ORIGINAL ARTICLE

Configuration estimation method for preliminary cost of ships based on engineering bills of materials

Myeong-jo Son · Sang Chul Lee · Ki-chang Kwon · Tae-wan Kim · Rajiv Sharma

Abstract Ships are complex engineering structures that are designed and built on the basis of technical experience. A shipowner will often be required to estimate the price of a new ship on the basis of the value of comparable ships identified in trade journals. Similarly, shipbuilders are often interested in estimating approximate costs during the tendering phase in order to determine whether a ship is likely to be competitive for a particular order. Thus, when designing a ship prior to having obtained a contract, one of the most important processes is the estimation of approximate costs, including materials, associated labor, and overhead. During this preliminary design phase, the design is temporary and subject to change based on variations in the shipowner's requirements. Hence, quick and flexible responses are key during this period and an integral aspect of the competitive powers of the shipbuilder. Given this environment, we propose a "configuration estimation method." Our method is based on the configuration design method that is widely used in three-dimensional (3D) computer aided design (CAD) systems. We assume that a product lifecycle management system is furnished and that the cost is then estimated via the configuration of the ship, using an engineering bill of materials (E-BOM). In referring to the E-BOM, we utilize technical parametric costs derived from similar ships built previously. Using the proposed method, it is possible to obtain an accurate list of materials from the quotation, as well as a detailed work assessment for labor costs and overhead rates, so that reliable cost estimates can be generated quickly and flexibly. To demonstrate the practical applicability and effectiveness of the proposed method, we implement the prototype of a shipbuilding configuration estimation system by using a Microsoft Structured Query Language database and an E-BOM from AVEVA Marine version 12.01, which is a representative CAD system for shipbuilding.

M. Son
Department of Naval Architecture and Ocean Engineering,
Seoul National University, Seoul 151-744, Korea

S. C. Lee
Intergraph Korea Ltd., Seoul 137-070, Korea

K. Kwon
SK C&C Co., Ltd., Seongnam-si 463-844, Korea

T. Kim (✉)
Department of Naval Architecture and Ocean Engineering,
and Research Institute of Marine Systems Engineering,
Seoul National University, Seoul 151-744, Korea
e-mail: taewan@snu.ac.kr

R. Sharma
Department of Ocean Engineering, Indian Institute
of Technology Madras, Chennai 600-036, India

1 Introduction

1.1 Cost estimation

Ships are complicated engineering structures that are designed and built on the basis of technical experience. To build a large merchant ship, a budget between $30 and $232 million would be required, and time required for building would be between 1 and 2 years [1]. As such, when a shipowner is interested in acquiring new tonnage, he/she would typically want to know the approximate budget (price)

required. To obtain this, the owner will typically estimate the approximate price on the basis of the value of reasonably similar ships as identified in trade journals. Similarly, shipbuilders are often interested in estimating approximate costs (rather than an approximate price) during the tendering phase to determine whether they are likely to be competitive for a particular order. Here, the cost of a ship is the sum needed to pay for all the materials and labor involved in its construction, including overhead costs, whereas the price of a ship is the sum of money that a shipyard quotes and eventually receives from the customer [2]. The difference between cost and price can be viewed as being equal to any allowances necessary for cash flow financing, anticipated inflation, the shipyard's desired profit, etc. The ship tender price for the shipbuilder is mostly dependent on the estimated cost; thus, when designing a ship prior to having obtained a contract for tendering purposes, one of the most important processes is estimation of the approximate costs, which includes cost of materials, associated labor, and overheads. Figure 1 shows the tendering process for ships, which is typically followed by a shipbuilder.

During the preliminary ship design phase, prior to the existence of a contract, the design is subject to change with variation in the shipowner's requirements. Hence, quick and flexible responses are key during this phase and constitute one of the competitive powers of shipbuilders. However, most shipyard estimates derive these costs from the costs per ton or man-hours per ton. These values are typically obtained from records of recent construction or from the figures supplied in a recent detailed cost estimate of a comparable ship [2].

Currently, there exist no systematic immersive systems in support of the shipbuilding tendering process. Thus,

often, a week or more is required to perform cost estimation in the preliminary design phase, because experts do so solely on the basis of prior experience, as identified above, occasionally employing a simple database system or an enterprise resource planning (ERP) system. Consequently, the resultant estimation may be relatively inaccurate and repetitive. If a quick and flexible response can be achieved for the various changes in the shipowner's requirements, and if the preliminary design information can be formulated in a manner such that it addresses all details required for completion of the construction phase, then the associated costs and time period from receiving the shipowner's requirements to the delivery of the ship would be significantly reduced and would result in cost saving. For this reason, most successful shipbuilders have recently been adopting the product lifecycle management (PLM) system for the shipbuilding industries [3, 4]. In keeping with the concepts of PLM, utilization of the engineering bill of materials (E-BOM) information in tandem with a three-dimensional (3D) computer aided design (CAD) system has the potential to meet the demand for quick and flexible cost estimation during the tendering phase. This study was motivated by this consideration.

1.2 Related research

Three primary types of cost estimation may be employed during the preliminary design phase in industries dealing with manufacture of general products. These vary by input: data-based, expert-based, and hybrid methods [5]. Traditionally, the cost estimation approach used in the shipbuilding industry is dependent on the knowledge of experts, who are informed by recent construction indices

Fig. 1 Typical sales process in shipbuilding business
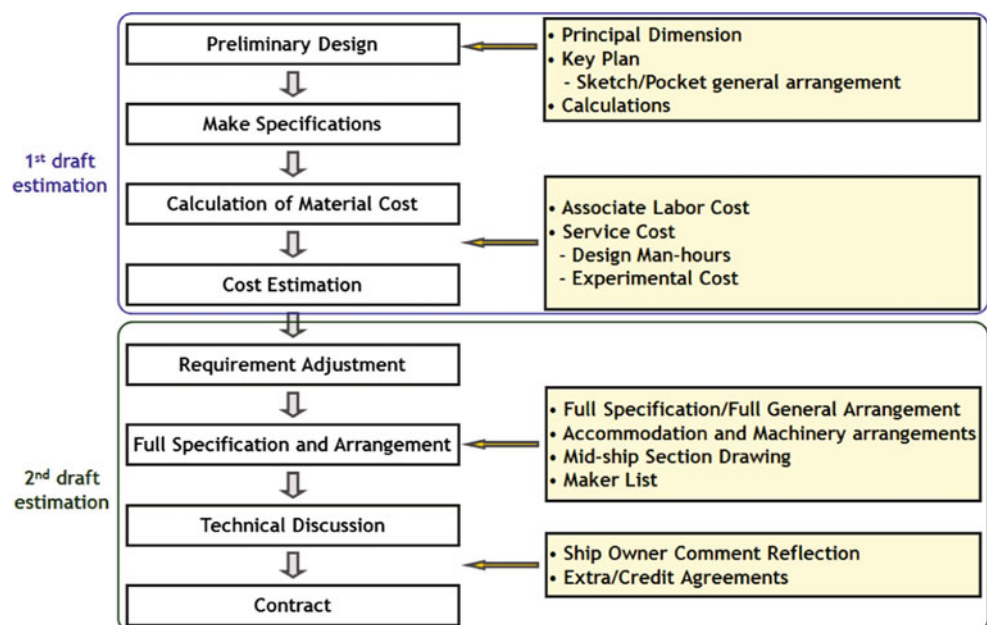
[6, 7]. Moving beyond the traditional methods, Ray et al. [8] presented a global optimization model of ship design for computer-aided cost estimation. However, while some have adopted automated calculation using computers, from the perspective of cost estimation, in general, the estimation method remains expert-based, producing approximate results. Kromker and Thoben [9] established a ship cost estimation method for use in the pre-design process of the ship. The aim of their estimation method is to integrate cost evaluation in the technical domain, thus incorporating the cost elements as real design attributes. It is notable that they have pointed out that the accuracy of their cost estimation method is highly dependent on the available time and reliability of previous cost data. Ross [10] presented three stationary cost estimation approaches for commercial ships through employing a conceptual design, preliminary design, or contract design, on the basis of the US Navy's ship work breakdown structure (SWBS) defined by the department of defense, USA (DOD). In each design stage, Ross performed a cost estimation using the ship's gross weight and total (labor) man-hours, employing a differentiation method for each stage. Caprace [11] provided some innovative solutions for cost and complexity assessment during ship design to enhance the "design for X" concept in a concurrent engineering framework. According to terminologies that he has suggested in the work, we follow the traditional cost "estimation" method, not "assessment" method, as the way shipyards have performed on the basis of case based reasoning (CBR).

To shorten the estimation time requirement, we present a hybrid estimation method using a computerized expert-based approach. It means we suggest a combined CBR and feature-based costing method. We derive, systemically and hierarchically, a standardization and modularization method of ship design, which incorporates the most recent construction design parameters and materials supported by 3D CAD systems. The user follows a conventional CBR method with accurate feature-based cost information provided by the 3D CAD systems. Our method is developed with PLM in mind, as this methodology has been commonly adopted in the shipbuilding industry.

PLM is a "total solution technique" that integrates various industrial systems such as CAD, computer aided manufacturing (CAM), computer aided engineering (CAE), product development and management (PDaM), product data management (PDM), and project management system (PMS), to support all activities, including the planning, design, manufacturing, operation, maintenance, disposal, and recycling of the product, as well as the management of the data and knowledge pertaining to it, throughout its lifecycle [12–16]. The integrative capabilities of PLM have inspired manufacturing industries to construct collaborative work systems that enable the management and definition of product information throughout the enterprise during the course of its lifecycle. As the inaccurate management of product information in this modern competitive environment can result in frequent design changes that increase the cost and delay of product delivery, real-time sharing of exact product information is needed [17–20]. The concept and the application of PLM systems have been researched specifically for shipbuilding industries [21–23]. In particular, standardization and modularization for design re-use has been proposed for shipbuilding PLM systems [24, 25]. Support for early conceptual design, detailed design, and fully functional system design are lacking in the current manifestation of a PLM system. In particular, the cost estimation is an industry-oriented process and therefore must be tailored to the shipbuilding industry, while simultaneously being defined within the bounds of PLM and in line with system and ship 3D CAD systems. We refer to the BOM, as maintained by PLM technologies, when seeking to address data exchange between PLM and 3D CAD systems, as well as its retrieval and usage in the cost estimation approach.

The BOM is an important data parameter in PLM, representing product information such as hierarchical parts that are associated with a certain product. As such, it can be employed as a criterion in managing the product information throughout the product lifecycle (e.g., the conceptual design, detailed design, production, sales, and disposal), in a consistent manner. The BOM can be classified according to purpose and department. First, the engineering BOM (E-BOM) is used in the design process and represents the product in terms of its functional sub-systems in a hierarchical manner. The manufacturing BOM (M-BOM) is used in the construction or production process and is obtained by modifying the E-BOM according to the production and assembly processes. The M-BOM contains the assembly group information, organized hierarchically. Finally, the planning BOM (P-BOM) is used in the production management process, sales, and marketing. It represents the production planning and master production scheduling [26, 27].

1.3 Outline

In this paper, we propose a configuration estimation method that follows a process similar to the configuration design method, which has been used widely in 3D CAD systems. The ship configuration is obtained on the basis of PLM, which is widely used in the shipbuilding industry. This is done, using various E-BOMs from recent construction efforts, to generate the ship's cost estimate inclusion in the tendering phase. Using data on exact materials and corresponding module costs from recent construction and assembly efforts, rather than man-hours

per ton, we can generate a reliable cost estimate in real time. To demonstrate this, we implemented a prototype cost estimation system. We present the model with an appropriate example.

In Sect. 2, we analyze a ship's E-BOM. Proposing an approach to encoding this data in a database, we seek to facilitate communication with a PLM system and the proposed cost estimation application by standardizing and modularizing the ship from the perspective of the E-BOM. The E-BOM is thus defined in a hierarchical structure. In Sect. 3, we describe the proposed configuration estimation method. In Sect. 4, we present the prototype demonstration using a ship-tendering example and implementation outline. Finally, in Sect. 5, we conclude the paper and describe future work.

2 Ship engineering bill of materials

2.1 Analysis of ship E-BOM

Conventionally, the ship represented in the SWBS is a product representation structured on the basis of the functional system [28]. Thus, the design engineer in charge of the cost estimation in a tendering phase has difficulty finding appropriate parts from similar ships built previously whose material and labor cost information can be re-used. This is because ship have traditionally been designed on the basis of an engineering zone (not a functional system) in a construction phase. Successful re-use can be possible when the experience and knowledge of the design engineer have been incorporated into the empirical formula that maps the functional system to the engineering zone. However, in this work we would like to propose an easier and more intuitive method for re-using the material and labor cost information of the similar, previously built ships, so that location-grouped components of ships, including the material and labor cost, can be swapped in and out easily. Therefore, on the basis of the product-oriented work breakdown structure (PWBS) [29] that enables a ship product representation in the form of a location-grouping-based engineering zone, we expand ship modularization using the E-BOM to provide the hierarchical structure.

The BOM of a ship represents the hierarchical structure between a ship and its parts. The BOM can be employed as a criterion to manage ship information during the course of its lifecycle in a consistent manner. In other words, the ship BOM implies ship–part relationships within a hierarchical structure. For instance, a ship consists of mega-blocks or pre-erection (PE) blocks, a PE block consists of several assembly blocks, and an assembly block consists of many small assembled parts and materials. The ship's BOM represents not only the ship's hierarchical structure, but

also the entire body of part information necessary for the ship's construction.

A major 3D shipbuilding CAD system is AVEVA Marine, which has been adopted in major shipbuilding yards such as Hyundai Heavy Industries and Daewoo Shipbuilding and Marine Engineering (DSME), the world's top two shipbuilding yards. This shipbuilding CAD system provides distributed design methods, which allow for the design of a ship by dividing it into smaller components, which are then addressed individually by a large number of design engineers. An example of this is the ship hull block E-BOM (shown in Fig. 2) exported from AVEVA Marine version 12.01.

The property data of the ship hull block parts can be extracted from AVEVA Marine v.12.01 in extensible markup language (XML) format. The XML data include the element name and part name, which are employed in the configuration method, as well as the material quality, weight, thickness, and area, which enable cost estimation. When ships' E-BOMs, employed in recent construction, are used in the preliminary design phase of a ship tendering process, exact and efficient cost estimation is possible.

2.2 Ship E-BOM classification

Ships are unique in terms of certain technical specifications that are related to the technical objectives underlying the design and type of ship. The intended usage of different ships varies widely (e.g., transportation of freight and passengers, offshore oil production, and survey/collection of information). We can classify a ship using these technical objectives and the ship's purpose. We use the technical parameters to handle the standardization of information so that it can be shared and exchanged across various systems. The details of the technical parameters used are described in Table 1 [24].

A ship is usually divided into a hull and an outfitting component. The hull is further divided into blocks, including components such as a forebody, an afterbody, and a cargo hold. Finally, an outfitting component is divided into steel outfitting, piping and electrical works, etc. These parts are all utilized in the ship design process.

This ship modularization determines the unit components that can be configured during the configuration estimation method. This means that we can produce a new design by the union of different modules.

We impose significant conditions on the performance of the proposed configuration estimation method by employing ship E-BOMs. That is, when we generate a new design by reconfiguration various modules from recent construction efforts, the recently built ships from which the modules are drawn must be in the same category, as defined by the standardization described previously.

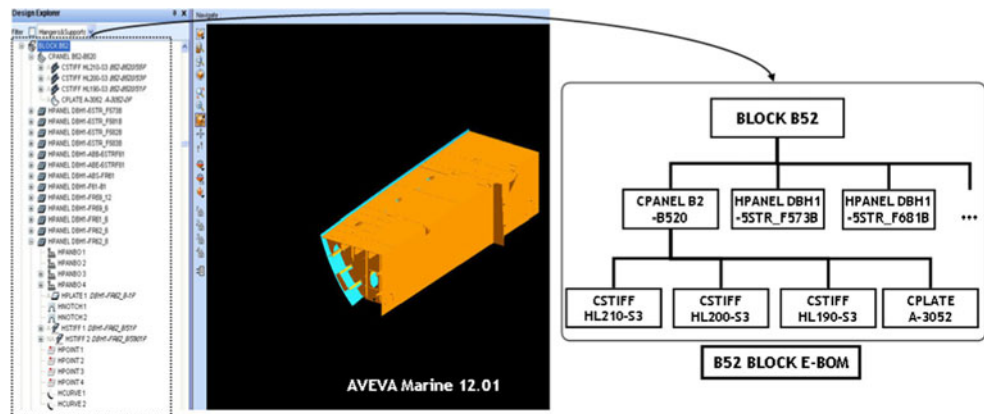**Fig. 2** Ship hull block E-BOM exported from AVEVA Marine v.12.01

Table 1 Details of ship E-BOM classification parameters

Classification parameters	Parameter details
1. Technical objectives or ship's purpose (large merchant ship only)	Container carrier, very (or ultra) large crude oil carrier (VLCC or ULCC), liquefied natural gas carrier ship (LNGCS), liquefied petroleum gas carrier ship (LPGCS), passenger carrier ship (PCS), bulk carrier, cruise ship, floating production, storage and offloading (FPSO), chemical tanker, etc.
2. Set of technical dimensions	The ship's deadweight, block coefficient (CB), bilge radius (BR), ratio of parallel middle body (RPMB), length between perpendiculars (LBP), mean molded depth (D), mean draft (T), ballast draft (both mean and of tankers) (TB), breadth (B), LBP/B ratio, and B/T ratio
3. Set of technical features pertaining to the ship parts	Aft part: bulbous stern or non-bulbous stern, forward part 1: bulbous bow or non-bulbous bow, forward part 2: X-shaped bow or non-X-shaped bow, bottom: double bottom or single bottom, side shells 1: single shell or double shell, and side shell 2: sloping side shell or non-sloping side shell
4. Set of technical features pertaining to the machinery	Engine: diesel driven (2-stroke or 4-stroke, reciprocating or non-reciprocating, engine construction: crosshead or opposed piston, engine speed range: slow [$\leq$ 300 rev/min] or medium (>300 and $\leq$ 900 rev/min) or high (>900 rev/min)], gas turbine driven, stern turbine driven, nuclear turbine driven, or hybrid system (diesel-electric, steam-gas turbine, etc.), and engine system arrangement: with gear box or without gear box
5. Set of technical features pertaining to the propulsion and maneuvering systems	Propeller: number of propellers (normally one to four), system arrangement: twin or contra-rotating or controllable-pitch or nozzle-style propellers, thruster arrangement: number (one to sixteen), location: aft, forward, or both, rudder type: horn, propac, hybrid, or Becker, rudder arrangement: single shaft or multi shaft, and duct arrangement: ducted or non-ducted

2.3 Ship E-BOM classification code

To construct a database of recent ship construction details, the ship E-BOM must include a classification tag that is mapped to the ship E-BOM modularization. Each of the configuration parts can then be composed on the basis of this tag. Figure 3 shows our suggested ship E-BOM classification code, which can be used to apply the modularization method to the hull and outfitting components.

Figure 4 shows the E-BOM classification code for the hull component of a ship. This is similar to the block division that is produced on the basis of the grand assembly blocks of a hull. The code is flexible, expanding from four digits to six digits according to the situation. The detailed code description is as follows.

The first code type (code A) reflects the division, which is depicted as a higher-level. The initial character of the division is written here.

The second code type (code B) reflects the area code, which is depicted as sub-level of code A, reflecting areas of the ship, such as the afterbody and forebody. The cargo hold consists of a variety of blocks that are classified by position, such as bottom, side shell, wing tank, upper deck, and hopper tank, and are described as sub-levels of code B.

The third code (code C) is the assistant code, which is used when there are over two of a given block type. This code type consists of "U" for "Upper," "C" for "Center," and "L" for "Lower," each of which is assigned according to the block position.

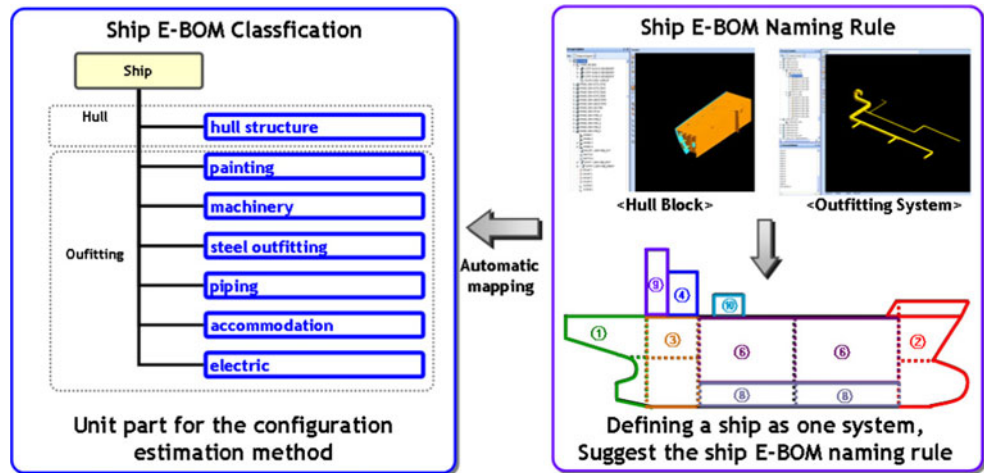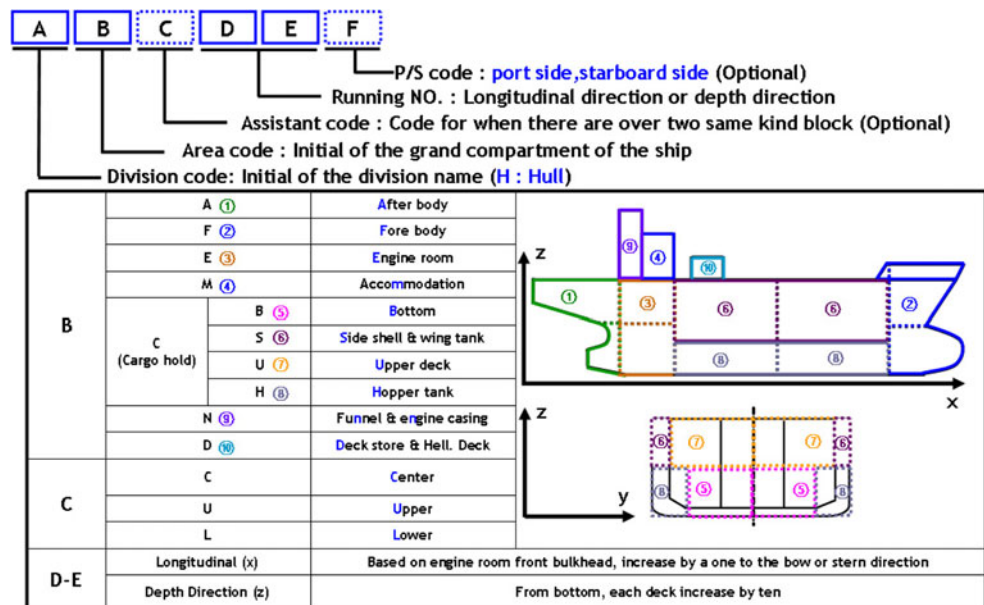Fig. 3 Relationship between ship modularization and E-BOM classification code

Fig. 4 Hull block E-BOM classification code

The fourth and fifth codes (codes D and E) are assigned as running numbers, which are assigned according to longitudinal position (x-axis direction) and depth directional position (z-axis direction), in reference to the engine room bulkhead. The first block of the engine room bulkhead can be assigned a value of "0" for its fifth code and the block next to it will be assigned a "1." Lower blocks have a value of "1" for their fourth code, whereas upper blocks have a value of "2" for their fourth code.
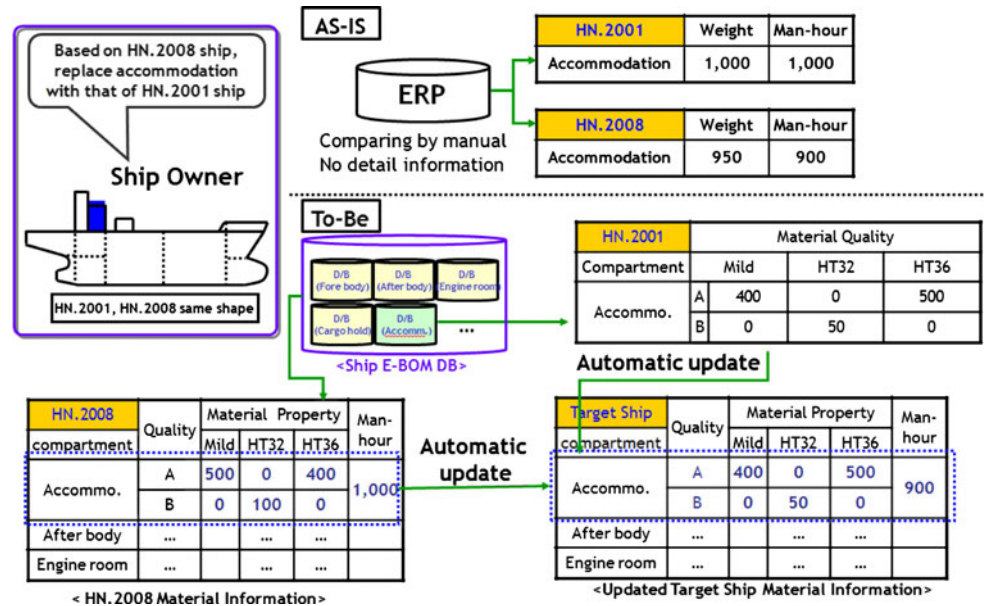
Lastly, the sixth code (code F) represents the width directional position code and may have values of "C" for "Center," "P" for "Port side," or "S" for "Starboard side." If the same type of block is present at both the port and starboard sides of the ship, this code is inapplicable and may therefore be omitted because either side (port or starboard) will be sufficient in the analysis.

Figure 5 shows an example of applying the E-BOM classification codes to a 310 K ton VLCC tanker block division drawing. Figure 6 shows the ship's E-BOM classification code for its outfitting system.

The first code (code A) is the division code, which is the same code as that assigned in the hull classification. This code set contains values of "T" for "paint protection," "M" for "machinery," "F" for "steel outfitting," "P" for "piping," "A" for "Accommodation," and "E" for "Electrical works."

From the second to the fourth code (codes B, C, and D), the running number is changed according to the type of outfitting system. Because there are so many outfitting devices, the running number is denoted by three-digit combinations. The second code is derived from level 2 and the third and fourth codes are derived from level 3, as shown in Fig. 6.

Fig. 5 Example of hull E-BOM classification code application to 310 K ton VLCC tanker

Fig. 6 Outfitting E-BOM classification code

3 Configuration estimation method

Figure 7 shows material information generation and cost estimation produced in the sales business phase using an ERP system (upper portion), and shows the suggested ship E-BOM, obtained by the configuration estimation method (lower portion). The shipbuilders do not have detailed material information available in an ERP system and have no connection with the CAD system; thus, it is difficult to obtain accurate material information in the preliminary design phase using such a system. All calculations and

estimations are performed manually, which requires a significant amount of time and effort. However, the proposed configuration estimation methods enable responsiveness to changes in the requirements of the shipowner, allowing one to update all the material information in a just-in-time (JIT) manner. Thus, suggested method concerns not detailed cost estimation method, as in related research, but the interfacing method and the database structure of PLM to provide 3D features of the CAD model and a ship E-BOM with corresponding material and labor cost information. In other words, from the perspective of

Fig. 7 Comparison between sales cost estimate generation by ERP and E-BOM

the detailed cost estimation method, we follow the conventional CBR. But the result of the suggested method, the actual cost information of similar ships' modules can be provided with a PLM system so that the proposed configuration estimation method could be enabled.

Our configuration estimation method is executed by selecting a benchmark (ship) from a database of recently built ships. First, the user selects standardized information to find a benchmark ship. We deal only with the case when several similar previously built ships exist so that the benchmark ship can be identified. Cost estimation of a new, innovatively designed ship, is beyond the scope of this method. Second, according to the ship modulization, the user selects from the database the specific module of any other ships that satisfy the technical parameters of the target ship. To satisfy the requirements of the shipowner, the ship is formulated using combinations of appropriate modules defined in the design of the recently built ships. When one module is exchanged for another, all the material information and all drawings are updated on-line automatically using the ship's E-BOM. In this way, we can derive a number of basic conditions for the configuration estimation method as follows:

- The ship E-BOM, which is used in the configuration, does not use CAD feature data; rather, it uses the material information and drawings.
- After choosing the benchmark ship which is nearest in design to the requested ship, we can apply the configuration estimation method, assuming that there exist similar, recently built ships in the same standardized category. Tthe module to be configured should come from the design of a recently built ship which is of the same type as the benchmark ship, and which has

the same technical dimensions and features corresponding to the module position.
- If there is no module that exactly satisfies the requirements, then technical-parameter-based interpolation must be performed using modules from several similar ships.

A large commercial merchant ship tends to be constructed in a series. The first ship built in a series is most expensive and the others can be constructed at lower cost, not only due to the reuse of experimental results such as towing tank tests and full hull structure analyses, and the construction and working drawings, but also for the accumulated productivity in the construction phase. Thus, when we apply the proposed method to a series of ships, the construction sequence must be considered. In other words, when selecting a benchmark, if the candidates of the benchmark are ships built in a series, then the first ship in a series should be the benchmark. And if there are data from ships previously built in a series, then the E-BOM and related costs from the ship in the same series should be selected. If not, the statistical cost decrease model from the experience of the yards can be considerable for the cost correction.

Figure 8 shows an outline of the steps involved in the configuration estimation method. When the ship tendering division of a shipyard receives the requirements for a container carrier from a prospective shipowner, the shipbuilder selects a comparable ship to act as a benchmark, one which most closely coincides with the supplied requirements. This ship is selected from their database of prior projects. To satisfy the requirements exactly, the shipbuilder then distinguishes those modules from the benchmark ship that are "not appropriate" to the new design. They then identify appropriate modules from the designs of other recently built ships satisfying the above

Fig. 8 Outline of configuration estimation method
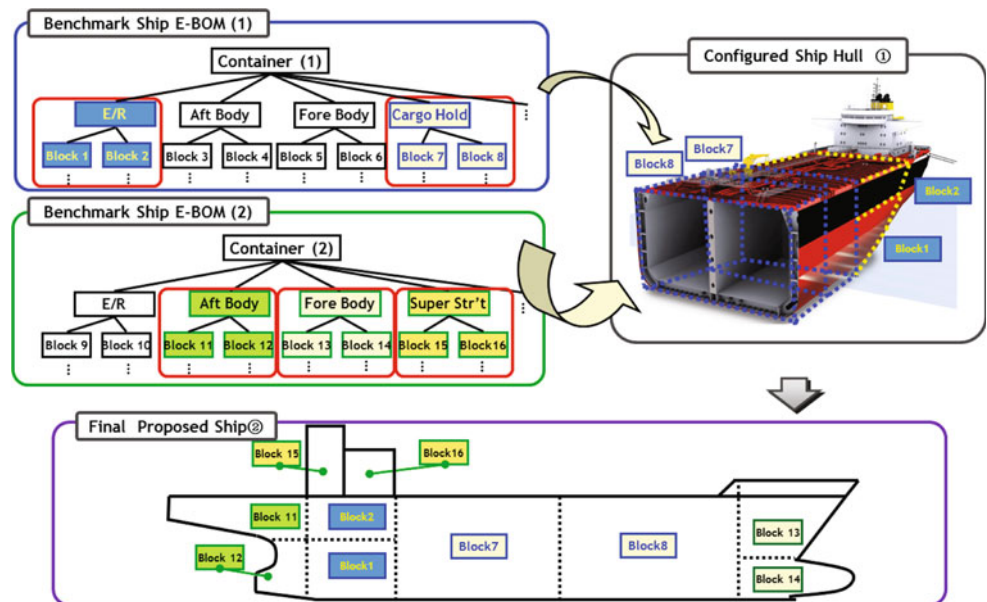
conditions in the database. When the appropriate modules are selected, the original modules in the benchmark ship are then replaced. A benchmark ship is thereby modified into the new ship. As the configured ship satisfies the customer requirements, the exact material information can be determined from the E-BOM. In this way, reliable cost estimation can be generated from these data.

4 Prototype demonstration

4.1 Scenario

Consider a scenario in which shipowner "A" wants to acquire a 4,800 TEU container carrier, so he/she requests a quotation from shipbuilder "H," one of the major shipbuilding companies in the world, having extensive experience in construction. "H" has adopted the PLM system that is associated with 3D ship CAD systems, as well as the configuration estimation method of cost estimation.

First, "H" obtains the requirements for the ship from "A." "H" analyzes the data and searches for comparable ships in a database of recent construction projects. Following this, the person in charge of the ship tender division performs a search within the database of recently built ships for ships that are 4,800 TEU container carriers. This is done in an effort to identify a benchmark ship for the design. "4,800_TEU_01," which is of a comparable capacity and class and was ordered by the same shipowner "A," is selected as a point of reference. The details of the benchmark's design include material information, such as weight per block, weight per outfitting system, and material properties, in the ship's E-BOM. Exact production information is available from the PLM system, including required man-hours. Thus, after automatic cost estimation is completed, using the ship E-BOM with some minor touch-up, "H" proposes a first draft quotation for the ship.

After considering the first proposal, "A" requests an extension to the steering gear room, which has been complained about by crews that have operated a similar ship that "H" built in the past.

Thus, "H" searches for another ship that has the same shape and technical dimensions as "4,800_TEU_01" in addition to having a larger steering gear room. "4,800_TEU_03" is found to satisfy the requirement and is therefore employed as a new point of reference. Using an estimation system employing the configuration estimation method, "H" replaces the afterbody of the "4,800_TEU_01" with that of the "4,800_TEU_03" and provides the second quotation, which is calculated automatically from the E-BOM cost estimation system.

After considering the second proposal, "A" requests that the builder include an extension to the ventilation capacity of the engine room heating, ventilation, and air conditioning (HVAC) system.

"H" then searches in the database for a ship that has the same technical dimensions in the same category of standardization as the configured ship, yet which also has a greater ventilation capacity for the engine room (HVAC system). The "4,800_TEU_02" is identified as satisfying the requirement; thus, "H" replaces the engine room of the configured ship with that of the "4,800_TEU_02." "H" hands over the third quotation, with the updated engine room HVAC system, to "A." "A" is so satisfied with the quick and flexible responses supplied by "H" that "A" order a series of twelve 4,800 TEU container ships.

Fig. 9 Selection of estimated ship from database

4.2 Implementation

This prototype is implemented using Visual Basic, .NET 2005, Microsoft Structured Query Language (MS SQL) 2005 Express on a MS Windows XP Professional platform. The prototype consists of a material information-generating program for sales cost estimation, and a program for data conversion between other related programs. The databases consist of a ship database, which manages ship data, and an estimation database, which manages estimation data [30].

This prototype functions by exchanging material information data between the material information-generating program and the sales cost estimation database. The material information-generating program modifies the ship estimate by editing its E-BOM on the basis of data pertaining to previously constructed ships and by calculating material information and the associated labor cost.

This prototype consists of a program for material information generation (for use in sales cost estimation) and a program for data conversion. First, a previously constructed ship that closely resembles the user requirements is identified, and its data is retrieved, by searching through a historical project database. We designed the detailed database of the ship modulization so that when the user selects several specific conditions, the corresponding SQL query is generated automatically to find the matching result. By editing the E-BOM, the cost estimate of the new ship is generated. Finally, the material information and labor costs can be determined for the estimated ship. The data conversion program converts data generated from other related programs so that they can be inserted in the database. We use engineering data from AVEVA Marine version 12.01 as the data source. We convert these data into XML format prior to storing them.

The database consists of a ship database and an estimation database. The former database manages the ship data, product structure data, workload data, and the weight data of parts. The latter database manages ship data, product structure data, and ship production data.

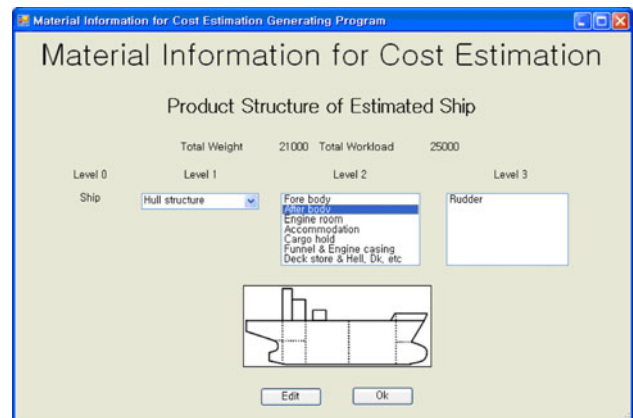**Fig. 10** Detailed information about Hull in E-BOM

Fig. 11 Selection of area for configuration for estimated ship

4.3 Result

The result presents not an actual cost estimation such that performed in the shipyards, but the process of the proposed estimation method. Figure 9 shows the filtered data from a previously built ship database, organized by user requirement. The most appropriate ship record that matches the requirement of "A" is "4,800_TEU_01." The first cost estimation process flow is based on this requirement.

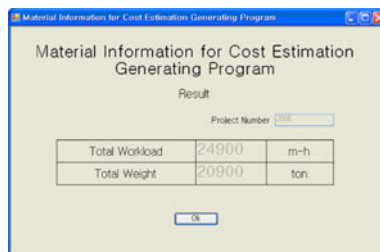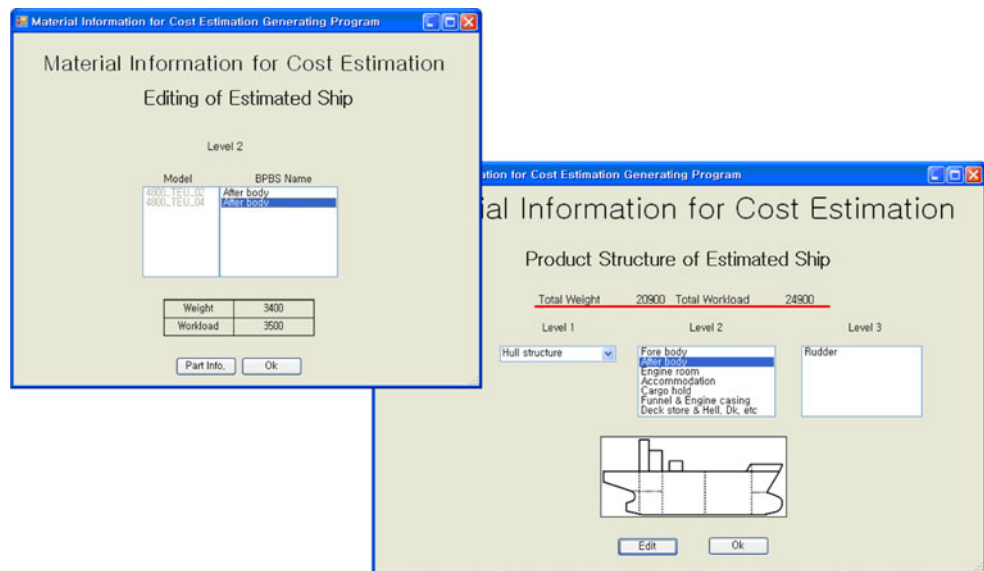**Fig. 12** Configuration E-BOM of configured ship

Fig. 13 Material information generation result

The cost estimate of the Hull in the E-BOM is calculated in this manner. For example, the weight of the "HA10P" block of the E-BOM, extracted from AVEVA Marine, is calculated by material quality, thickness, and area. The total workload reflects the actual workload involved in block design and manufacturing. Further, the weight of the interior system equipped within the block is recorded. The total weight and cost of all blocks comprising a ship are calculated and recorded, as shown in Fig. 10.

The second cost estimation step is to change the aft body. This is done in level 2 for "4,800_TEU_03," as shown in Fig. 11.

After completing the configuration estimation, the total weight and workload are calculated. A cost estimation can then be performed on the basis of these values. This is shown in Figs. 12 and 13.

5 Conclusions and future work

In this paper, we have proposed a configuration estimation method that is based on the configuration design method, which is used extensively in 3D CAD systems, to precisely estimate cost during the preliminary design phase (prior to the existence of a formal construction contract). By referring to the ship's E-BOM, from a 3D ship CAD system, it is possible to configure the ship in terms of modules and then automatically generate an associated cost estimate using the E-BOM-based material information. To demonstrate the effectiveness of the proposed method, we implemented a prototype of the shipbuilding configuration estimation system using an MS SQL database and the E-BOM from AVEVA Marine version 12.01, a representative shipbuilding CAD system that provides a typical demonstration of the ship tendering process.

Using the proposed method, it is possible to obtain an accurate list of materials from the quotation, as well as a detailed work assessment for labor costs and overhead rates, so that reliable cost estimates can be generated quickly and flexibly. Especially, when the yards develop their own cost estimation systems with actual cost correction formulas and know-how, then the lack of reliability of the estimation result from the proposed method can be overcome, and the benefit of a quick response and a flexible variation from the concept of the proposed method can be guaranteed.

In the future, by looking at synergies between features of 3D CAD feature systems and a ship's E-BOM, we intend to research the integration of the configuration design method with the proposed configuration estimation method. In addition, according to the shipbuilding process, we intend to research algorithms for automatic mapping from the ship's E-BOM, which is generated from the preliminary design, to the M-BOM, which is employed in the construction phase. This will contribute to the ship's master BOM for the PLM system and will allow the cost estimation process to be integrated online in real time.

References

1. The Korea Shipbuilders' Association (2009) http://www.koshipa.or.kr/
2. Watson DGM (2002) Practical ship design. Elsevier, Amsterdam
3. Dassault Systemes ENOVIA (2009) http://www.3ds.com/products/enovia
4. Siemens PLM Software (2009) http://www.siemens.com/plm
5. Trendowicz A, Heidrich J, Munch J, Ishigai Y, Yokoyama K, Kikuchi N (2006) Development of a hybrid cost estimation model in an iterative manner. In: International conference on software engineering archive, proceedings of the 28th international conference on software engineering, pp 331–340
6. Carreyette J (1978) Preliminary ship cost estimation. RINA 120:235–258
7. Fisher KW (1974) The relative costs of ship design parameters. RINA 116:129–155
8. Ray T, Gokarn RP, Sha OP (1995) A global optimization model for ship design. Comput Ind 26:175–192
9. Kromker M, Thoben KD (1996) Re-engineering the ship pre-design process. Comput Ind 31:143–153
10. Ross J (2004) A practical approach for ship construction cost estimating. In: COMPIT 2004, Siguenza, pp 98–110
11. Caprace J-D (2010) Cost effectiveness and complexity assessment in ship design within a concurrent engineering and design for X framework. PhD thesis, University of Liege, Belgium
12. Saaksvuori A, Immonen A (2002) Product lifecycle management. Springer, Berlin
13. CIMdata (1997) PDM: the definition. CIMdata Report. http://www.cimdata.com/
14. CIMdata (2002) Product lifecycle management. CIMdata Report
15. Crnkovic I, Ulf A, Dahlqvist AP (2003) Implementing and integrating product data management and software configuration management. Artech House
16. Stark J (2004) Product lifecycle management. Springer, Berlin
17. Dho NC (2007) The introduction and the application of PLM. Life and Power Press, Korea
18. Yosio I, Gondo D, Kimura D (2006) PLM strategy. Standard and Consulting United Korea
19. Trott P (2005) Innovation management and new product development, 3rd edn. FT Prentice Hall, Englewood Cliffs
20. Yamada T (2006) Let's do it! PLM strategy. Han's Contents
21. Oh DK, Jeong YH, Shin JG, Yeo YH, Ryu C (2008) Development of product model management system for naval shipbuilding. J Ship Prod 24:82–91
22. Kim TW (2009) Future challenges in the areas of computer aided ship design and production. In: Proceedings of first international conference on ship and offshore technology. Developments in Ship Design and Construction, The Royal Institution of Naval Architects, Kharagpur, India
23. Kim TW, Kang SC, Mo NJ (2009) Development of a PLM model for shipbuilding industry. In: Proceedings of ICSCI-2009, international conference on systemics, cybernetics and informatics, Hyderabad, India
24. Sharma R, Kim TW (2010) Development of a logic-based product life-cycle management (LBPLM) system for shipbuilding industry: conceptual development. J Ship Prod Des 26:1–21
25. Erikstad SO (2009) Modularisation in shipbuilding and modular production. Working Paper, Innovation in Global Maritime Production 2020 (IGLO-MP 2020)
26. Kim WJ (2005) Definition of racing boat's product structure and implementation of engineering bill of material for the product data management. Masters thesis, Seoul National University, Seoul, Korea
27. Lee WJ (2002) A study on the semantic data model for the initial hull structure product modeling. Masters thesis, Seoul National University, Seoul, Korea
28. Naval Ship Engineering Center (1977) Ship work breakdown structure. Naval Sea System Command Report
29. US Department of Transportation (1982) Product-oriented work breakdown structure. The National Shipbuilding Research Program Report
30. Jagdev HS, Wortmann JC, Pels HJ (2003) Collaborative systems for production management. Springer, Berlin