirements - Criterion No. 2

TECHNOLOGICAL REQUIREMENTS, CRITERION NO. 2		
No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_x) 1 to 5
1	LIMITATION OF SPACE FOR INSTALLATION ON BOARD	1 - Ship equipment can be installed on board without restrictions. 2 - Ship equipment can be installed on board using auxiliary tools and devices. 3 - The space on board dedicated to the installation of ship equipment cannot be done in safe conditions. 4 - Transport routes limit the space reserved for the installation of ship equipment on board. 5 - The space on board dedicated to the installation of ship equipment is inaccessible.
2	POSITION OF BLOCK DURING BLOCK ASSEMBLING	1 - Installing ship equipment inside and outside the block is impossible. 2 - Installing ship equipment inside the block is impossible. 3 - Installing ship equipment outside the block is impossible. 4 - Installing ship equipment is possible by turning the block in a suitable position. 5 - Installing ship equipment is possible in the block assembly position.
3	TIME REQUIRED FOR BLOCK OUTFITTING	1 - The planned time for block outfitting is close to the time it is erected. 2 - It is not technologically possible to simultaneously perform works on block assembling and outfitting. 3 - Extra time for block outfitting upon its completion is provided. 4 - Technologically, works on block assembling and outfitting can be performed simultaneously, and additional time for outfitting after block completion is provided. 5 - It is technologically possible to complete the process of block outfitting at the same time as the block assembly.
		$Gr_{TR} = \frac{Gr_1 + Gr_2 + Gr_3}{3}$

There is no explicit and detailed delimiter of activities and recommended equipment installed in the pre-outfitting stage. Criteria for evaluating the pre-outfitting process are shown in Fig. 6 and Tables 6 to 8. A higher rating in Tables 6 to 8 means greater justification for applying the pre-outfitting process.

The overall grade for the level of ship outfitting is derived using Equation 3, which includes the average grade based on the preparation process (Gr_{PP}), the average grade based on technological requirements (Gr_{TR}), and the average grade based on shipyard technological limitations (Gr_{TL}).

$$\boldsymbol{Gr_{TLO}} = \frac{\boldsymbol{Gr_{PP} + Gr_{TR} + Gr_{TL}}}{\boldsymbol{3}} \quad (3)$$

Table 8 Evaluation of shipyard's technological limitations - criterion No. 3

SHIPYARD TECHNOLOGICAL LIMITATIONS, CRITERION NO. 3		
No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_x) 1 to 5
1	SHIPYARD WORKING PLACES DEDICATED FOR PRE-OUTFITTING	1 - The working place for the pre-outfitting process is insufficient and far from the place of shipbuilding. 2 - The working place for the pre-outfitting process is satisfactory but far from the place of shipbuilding. 3 - The working place for the pre-outfitting process is insufficient but close to the shipbuilding place. 4 - The working place for the pre-outfitting process is satisfactory and close to the shipbuilding place. 5 - The working place for the pre-outfitting process is large and close to the place where the ship is being built.
2	SHIPYARD TRANSPORT ROUTES FOR THE PURPOSE OF PRE-OUTFITTING	1 - The transport routes are long and inaccessible. 2 - The transport routes are long and accessible. 3 - The transport routes are short and inaccessible. 4 - The transport routes are short and occasionally crowded. 5 - The transport routes are short and accessible.
3	CRANE COVERAGE ON PRE-OUTFITTING PLACE	1 - No coverage by fixed and mobile cranes. 2 - No coverage by cranes, but it is possible to use crane trucks. 3 - Limited coverage by cranes. 4 - Limited coverage by cranes and crane trucks. 5 - Good coverage by fixed and mobile cranes.
4	CAPACITY OF TRANSPORT EQUIPMENT AND CRANES FOR PRE-OUTFITTING	1 - Limited lifting and transportation using special tools and devices are possible. 2 - Lifting and transportation are possible by using special tools and devices. 3 - Limited lifting and limited transportation are possible. 4 - Lifting is possible but with limited possibilities for equipment transportation. 5 - Complete transportation and lifting are possible.
5	AVAILABILITY OF ENERGY RESOURCES	1 - Energy resources are unavailable. Hence, portable systems must be used. 2 - Energy resources are currently unavailable, but a temporary portable energy system is possible. 3 - There is partial energy availability, but a portable energy system is still occasionally needed. 4 - There is partial energy availability, with a temporary (backup) energy system occasionally needed. 5 - Energy resources are available.
		$Gr_{TL} = \frac{Gr_1 + Gr_2 + Gr_3 + Gr_4 + Gr_5}{5}$

5. Criteria for evaluating the influence of amendments to technical documentation on ship production

Amendments to technical documentation are carried out when the drawing does not provide relevant information for ship production. Amendments can be omitted from the drawing, be incomplete or inaccurate; hence, they are a major cause of modifications in ship production. Modification is a term used for working on a product that needs to be redone, and the product is often repaired or rearranged [25]. The leading indicator of the unreliability of technical documentation is the number of revisions on each drawing.

Drawing amendments can be achieved by updating or making changes to drawings. When a drawing is updated, it is supplemented with missing information, but existing information in the drawing is not changed. In contrast, introducing changes to drawings means the information contained in the drawing is modified and updated. Changes to technical documentation usually occur due to requests or remarks from ship owners, classification societies or vendors. Depending on the time of the changes, it will require subsequent modifications of technical documentation, the shipbuilding schedule, testing, controlling and commissioning plans. If the need to change technical documentation is identified in the design stage, the effect will be limited to the cost of changes in the technical documentation, with a possible time extension for completion. However, if needed changes to technical documentation are identified once ship production has already begun, depending on the production stage, the cost of such changes increases. Also, changes to some ship systems often lead to changes in systems not directly related to the initially requested change.

The lack of information that should be incorporated in a drawing is also one of the causes of amending technical documentation. It delays the completion of drawings due to the additional time required to process or include the missing information in the drawing or drawing amendments. The recommendation for overcoming the impact of insufficient information on the continuity of ship production is to add appropriate space for subsequent missing information in the drawing. Another solution is to specify and mark parts of the drawing created using incomplete and unreliable information. The marked area should be avoided during ship production until sufficient information (amendments) is provided. It ensures the continuity of ship production and the ability to work on verified details provided in the technical documentation, preparing ship production stakeholders for future changes. If amendments to technical documentation are needed when work commences, the work should be halted, and the parts of the drawing intended for modification should be avoided. This approach reduces the impact of modifications and also costs.

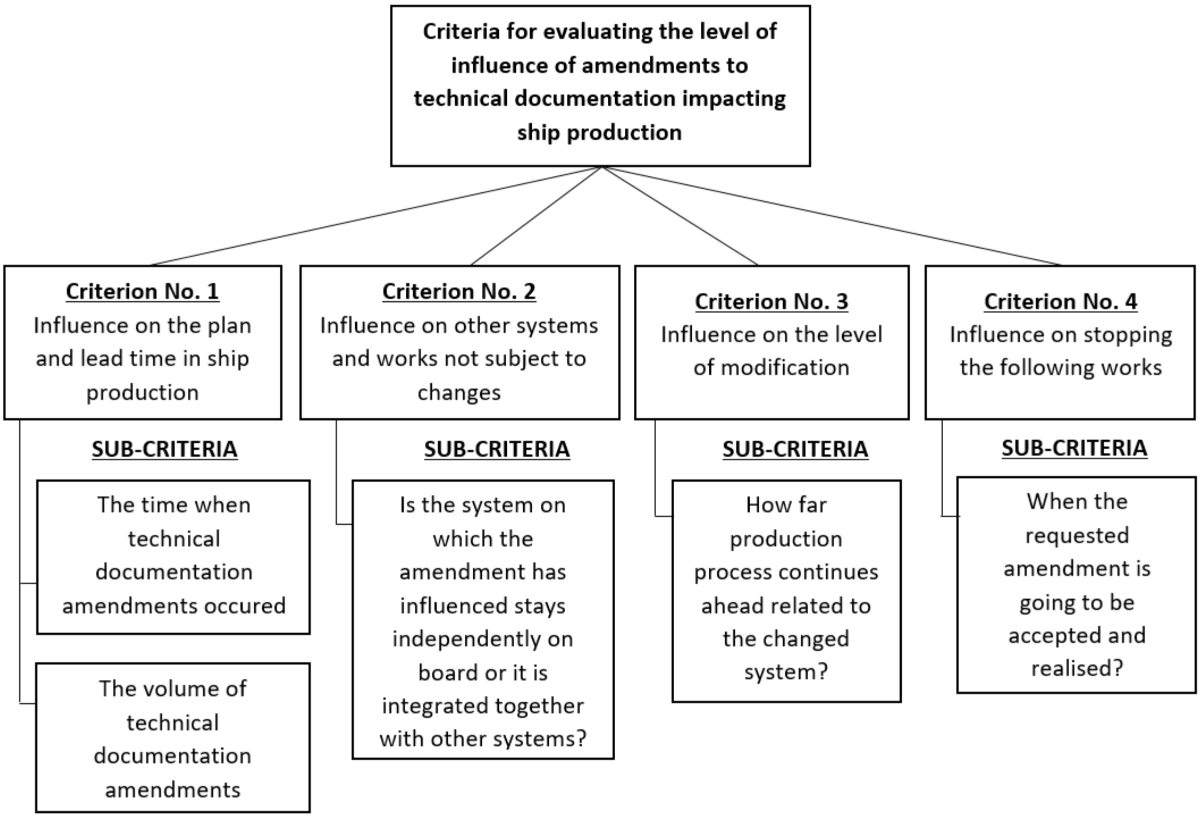

Fig. 7 Breakdown structure of criteria for evaluating the level of influence of amendments to technical documentation impacting ship production

Criteria for evaluating the level of influence of amendments to technical documentation impacting ship production are shown in Fig. 7 and Tables 9 to 12. A higher rating means a greater impact on ship production.

Table 9 Evaluation of the influence on the plan and lead time in ship production - Criterion No. 1

No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_x) 1 to 5
1	TIME OF AMENDMENTS TO TECHNICAL DOCUMENTATION	1 - Basic design stage. 2 - Functional design stage. 3 - Fetail design stage. 4 - Stage of material purchasing. 5 - Stage of ship production.
2	AMOUNT OF AMENDMENTS TO TECHNICAL DOCUMENTATION	1 – Only technical documentation. 2 - Technical documentation and material specifications. 3 - Technical documentation, material specifications and partially installed details. 4 - Technical documentation, material specifications and completely installed details. 5 - Technical documentation, material specifications, and fully installed details, along with modifications to the surrounding systems not directly subject to drawing amendments.
		$Gr_{PL} = \frac{Gr_1 + Gr_2}{2}$

Table 10 Evaluation of the influence on other systems and works not subject to changes - Criterion No. 2

No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_{ST}) 1 to 5
1	IS THE AMENDMENT-INFLUENCED SYSTEM INDEPENDENT OR INTEGRATED WITH OTHER SYSTEMS?	1 - The system is independent. 3 - The system is partly integrated with other systems. 5 - The system is fully integrated with other systems.

Table 11 Evaluation of the influence on the level of modification - Criterion No. 3

No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_{LM}) 1 to 5
1	HOW FAR HAS THE PRODUCTION PROCESS PROGRESSED ON THE AMENDMENT-INFLUENCED SYSTEM?	1 - The production process has not yet started. 3 - The production process has partially started. 5 - The production process is completed.

Table 12 Evaluation of the influence on stopping the following works - Criterion No. 4

No.	INFLUENTIAL SUB-CRITERIA	GRADE (Gr_{FW}) 1 to 5
1	WHEN IS THE REQUEST FOR THE AMENDMENT PLANNED FOR APPROVAL AND REALISED?	1 - Immediately. 3 - Waiting for approval from the person responsible FOR the shipyards. 5 - Waiting for approval from the classification institution or shipowner.

The overall grade for evaluating the level of influence of amendments to technical documentation affecting ship production (Gr_{TLD}) is calculated using Equation 4:

$$Gr_{TLD} = \frac{Gr_{PL}+Gr_{ST}+Gr_{LM}+Gr_{FW}}{4} \quad (4)$$

where (Gr_{PL}) is the average grade of the influence on the production plan and lead time, (Gr_{ST}) is the grade of the influence on the systems and works not subjected to change, (Gr_{LM}) is the grade of the influence on the level of modification, (Gr_{FW}) is the grade of the influence on stopping further work.

6. Conclusion

The authors of this paper have proposed a methodology for evaluating the technological level of the observed shipyard based on the definition, structure and valuation of relevant criteria. The identified criteria in the proposed methodology are divided into three major groups. They are the criteria for the technological level of ship production, the criteria for evaluating the technological level of ship pre-outfitting and the criteria for amendments to the technical documentation that affect evaluation of ship production. For a more detailed analysis, each of these three criteria is divided into more sub-criteria and properly evaluated to obtain the overall grade of the shipyard technological level. Furthermore, the suggested methodology also provides a solution to management that continuously monitors and improves shipyard design and production processes. In ongoing research, the authors will use the proposed methodology for several different shipyards in order to analyze and compare results from different shipyards to and finally evaluate the respective technological levels.

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