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PROCEDURE FOR ESTIMATING THE EFFECTIVENESS OF SHIP MODULAR OUTFITTING

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Abstract: *The shipbuilding industry plays an important role in increasing employment and productivity of the national industry. It is especially important when the market has fallen due to the influence of the global economical crisis. This paper is based on modular outfitting concepts which are used in modern shipyards, with the aim of optimising the shipbuilding production process by increasing the portion of modular vessel outfitting as a way of shortening the duration of the shipbuilding process, reducing costs and increasing competitiveness without investing in new facilities, machines and tools. To illustrate the cost savings potential obtained by this research, a comparable procedure for cost benefit estimation for a conventional strategy versus cost estimation for a modularised design approach and relevant build strategy is developed. On the basis of the results it is possible to measure cost benefit as a consequence of using the modular outfitting concept within the shipbuilding process.*

Keywords:
– shipbuilding production process
– ship modular outfitting
– modularised design approach
– outfitting optimisation

1. INTRODUCTION

If shipyards wish to become successful and competitive in the world shipbuilding market, they have to build quality ships along with decreasing costs of the production process and shortening of delivery time of the ship. Shortening the time of the shipbuilding process by using the modular outfitting concept is one way of reducing total ship production time, thus improving efficiency and cost performance.

The shipbuilding industry explores increasingly various outfitting concepts, which can contribute to reduction of time and cost in shipbuilding, especially in the field of improving on-block outfitting. But the mentioned concept cannot be used in the same manner for different shipyards, due to internal shipyard obstacles, such as lack of space, constraints of lifting crane capacities and transportation vehicles. Thus, the modular outfitting concept is widely seen as an area where considerable progress is still possible to avoid the mentioned obstacles, and the authors suggest the further improvement of advanced outfitting to be achieved by introducing larger standardised, unitised and typified modules, pre-assembled in the workshop. As modules become more and more standardized, still more cost and schedule benefits can be garnered as efficiency increases from repetitive manufacturing.

In this paper the modular ship outfitting concept is taken into consideration as a way to improve shipbuilding productivity, and a new procedure for modular outfitting efficiency measurement is developed. This procedure is derived from rules of thumb and the empirical knowledge of experts in the observed shipyard.

2. DEFINITION

Because different countries, shipyards, and even workers in same shipyard use different words to explain the same concepts, in this paper clear definitions for use of specific words applicable to advanced outfitting are provided. For better understanding, illustration of some concepts is depicted in Figure 1.

ADVANCED OUTFITTING. The installation of outfit systems and components on a structural block or outfit unit prior to shipboard erection.

GROUND OUTFITTING. Outfit installation during on-block outfit stages or on-unit in the workshop.
ON-UNIT OUTFITTING. Outfit assembly and installation on an outfit unit in the workshop prior to erection onboard.
ON-BLOCK OUTFITTING. Outfit installation on a structural block prior to erection on the building berth.
ON-BOARD OUTFITTING. Outfit installation on a building berth before launching or on-board after launching.
FINAL OUTFITTING. Outfit installation and testing on-board at an outfit pier after launching.

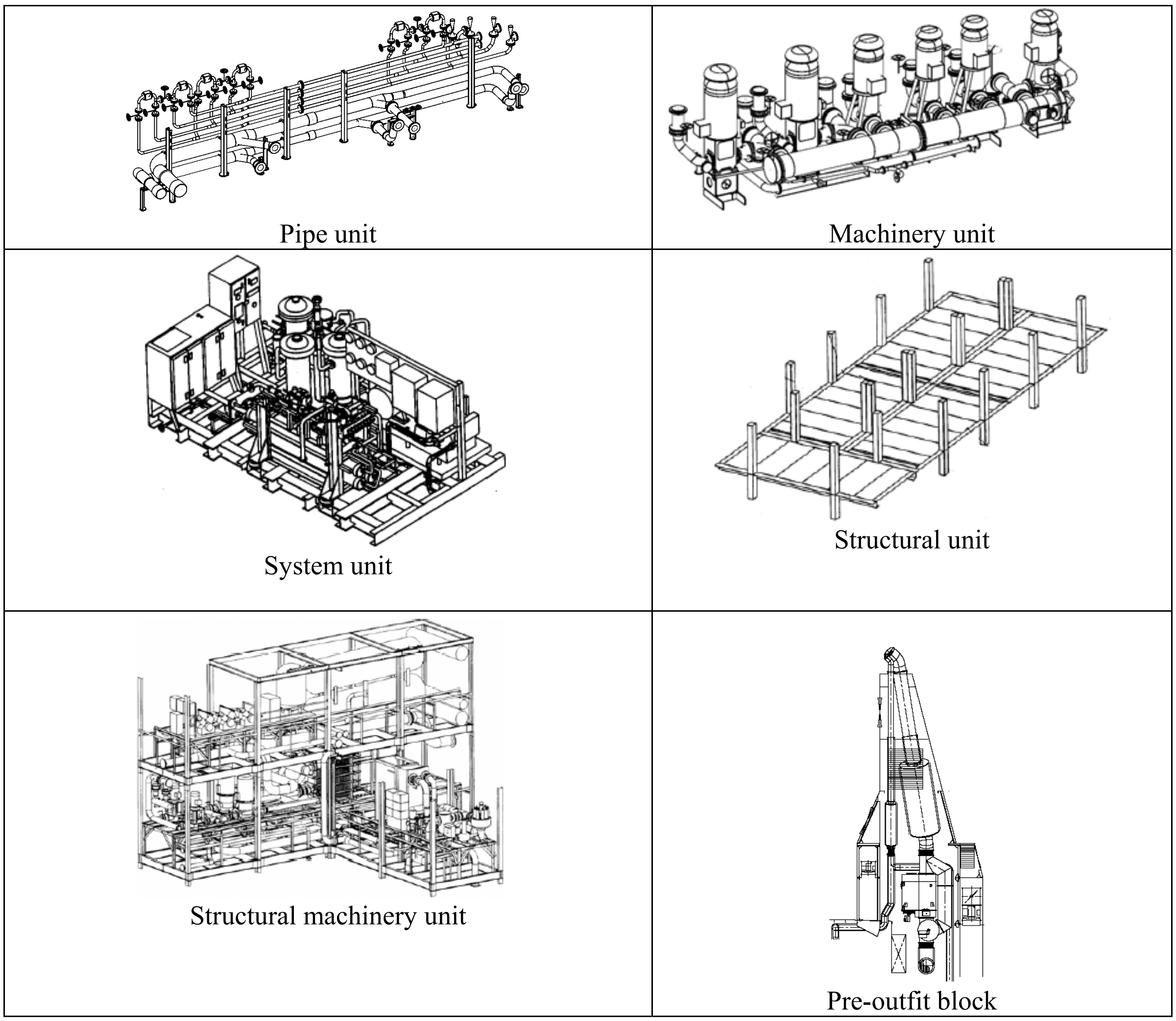

Figure 1. Modular outfitting definitions.

OUTFIT. A broad definition of all non-structural equipment and systems which are to be installed in or on a ship, including machinery.
UNIT. A packaged group of outfit, equipment and machineries designed to be treated as a single component, installed on common supports and foundation and manufactured in a workshop independently of the hull construction.
ON UNIT. The term used to identify the activity of installing a group of outfits on a common foundation and supports into a package consisting of machines, equipment, pipes, cable traces, wirings, gratings, and controls.

ZONE. An assigned area or compartment in the shipyard and/or onboard the ship for the purpose of organizing information, planning, material, and resources to support the design and construction of the ship.
UNIFICATION / TYPIFICATION. The design of identical system details for identical equipment, for example, an identical part for a diesel engine
SINGLE PART. A structural interim product which is fabricated from plates or shapes and after cutting will be incorporated with other single parts into a subassembly, assembly or block.
ASSEMBLY. A structural interim product, which is fabricated from processed plates and shapes, and which when completed will be incorporated with other subassemblies into an flat block, block, grand block, ring unit or on board.
PANEL. A structural interim product consisting of two or more butt welded plates with fillet welded longitudinal shapes.
PANEL ASSEMBLY. A structural interim product consisting of a flat or curved panel block made up from individual flat or curved plates, shapes, and subassemblies, such as deck, shell, bulkhead, etc.
FLAT BLOCK. A structural interim product characterized by one dominating flat side, consisting of one or (normally) more butt welded plane plates, some ship longitudinal shapes and girders and some transversal frames, such as flat deck or bulkhead
BLOCK. Hull structural interim product, which can be erected as a block or combined as grand block. It consists of one or more panel assemblies made up from individual part and assemblies.
GRAND BLOCK. Hull structural interim product consisting of two or more structural blocks mated prior to onboard erection.
RING BLOCK. A large and heavy type of block as a part of a ship between two cross-sections, consisting of a number of conventional blocks.
PIPE UNIT. Assembly manufactured in the shipyard's workshop consisting of all pipe, and adjacent distributed system supported on a common hanger system.
MACHINERY UNIT. Ship specific assembly manufactured in the shipyard's workshop, consisting of one or more outfit systems including all mechanical and electrical components and subsystems in an area, installed on common supports and foundation.
SYSTEM UNIT. An assembly ordered by the supplier, consisting of all mechanical and electrical components making up a single subsystem on common supports and foundation.
STRUCTURAL UNIT. Structural foundation and grating support intended for a machinery unit.
STRUCTURAL MACHINERY UNIT. Assembly consisting of a structural unit, one or more system units, and all of the ship's distributed systems installed in an observed area.
PRE-OUTFIT BLOCK. Ring block, grand block, block or assembly outfitted before erection at the building berth.

3. TRADITIONAL OUTFITTING PROCESS

The traditional outfitting process is based upon large scale outfitting works performed during the building berth stage or in the pier after vessel launching. Only a small portion of advance outfitting is performed on steel blocks during the later stages of block assembly just prior to erection on the building berth [1].
Pipe spools, ventilation ducts, foundations, cable traces, etc. are fabricated in shipyard workshops and sent to the outfitting location on large pallets, followed by their installation at the appropriate stage. As a consequence, the completed outfitting process then requires an extensive paint touch-up.

4. MODULAR OUTFITTING APPROACH

The modular outfitting approach is based upon pre-outfitting in the workshop. It begins in the early stage of design, especially in machinery arrangement design. At this stage, functionally related equipment, systems, and tanks are located to reduce the distributed system footage and maximize unitisation and standardisation potential. The goal is to identify the largest possible assembly of the equipment and outfitting components that can be completed in the workshop, assembled concurrently with hull construction and easily lifted without exceeding crane-lifting capacities and workload during the installation. The final module content and layout is confirmed by a series of studies, build strategy, and preliminary system routing. Thus, modules are optimised, based upon engineering, spatial, regulatory, and economic parameters [1, 2].
Using the modular outfitting approach requires some changes in design and technological processes in shipbuilding, such as a higher effort in designing and documentation preparation, better engineering,

better quality assurance and a higher level of design standards to minimize interferences and disconnections [3].
Modules may be as small as a single piece of equipment mounted on their common supports and ready for installation on panel, on-block or on-board. Or as a complex assembly of equipment, piping, floors, electrical and other systems all pre-mounted on a support structure.
One main advantage of the modular approach of outfitting is that the modules can be manufactured and assembled by smaller, more flexible manufacturers located outside of the shipyard [4]. Such alternative manufacturers can be significantly more efficient than the traditional fully-integrated shipyard that often struggles to maintain high levels of efficiency for the many different worker trades and facilities needed to build a ship.
Some potential benefits that could be enabled by modular outfitting are as follows [5]:

- improving productivity and efficiency within the production labour force,
- reducing outfitting costs and man hours,
- minimizing the number of interface points between workers on-board, thus streamlining the shipbuilding process,
- modules can be built by workshops outside of the shipyard. It gives more opportunities for small and medium enterprises, and can lead to greater participation of the supplier base that can assume more development responsibilities to improve quality and further reduce costs,
- standardised and unified modules can lead to lower costs through reduction in design and drafting time, reduction in material procurement and preparing time, reduction in production time, as well utilisation in various types of ships.

But the modular outfitting approach has some disadvantages, indicated as follows:

- it reduces design freedom, due to the obstacle of installing functional systems in limited space,
- the space requirement is increased,
- modules are heavier than in conventional outfitting, due to stronger supports and foundations,
- the possibility of a higher risk of rework is observed due to immature detail engineering by a compressed production schedule.
- a need for more experienced designers who can link conceptual and production design with the capabilities of shipyard outfitting technology.

Despite the potential disadvantages, modularisation is increasingly used by successful shipyards, indicating that there is still considerable potential for improvement in the industry in terms of using modular approaches in design and production.

5. PROCEDURE FOR MODULAR OUTFITTING COST BENEFIT ESTIMATION

The procedure for modular outfitting cost benefit estimation in this paper is derived on the basis of *rules of thumb* data collecting and statistical data processing in the observed shipyard on various types of ships during a longer period of time, applied in order to estimate savings. As a result, the authors discovered the labour costs on-board can be on average 3-5 times higher than equivalent work done in the shop or on the platform [6].
From the detail work breakdown structure it is found that labour cost is dependent on the system as well as on the type of work included in the outfitting process during various stages [6]. Thus, the authors introduced the factors for fine labour cost regulation that are used for cost savings calculations in equations (1) and (2), which are shown in Table 1 [8,9].
In column 1, the work breakdown structure according to systems and work type is itemized, whereas column 2 provides the present level percentages of modular outfitting (PM) in the observed shipyard. Column 3 provides the maximum possible percentage level of modular outfitting. Finally in columns 4, 5, and 6, the factors for labour cost influence at different stages is defined. For on-board outfitting (OF), the factor value of 1 is used, while the factors for outfitting cost reduction in the other two stages, on-block (BF) and on unit (UF) are adjusted accordingly. The impact of increasing the portion of modular outfitting in relation to the decreasing cost of on-block or on-board outfitting is analysed, as well as the increasing cost for designing, constructing and preparing the production process for higher levels of modular outfitting and higher levels of accuracy during manufacturing [10]. While the outfitting cost, by increasing the portion of modular outfighting usage, decreases at the same time the design cost increases, which is shown in Table 1, the BF and UF factors for designing and drafting increase.

In this paper the authors described a new procedure developed for modular outfitting cost benefit estimation as well as the labour cost savings calculation. Furthermore, the authors discovered that modular outfitting is dependent on the ship type and ship spaces within various types of ships. See results in Table 2. The ship space with the highest potential for increasing modular outfitting usage is the engine room (ER), while the accommodation (AC) is middle, irrespective of ship type. The potential of modular outfitting in the cargo area spaces depends on the ship type (Table 2).

Table 1. Cost saving factors for various stage of the outfitting process.

1	2	3	4	5	6
Work breakdown structure	**PM %**	**TM %**	**OF**	**BF**	**UF**
Sea water system	40	80	1	0,4	0,2
Fresh water system	30	75	1	0,4	0,25
Fuel oil system	25	70	1	0,4	0,35
Lubrication system	25	70	1	0,4	0,3
Ballast system	20	60	1	0,4	0,35
Bilge system	25	65	1	0,4	0,2
Fire fighting system	25	70	1	0,4	0,3
Sanitary system	10	60	1	0,4	0,2
Hydraulic system	5	55	1	0,5	0,3
Exhaust system	10	80	1	0,4	0,4
Propulsion system	5	50	1	0,5	-
Ventilation	0	50	1	0,6	0,4
Air-condition	5	70	1	0,5	0,3
Cable trays	0	70	1	0,6	0,4
Electrics	20	70	1	0,5	0,2
Electronics	20	70	1	-	0,2
Foundation	30	95	1	0,4	0,2
Furniture	80	100	1	0,3	0,2
Accommodation	30	85	1	0,5	0,3
Basic design	5	40	1	1,1	1,3
Conceptual design	10	70	1	1,2	1,4
Detail design	25	70	1	1,4	1,6
Production drawings	25	70	1	1,4	1,6

LEGEND:

- *PM (present level of modular outfitting) = existing percentage of modular outfitting in relation with all outfitting work,*
- *TM (total level of modular outfitting) = estimated maximum percentage of work that can be modularised,*
- *OF (Onboard Factor) = labour cost factor at onboard stage of construction,*
- *BF (On-Block Factor) = labour cost factor for on-block work relative to onboard cost,*
- *UF (On-Unit Factor) = labour cost factor for on-unit work relative to onboard cost,*
- CS_{OF} *(on-board cost saving) = cost saving for advance modular outfitting allocated from on-board outfitting,*
- CS_{BF} *(on-block cost saving) = cost saving for advance modular outfitting allocated from on-block outfitting,*
- CS_{TOT} *(total cost saving) = total cost saving by using modular outfitting approach,*
- *MH = man hour,*
- *LC = labour cost per man hour.*

From the described procedure it is possible to define:

- present level and labour cost of modular outfitting,
- potential for improvement in modular outfitting through finding the systems and types of work where there is a possibility for subsequent improvement in modular outfitting,
- potential for further cost reduction of ship outfitting, time reserve in the outfitting process.

To avoid the risk of rework mentioned in Section 4, the overlap between basic, conceptual and detail design shall be minimized as possible and the actual production should not start before the production drawings for the applicable space, phase and stage are completed. This can ensure precocious information needed for the accurate design and production process, described as *do it right the first time* (DRIFT). However, if rework becomes necessary, the production cost could increase more than eight times, because repair will need to be performed in a less appropriate stage. Thus, repair work can be avoided through better and more accurate scheduling of the production processes, which requires that each subsequent activity starts only upon full completion of the previous activities. This means that the design, purchase and production preparation processes have to start earlier in order to facilitate the availability of all production information prior to the start of production.

Table 2. Potential of modularisation in relation with ship spaces for various types of ships.

Type of ship	**Potential of modularisation**		
	ER	**CA**	**AC**
RoRo	High	Low	Medium
Tanker	High	Medium	Medium
Bulk	High	Low	Medium
Container	High	Low	Medium
FTSPO	High	High	Medium
Car/Passenger ferry	High	Low	Medium

LEGEND:
- *ER – engine room,*
- *CA – cargo area,*
- *AC – accommodation.*

The procedure for the cost saving calculation obtained by modular outfitting usage for work that is made in the workshop instead of the same work performed on-board is depicted in following equation:

$$CS_{OF} = \frac{TM - PM}{100} \circ \left| OF - UF \right| \circ MH \circ LC \quad (1)$$

The procedure for cost saving calculation obtained by modular outfitting usage for work that is made in the workshop instead of the same work performed on-block is depicted in following equation:

$$CS_{BF} = \frac{TM - PM}{100} \circ \left| BF - UF \right| \circ MH \circ LC \quad (2)$$

The cost savings, obtained by the modular outfitting approach in this paper, is expressed in monetary units, instead of working hour consumption as is used in the conventional manner. The reason for this is that the working hour consumption does not provide the real nature of the cost, because in a group of workers engaged in the same job task, the man-hour price for each worker respectively is not identical, due to the education level, working skills and competence as well interestedness and motivation of workers. The real cost saving expressed in monetary units is directly dependent on the number and structure of workers who are involved in the group to realize the working task. As the number of qualified, better paid workers in a working group increases, for the same working hour consumption, the cost will be proportionally greater. For cost saving calculation by using modular outfitting expressed in equations (1) and (2), the average hourly wage of the entire group of workers assigned to the same job task is applied. Even so, it is more advisable to analyze the cost savings on the level for each worker individually. Thus new equations (3) and (4), derived from equations (1) and (2), are developed.

$$CS_{OF} = \frac{TM - PM}{100} \circ \left|OF - UF\right| \circ \sum_{i=1}^{n} MH_i \circ LC_i \quad (3)$$

$$CS_{BF} = \frac{TM - PM}{100} \circ \left|BF - UF\right| \circ \sum_{i=1}^{n} MH_i \circ LC_i \quad (4)$$

Where i = worker as individual, n = total number of workers. The total cost savings is obtained by addition of the cost savings for advanced modular outfitting allocated from on-board outfitting and the cost savings for advanced modular outfitting allocated from on-block outfitting as follows:

$$CS_{TOT} = \sum CS_{OF} + \sum CS_{BF} \quad (5)$$

6. CONCLUSION

Modular outfitting is a way to shorten the duration time of the shipbuilding process and reduce costs, without making capital investments in new facilities, machines and tools, which will significantly increase the shipyards competitiveness level as well as the complementary domestic industry. In this paper a new procedure for shipbuilding cost benefit measurement is developed, as a consequence of using the modular outfitting concept within the shipbuilding process. The result will be applicable in observed shipyards and wider, through the procedure for fast and simple selection of the existing level of advanced outfitting, with the possibility of using a multicriterial decision process in defining a strategy for further improvement of the ship outfitting process with an exact indicator for impact in cost reduction.

Additionally, terms and concepts used in advanced outfitting are defined in order to avoid confusion and the authors propose using them as standard jargon.

The authors also suggest further improvement of ship modular outfitting by introducing a higher degree of standardization, unification and typification of ship modules, which leads to the development of a fully integrated structure and outfit construction.

7. LIST OF SYMBOLS

present level of modularised outfitting	*PM*,	%
total level of modularised	*TM*,	%
on-board ship outfitting factor	*OF*,	-
on-block ship outfitting factor	*BF*,	-
on-module ship outfitting factor	*UF*,	-
on-board ship outfitting cost saving	CS_{OF},	€
on-block ship outfitting cost saving	CS_{BF},	€
total cost saving	CS_{TOT},	€
man hour	*MH*,	h
labour cost per man hour	*LC*	€/h

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