A REVIEW OF WORK BREAKDOWN STRUCTURE AND MAN-HOURS ESTIMATION METHOD USED IN SHIPBUILDING PRODUCTION

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ABSTRACT

The aim of this research is to define the Work Breakdown Structure (WBS) and to understand the linkages between WBS and man-hours development for Shipbuilding Project. The Work Breakdown Structure (WBS) is the best tool to simplify the complexity of the project and this research will define the complete and accurate WBS of a Hull Ship since it is an important and critical activity in every shipbuilding to estimate the project schedule, cost and labour man-hours. The methodology will involve latest literature review related to Shipbuilding WBS and man-hours estimation and a suggestion will be made for the best method of WBS and man-hours development. Implication from this research will assist Project Manager and Project Team to develop an improved project schedule planning method, which be utilized during project management to identify the best WBS and project man-hours. This also will lead to cost reduction in terms of man-hour optimization when the proper tasks and activities are clearly defined during WBS development.

Keywords: work breakdown structure, labour man hours calculation, hull ship, project schedule.

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1. INTRODUCTION

A complex and complicated project like shipbuilding can be simplified and made manageable by breaking into smaller components in hierarchical structure known as work breakdown structure. An effective WBS plays a key role in the implementation of a shipbuilding project (Pal, 2015). A WBS, also referred to as Contract Work Breakdown Structure or CWBS (DefenseAcquisitionUniversity, 2017), also delivers oriented breakdown of project into
A Review of Work Breakdown Structure and Man-Hours Estimation Method used in Shipbuilding Production

smaller components and later plays a key role in project delivery that organizes project management teams into manageable sections. The Project Management Body of Knowledge (PMBOK 5) defines the work breakdown structure as a hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables. The WBS organizes and defines the total scope of the project, and represents the work specified in the current approved project scope statement (Rose, 2013).

WBS element can be classified as a product, service, system, data or any combination thereof. WBS can be used to generate a framework for cost estimating and schedule development (Booz, 2011). Basically, the planned work can be identified on the lowest WBS structure or breakdown known as work packages. This work packages can be grouped together and then the work can be easily cost estimated, monitored and controlled. In the context of the WBS, work refers to work products or deliverables that are the result of activity and not to the activity itself (Rose, 2013).

The WBS is also useful to serve as a coordinating medium. This occurs when WBS has defined the technical objective and specified work tasks, which are then assigned to every level of contractor’s organization elements inclusive of resources, materials and method or process required to attain the objectives. Pal (Pal, 2015) mentioned that there are linkages between specification requirements, the WBS, the scope of work, the master and detailed schedules which provided relationship between schedule, cost and performance. In an actual project or a contract, the WBS is always developed starting with end of objective and further dividing into manageable components such as area, size, zone, duration, etc.

WBS was initially a concept developed with the Program Evaluation and Review Technique (PERT) by the United States Department of Defence (DoD). A detailed history of WBS can be found in Jones (Jones et al., 2006). Military standards MIL-STD-881C in 2011 defined the common WBS elements such as Integration, assembly, test, and checkout; Systems engineering; Program management; System test and evaluation; Training; Data; Peculiar support equipment; Common support equipment; Operational/Site activation; Industrial facilities; Initial spares and repair parts. The standard also includes additional common elements unique to Space Systems, Launch Vehicle Systems and Automated Information Systems (DoD, 2011).

WBS should consider flexibility for future additional activities and elimination of work scope. Project team members should be involved in all stages of WBS preparation, design, review, comment and approval. The team members are required to provide their respective assigned work scope. Project Director (PD) or Project Manager (PM) then should conduct a training session to project management, Project Management Team (PMT), Integrated Project Team and other team members for understanding the WBS structure and purpose.

2. SHIPBUILDING WBS

Malay Pal (Pal, 2015) stated that work breakdown structures commonly used in shipbuilding are either system or product-oriented. The common WBS used for shipbuilding is Program Work Breakdown Structure, Contract Work Breakdown Structure (CWBS), Ship Work Breakdown Structure (SWBS), SFI Group System, Product Work Breakdown Structure (PWBS) and Zone Work Breakdown Structure (ZWBS).

WBS in shipbuilding began as early as 1970 by U.S. Navy who introduced the Ship Work Breakdown Structure (SWBS) as its basic shipyard cost collection and analysis data structure. SWBS is the only firm-independent work breakdown structure currently in use in the U.S. shipbuilding industry. It is used by the Navy to collect and manage data on ship acquisition

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programs at all six large U.S. shipyards. SWBS was designed as a single indenturing language which can be used throughout the entire ship life cycle, from early design cost studies and weight analysis, through production and logistic support development, to operational phases, including maintenance, alteration and modernization (Koenig & Christensen, 1999).

2.1. Program WBS

The Program WBS usually provides a framework to specify the objectives of the program related to product-oriented elements. Each element provides logical summary points for assessing technical accomplishments and for measuring cost and schedule performance (Pal, 2015). The Program WBS is developed early in the conceptual stages of a program through systems engineering and management planning processes. It advances through iterative analysis of the program objective, functional design principles, technical performance requirements, program scope, acquisition strategy, and other technical documentation.

During concept exploration stage, the Systems Engineer made efforts to analyse, determine and establish the user’s requirement (Requirement Analysis) in terms of ship performance, project management, safety, environment, human resources, software, logistics, test, acceptance, etc. System requirement must be established prior to system design and development. This will make the user requirement become basis of the contract and acceptance for easy monitoring and supporting the ships through their life cycle. He/she will translate the requirement in Requirement Analysis into functional description that describes the products in terms of assembly, required performance and other interfaces. Configuration items can be manpower, hardware or software.

Functional Analysis converts the ship’s objective, mission, performance and other requirements into a function (Pal, 2015). The objective of functional analysis is to ensure all activities in producing ships is identified and should represent what must be done and how to do it. The function will be broken down until sub-function elements. The sample of Program WBS is shown in Figure 1. The Program WBS is developed at this point and precedes issue of a formal request for proposal (RFP). Contractor later will be using the Program WBS to perform more detailed analysis called Contract Work Breakdown Structure (CWBS) which includes all product elements (hardware, software, data, or services) for which the contractor is responsible.

![Figure 1 Program WBS](http://www.iaeme.com/IJMET/index.asp)
2.2. Contract Work Breakdown Structure (CWBS)

Contract Work Breakdown Structure (CWBS) is normally known as a comprehensive WBS that is generated for a specific contract from issuance of Program WBS issued during RFP. It includes all scope of works required and have Program WBS elements for products such as hardware, software, data, or services which are to be provided by the contractor. Contractors extend the Program WBS and submit the complete Contract WBS with their proposal (Pal, 2015).

The Program WBS and CWBS have strong relationship with each other as it involves user or customer and contractor. The user will have supplied Program WBS while contractor will expand the Program WBS into detailed elements. U.S. Department of Energy (DOE, 2000) highlighted the CWBS development in which contractor is required to develop all management activities between both contractor and client. Contractor must also make sure the agreement of scope, cost and schedule is agreed between both parties. CWBS will act as a basis of reporting criteria during project execution.

CWBS is useful in terms of consistent framework that relates to uniform planning, work responsibilities and progress reporting. The CWBS methodology supports all project stages, critical points and other activities required in the project. This only can only be achieved subject to Program WBS oriented submission.

2.3. Ship Work Breakdown Structure (SWBS)

The U. S. Navy pioneered SWBS in 1970. Currently they are expanding into systems-oriented breakdown known as Expanded Ship Work Breakdown Structure (ESWBS). It is system-oriented based but covers the entire ship life cycle to organize and consolidate all WBS elements for cost, weight, system function and specifications, effectiveness, design, production, and maintenance studies. All of their ESWBS elements act as reference especially the numbering systems for ship’s drawings and related documents, general and contract specifications, ship’s weight groups, technical manuals, etc. The US Navy's SWBS was originally issued in March 1973 as a structured system (3-digit numbers providing 5 levels of breakdown) which was intended for use in specification preparation, cost estimating, cost progressing, management, weight control, drawing numbering, shipyard job order coding, and similar purposes (Pal, 2015).

SWBS is a hierarchical system. At the top level, SWBS contains nine groups: (1) hull structure, (2) propulsion plant, (3) electric plant, (4) command and surveillance, (5) auxiliary systems, (6) outfit and furnishings, (7) armament, (8) integration and engineering, and (9) shipyard support services. Within each of these single-digit groups, there are further breakdowns which become progressively more detailed. For example, within group 2 (propulsion plant) there are groups 23 (propulsion units) and 24 (transmission and propulsion systems) among others. Within the two-digit groups, further details are broken out at the three, four, and five-digit levels (Koenig & Christensen, 1999).

ESWBS provides another two (2) levels to breakdown the functional systems in order to support the logistic, maintenance and life cycle i.e. spare part requirements. It has five (5) digit functional classification system, with the fourth and fifth single digit classification levels reserved for maintenance support and repairs. For example, for weight reporting purposes, only the first three digits of this system apply. This differs from the SWBS groups that are defined by basic function and functional segments of a ship represented by a ship’s structure, systems, machinery, armament, outfitting, etc., which are classified by a system of 3-digit numeric groups (Pal, 2015).
2.4. SFI Group System WBS

The SFI group system WBS was developed at the Norwegian Ship Research Institute (Senter for Forskningsdrevet Innovasjon - SFI), now known as MARINTEK. Concept of SFI group system is to provide the international standard reference with a unique code that is normally used for a functional breakdown of technical elements, economic information of ships and offshore structures. It systemized of all ships components through a 3-digit coding structure. Through the ships’ lifetime, the SFI coding system is used for different purposes such as to control shipping, offshore or shipbuilding operations. In cost management, this structure works as a cost work breakdown structure (Pal, 2015).

The concept of SFI Group system WBS is similar to SWBS or ESWBS, however it has different groups description. The ship is divided into 10 main groups from 0 to 9, but often only main group 1-8 are used (refer Figure 2). User can address the cost related to the different groups. The single digit of SFI Group further expands into 2-digit group and again up to 3-digit subgroup as shown in Figure 3 and Figure 4. This system will enable ship constructors to easily manage the project including ship building, ship operation, maintenance and repair. SFI will merge all supply chain keys in shipping industries such as shipping and offshore companies, shipyards, suppliers and consultant with similar or common coding system for all aspects of specifications, estimation, drawings, purchasing, material administration, maintenance and repair planning, budgeting and cost controlling, files and record. This will increase the efficiency in the maritime industry supply chain activities.

<table>
<thead>
<tr>
<th>SFI Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(reserved)</td>
</tr>
<tr>
<td>1</td>
<td>Ship General</td>
</tr>
<tr>
<td>2</td>
<td>Hull</td>
</tr>
<tr>
<td>3</td>
<td>Equipment for Cargo</td>
</tr>
<tr>
<td>4</td>
<td>Ship Equipment</td>
</tr>
<tr>
<td>5</td>
<td>Equipment for Crew and Passengers</td>
</tr>
<tr>
<td>6</td>
<td>Machinery Main Components</td>
</tr>
<tr>
<td>7</td>
<td>Systems for Machinery Main</td>
</tr>
<tr>
<td>8</td>
<td>Components</td>
</tr>
<tr>
<td>9</td>
<td>Ship Common Systems</td>
</tr>
</tbody>
</table>

Figure 2 SFI Groups

Figure 3 SFI Groups System: Example of The Subdivision of Main Group 7
A Review of Work Breakdown Structure and Man-Hours Estimation Method used in Shipbuilding Production

Figure 4 SFI Groups System: Example of The Subdivision of Main Group 6

2.5. Product Work Breakdown Structure (PWBS)
Product Work Breakdown Structure (PWBS), a product-oriented WBS derived from conventionally system-oriented, was developed to support group technology shipbuilding and consistent with construction method, planning and scheduling used by shipbuilder. The work subdivides into interim product view in which part and sub-assemblies are grouped together based on common characteristic, and both design and manufacturing methodology. Pal (Pal, 2015) mentioned the classification system which requires that parameters including dimension, tolerances, form, materials and complexity of machinery types be specified. PWBS provides a uniform breakdown that is useful for progress monitoring and costing.

In the first dimension, the process of PWBS started with dividing the shipbuilding process into three (3) work categories known as hull construction, outfitting, and painting. These categories have unique manufacturing or production problems which must be grouped together. This group later was divided into fabrication and assembly method. For example, painting work categories can be divided into fabrication, which applies to paint manufacture, and assembly, which relates to paint application (Okayama, 1980). The assembly subdivisions are naturally linked to Zones Work Breakdown Structure (see next section 2.6).

In the second dimension, PWBS expands the interim products into Material, Manpower, Facilities and Expenses. Material can be form of steel plate, machinery, cable, etc. Manpower will consist of fitter, welder, rigger, etc. Facilities can be referred to buildings, docks, machinery, tools, etc. Expenses refer to designing, transportation, sea trials, etc.

In the third dimension, PWBS classified the interim products into four (4) product aspects which are important in control of production. The four aspects are known as System, Zone, Area and Stage. It is further categorized under Design Function consisting of System and Zone, while Production Function consists of Area and Stage. System aspect normally refers to the characteristic of product, either a structural or an operational system, such as longitudinal or transverse bulkhead, lighting system, fuel system, etc. Zone aspect classifies the ship into geographical section such as cargo room, engine room and part of their sub-section i.e. structural block or outfit parts. Area aspects focus on similar types of production such as by feature (i.e. flat panel, angle), quantity (i.e. Batch-by-batch), quality (i.e. grade of workers), work type (marking, cutting, fit-up, welding), etc. Stage aspects can be classified into production sequence cycle like preparation, fabrication, assembly, etc. Figure 5 defines the PWBS three-dimensional dimension and their work relationship.
2.6. Zone Work Breakdown Structure (ZWBS)

Zone Work Breakdown Structure (ZWBS), defined as a spatial breakdown of the ship, is sometimes used interchangeably with Area Work Breakdown Structure (AWBS). Each zone is designed with piping, wiring, outfitting, machinery, and furniture to be contained within that zone. Examples of zones defined in ships to address particular functions or services are Fire zone, Collision zone, Electronics zone, Weapons zone, Underwater Sensor zone, etc. Pal (Pal, 2015) agreed that the current shipbuilding productivities was significantly improved, mainly due to the exchange of conventional system oriented WBS like SWBS and SFI Group System into zone oriented method like Hull Block Construction Method (HBCM), Zone Outfitting Method (ZOFM) and Zone Painting Method (ZPTM). This is due to advantage of similarities in the products or subassemblies, those common characteristics classified by both design and production attributes.

Okayama (Okayama, 1980) discussed the concept of HBCM which started with grand hull as a zone then further expand to subdivision of block zones, sub-block zones and expand further until it cannot be divided or reach to final parts. This concept is correlated with manufacturing or production level of works; however, it works for hull construction but not in outfitting. Identification of the correct blocks allows for the highest improvement in production productivity. This is achieved when the grand block level has minimum works in building dock. Maximizing uniform workflow will give maximum productivity.

ZOFM is a natural consequence of HBCM because it uses a similar concept. ZOFM planners will follow the segregation of hull blocks in HBCM to highlight and address the outfitting requirement installation for all systems in on-board zone and maximize it to be installed on-block zone. It then further expands the ideas to maximize installation from on-block zone into on-unit zones, which are the final zones. The objective is to reduce and minimize the outfitting installation works during and after hull erection. The other objectives of ZOFM include arrangement of difficult position to easy position, inaccessible area to good accessibility, crane accessibility for material handling.

ZPTM also used the same concept as HBCM and ZOFM. This ZPTM is introduced to exchange the conventional method of painting on dry-dock or building dock which require a lot of space and time consumption. Then the ZFTM methodology transferred the requirement to the earliest manufacturing levels when it can be integrated with hull construction and outfitting processes.

ZPTM is not only defined as the zone up to engine room, cargo room and others, it also considers hull blocks, sub-blocks and assembly parts. ZPTM defined the hull blocks as having identical correlation with definition of HBCM and ZOFM. Painting can be divided into shop
primer, primer, undercoat and finish paint, and all of these categories can be done separately at lower level. This can be done differently by doing the shop primer after material received and it will reduce final paint works (Y. Okayama, 1980).

2.7. Critical Analysis on existing Shipbuilding WBS development

Traditional or conventional method of ship WBS refers to Program WBS, Contract WBS, SWBS and SFI Group WBS. Most of these methods use system oriented elements to create a WBS that can be used for estimating man-hours and cost for Level 1 with less accurate results. On the other side, in terms of coordination of work, it has become unrealistic to control results from huge work packages and ineffective to control material, man-hours and schedules. Focusing on system oriented will be made it difficult to arrange other construction management such as procurement of materials or fabricating parts to meet the system basis of construction. For example, procurement always has minimum order quantity (MOQ) and when construction materials are not grouped in terms of similarity, this will have an effect on the overall project cost. It is a fact that most manufacturing produces the products by procurement of various parts, joining them in sub-assemblies and final assemblies. This concept enables the manufacture to separate the production levels to cater to the larger subassemblies. The ideal way is to focus on required parts and assemblies based on final product and the actual interim products that preoccupy workers should be known. A scheme to subdivide work in accordance with an interim-product view is a product-oriented work breakdown structure or PWBS.

2.7.1. Problems with SWBS

The problem is that SWBS does not reflect shipbuilding processes. It provides no visibility to intermediate shipbuilding products and processes. Therefore, it cannot be used for collecting or organizing the type of data that is needed to assess productibility or evaluate alternative build strategies. In order to make intelligent choices on design questions that affect shipbuilding costs, information on the behaviour of cost drivers such as labour hours or man-hours is needed. Labour content cannot be effectively estimated when SWBS is used to organize ship design and cost data because SWBS data does not show the product and process attributes upon which labour hours depend. SWBS, being a system-based structure, fails to reflect shipbuilding practice. Modern shipbuilding is organized around hull block construction, zone outfitting, and intermediate products rather than hull construction followed by system outfitting. A breakdown based on functional divisions cannot capture block, zone, and intermediate product information because this information does not conform to system boundaries.

2.7.2. A view of PWBS

PWBS must consider other work breakdown systems to cater to the work requirements that are normally correlated with different work scope and categories. A PWBS should consider HCBM, ZOFM and ZPTM during work breakdown, especially in ship construction. The final work packages developed using this method will be ideal for construction management when the working times and work amounts are similar to each other for every level of work they set.

The PWBS concept is to transfer all complicated ship construction fabrication methods into manufacturing standard line processing and production, which can reduce a lot of time when compared to using conventional method like SWBS. This will allow each single production line to start and stop production in a uniform and constant manner.
2.7.3. Latest Review on PWBS Research

Jong-Ho Nam, Jong Hak Lee & Jong Hun Woo (Nam, Lee, & Woo, 2015) investigated WBS codes used by actual shipbuilding companies and reveal that the characteristics of the shipbuilding WBS structure analyzed in this work are two-level data structure of mid-term planning (work package and work order). The production details are defined for each zone, block and stage while production volume and block location are estimated by connecting with the product Bill of Material (BOM). This conformed to PWBS method which is comprised of HBCM, ZOFM & ZPTM. He discussed scheduling development, which is not standardized between shipbuilding, and it was agreed that WBS using PWBS is the best tool since it is important before any schedule development. The PWBS focus on application of numbering system identification and PWBS concept is discussed but not in detail on schedule duration development. He was successful in converting Microsoft Excel (*.xml) base data to any schedule software; however, the result is not significant in terms of schedule duration, which was not fully analysed.

Malay Pal (Pal, 2015) defined various complex and critical SWBS from the inquiry and concept design stage to construction to decommissioning. PWBS was used as a core in developing 4th Generation Design (4GD) software technology to link Project Lifecycle Management (PLM). A basic understanding of the type of ship WBS without further recommendation on application advantages of each WBS on other application i.e. schedule, man-hours and cost estimation was provided. Further explanation on advantages/disadvantages of each WBS will be useful in Shipbuilding industry. The Shipbuilder or Project Manager is required to expand the WBS based on software guidance to link with actual project and is expected to consume more time. The software also not have verification data analysis with respect to the actual shipbuilding production.

(Koenig & Christensen, 1999) discussed SWBS used at U.S. Navy Shipbuilding, which is currently not suitable for modern shipbuilding era. An Implementation proposal of new PWBS for ship design and construction in U.S. Shipyard is then discussed on the implications impact, which shows that the PWBS is the best WBS in determining project schedule and cost. All criteria of SWBS versus PWBS are well explained; however, a brief application in terms of planning and costing is not provided. Author recommended to have further analysis in terms of schedule and costing by using Product Oriented Design and Construction Cost Model (PODAC). (TRUMBULE et al., 2000) General concept discussion was provided without actual validation using PWBS in real project. Real data analysis between SWBS and PWBS is required to depend on the actual result.

3. MAN-HOURS ESTIMATION DEFINITION

Man-hours or labour hours is the number of hours taken by a labourer to complete the unit of production. It is widely used in project management to measure price for projects, resource budgeting or monitoring the actual progress in certain project. A business shall have internal and external data to estimate the amount of time needed to complete a product. The time then will multiply with the number of products in the project to get the man-hours.

The business option of estimating man-hours was described below:

- Historical Date: A set of log data must be collected and the data will be stored carefully to analyse the correlation between task and time. For example, a restaurant may estimate the labour hours needed to complete Recipe X by averaging historical data for similar Recipe X that employees prepared in the past.
- Industrial Standard: Managers can rely on industry standards, industry data and experts in the field to estimate the labour hours needed to create a product.
Once man-hours data is gathered and confirmed, a company can set the man-hours as standard in their process or production lines. However, this must be reviewed periodically to make adjustments to man-hour estimates as necessary.

In shipbuilding, the man-hour is a unit widely used for production planning, with systematic prediction of man-hour taking greater importance in cost reduction. However, as the man-hours are predicted by experts at shipyards, existing methods have often resulted in incorrect predictions and cost significant amount of time. There have been several attempts made by many researchers to overcome such problems resulting from prediction by experts. Yet, their approaches considered only a limited number of factors such as ship specifications, and were not highly applicable at shipyards (Hur et al., 2013).

3.1. Man-hours Estimation in Shipbuilding by Expert

Man-hours is very important in shipyard industries to manage the production labour. To complete a certain task a shipyard manager must know the estimation of time (man-hours) to complete. This can be calculated by combination of labour and time required to complete a certain product in production line. For example, the requirement of man-hours to cut a 2m x 2m width steel plate is based on labour requirement. If the task required two (2) workers and took 1 hour to complete, then the total man-hours is 2 man-hours. Within shipbuilding industries, the man-hours of each task is predicted comprehensively by considering the task characteristic, past experiences and environment. Gullander (Gullander et al., 2011) highlighted that the man-hours for identical task will give different man-hours due to timing and type of task.

Most shipbuilding projects can last as long as two (2) years or even longer. This will require that prediction of man-hours will occur more than once and may occur up to four stages. The earliest stage or first stage is considered when the one-year plan is established. In one-year plan, overall ship production planning occurred parallel with total man-hours planned. The man-hours planned for first stage is normally a long term perspective, which is not really accurate as it does not extend to detailed tasks.

In the second stage, one-year plan activities are divided into four quarters and the man-hour plan should be established for every quarter plan in parallel. The expert in the shipyard will have predicted the man-hours based on 3-month cycle activities.

In the third stage, establishment of monthly plan will be considered. The work categories defined previously in quarter plan was further expanded and detailed to tasks such as marking, cutting, fit-up and welding. The man-hours required for following months is predicted for each task.

Final stage or fourth stage is to establish day plan. The activities are defined for daily basis and man-hours required will be predicted. This stage will provide high accuracy data and is highly utilisable compared to the first stage, where many man-hours are predicted and external factors of specific timing and environment is unknown. Figure 6 illustrated the man-hours stages prediction at shipyard (Hur et al., 2013).
The overall prediction process is dependent on shipyard expertise and it sometimes uses various factors in their assumption for estimating. The estimation is not objective and can be questioned by others. Since the expert prediction was carried by a human, we cannot guarantee the consistency of prediction.

References can be made in man-hours estimation for Offshore Structure using Spon's Fabrication Norms, a handbook for the oil, gas and petrochemical industries (Andrews, 1992). This handbook offered a variety of man-hours of offshore and jacket structures, which is similar to shipbuilding parts. The historical data came from actual projects. The objective is to provide a general guide of the direct man-hours involved in a particular item or activity on an offshore construction project. It should be noted that the figures in the handbook are averages and the results of statistical analysis of many individual figures taken from a wide range of projects.

3.2. Other Latest Research Man-Hours Prediction Method in Shipbuilding

3.2.1. Multiple Linear Regression (MLR) and Classification Regression Tree (CART) models

Hur (Hur et al., 2013) performing a study to predict the man-hours for shipbuilding industries by using Multiple Linear Regression (MLR) and Classification Regression Tree (CART) models. This methodology, widely used in manufacturing and MLR, is reported as a popular tool for modelling and in predicting the dependent variable which is normally continuous. MLR is capable to identify the best linear combination of independent data variables that match as optimally as possible. It provides results and analysis based on factors that influence the dependent variable. This makes the MLR a popular tool to check which factors affect man-hours prediction.

CART is another prediction model based on a binary tree composed of several nodes. These nodes then split according to various rules on each factor from top to bottom (Breiman, 1993). Shmueli (Shmueli, 2011) explained that every split in the node refers to conditions the factor would have and the estimation of target value is done in the leaf node from the root by such consecutive splits. CART offered predictions with good interpretability compared to MLR. CART is mostly used in the research and industrial area, which require critical prediction quality and explanation.

MLR and CART required huge data in order to predict the accurate man-hours. Hur (Hur et al., 2013) mentioned that the data required included Quarter, Month and Day plan of man-hours from various shipyards. Hur (Hur et al., 2013) gathered all variable data similar to what was actually used by expert in shipyards. Methodology of their research as shown in Figure 7.
A Review of Work Breakdown Structure and Man-Hours Estimation Method used in Shipbuilding Production

3.2.2. Single Linear Regression (SLR), Multiple Linear Regression (MLR) and Artificial Neural Network (ANN) models

Liu (Liu & Jiang, 2005b) agreed and mentioned that the conventional man-hours prediction for shipbuilding industries was simply calculated based on function of weight. He then performed a study to predict the man-hours by using conventional data collected at shipyard. He uses 28 samples of product characteristics including man-hours, which were randomly collected on the spot to develop a simple linear regression (SLR) model for prediction. In the SLR, he only depended on the weight of product as a valuable factor for man-hours prediction. Bunch (Bunch, 1989) mentioned that the assembly man-hours depended not only on the weight itself, since many factors contribute to man-hours prediction. Chou (Chou & Chang, 2001) produced the MLR models, which is similar to a better prediction concept done by Hur (Hur et al., 2013). Salem (Salem, 1997) confirmed that the MLR gave more precision and accuracy compared to SLR.

Liu (Liu & Jiang, 2005b) estimated the man-hours of shipbuilding interim products again in terms of reliability and accuracy by using three models for man-hour estimation, which SLR, and MLR as well as Artificial Neural Network (ANN) Model. This model is used to identify which one has a better prediction. The reliability and accuracy must be defined in terms of mathematical model to achieve the comparison. It is then verified and confirmed that the ANN models give more accurate and reliable results than SLR and MLR. Methodology of their research for ANN is illustrated in Figure 8.

3.2.3. OKP Man-Hour Estimation and Optimization Method

One-of-a-kind is defined as unique in thesaurus definition. Mei et al. (Mei, Zeng, Feng, & Tu, 2015) mentioned that one-of-a-kind production (OKP) face various manufacturing problems and require different controlling production management compared to mass production.

An OKP industry can be characterized by the following:

a) The industry’s product designs essentially change with every new order (Madsen, Holm, Trostmann, & Conrad, 1993).
b) Most of their customers’ orders contain one and only one product type (Madsen et al., 1993).

c) Produced once only and if re-produced it has no repetitive period

d) Poor production stability which has low degree of production and process specialization and multiple work processes

e) Low production automation compared to non-OKP industries

Examples of OKP industries can be found in heavy-industries such as shipbuilding, steel structure buildings, large electrical equipment buildings, boiler manufacturing, etc. This shows that this type of manufacturing carries a complex and complicated type of manufacturing, in which man-hours optimization is problematic because it is focused not only on the parameter of products itself like fabrication phases, trade of workers, various production equipment, but is affected by production process parameters. As Liu (Liu & JIANG, 2005a) discussed, the parameters of production i.e. structural and assembly sequence are discrete and non-numerical.

Mei (Mei et al., 2015) studied the OKP man-hours and focused on the optimization man-hours using matrix real-coded genetic algorithm (MRCGA). The utilization of MRCGA require a specified data from actual shipyard man-hours. In order to do that, a set of data from actual shipyard is required in order to analyse and apply dynamic programming to get the optimum man-hours with respect to relevant work force. He used the actual shipyard data to analyse and improved the shipyard production efficiency with the new man-hours optimization. Figure 9 shows the result of MRCGA analysis. It obtained the actual man-hours by expert estimation and refined it for optimization.

**Figure 9** MRCGA Results on Man-hours Optimization in Shipbuilding

### 3.2.4. Smart Product Model (SPM)

Proteus Engineering from U.S. produced Smart Product Model (SPM) (J. Ross, 2002; J. M. Ross, 2004; J. M. Ross, McNatt, & Hazen, 2002) which was designed to fit the best cost estimates at all times when a certain ship was constructed. The SPM estimates the ship production costs related to SWBS methodology and has three independent levels as demonstrated in Figure 10. The three independent levels methodology is defined as below:

a) Concept Design – The cost normally estimates the whole vessel technical data and characteristic based on 20 level 1 data items such as ship length, type of beam, total displacement and type of power installed.

b) Preliminary Design – Capable to do cost estimate based on 125 system information data or Level 2
A Review of Work Breakdown Structure and Man-Hours Estimation Method used in Shipbuilding Production

c) Contract Design – Detailed predictions can be found here based on thousands of data items. Accuracy will improve once the design progresses to this stage.

Figure 10 SPM Cost Estimation Component Flow Chart

SPM software comprises two associated elements that focus on engineering and cost. Each element has their own modules for specific operations. There are four modules in the cost element as described below.

a) Parametric Cost - Estimation of cost based ship design base

b) Assigned Costs – Cost already built-in to the software based on estimation from suppliers and purchasing order

c) Cost Source Selection – Optional to user to select either Parametric Cost of Assigned cost

d) Cost Reports – Provide three (3) types of report with overall confidence level. Report based on 1-digit, 2-digit, and 3-digit SWBS cost estimates

The outcome of the SPM software consists of type of ship structure and engineering model breakdown using SWBS methodology, project overview and others. User can give input related to ship requirement such as number of crews, ship type, payload capacity, etc. The result of cost estimation, labour hours and other estimation can also be determined. With this SPM software, the man-hours can be defined easily for ship construction.

3.2.5. Mitsubishi CIM System

Sasaki (Y Sasaki, 2001, 2003; Yuichi Sasaki & Sonda, 2002) discussed new development of Computer Integrated Manufacturing (CIM) by Mitsubishi Heavy Industries (MHI) from Japan. This system interfaced to its original structural design CAD system. The CIM system integrated all production planning, estimation and levelling function into commercially available line simulation system. It produced less duration resulting in reducing 2 to 3 weeks required for conventional method to just one (1) day. The 3-D visualization made the designer improve the hull block assembly sequence and capable to define cost, time and weight for each ship parts. The cost is a function of difficulty method. For example, in welding, it multiplies the work difficulty (i.e. 1 for downward, 1.5 for horizontal, 2 for upward).

In Figure 11 is shown the concept in CIM integration. User only defines first parts i.e. Hull Base Plate pre-assembly. The software will automatically define the assembly tree based on production rules in knowledge base store. Not all blocks can be automatically defined at
first, and this system is equipped with assembly tree editor that helps the production engineer modify it efficiently.

![Figure 11 Flow Assembly procedure definition function](image)

### 3.2.6. Critical Analysis on Man-Hours Development in Shipbuilding

They are various research in the Shipbuilding man-hours development. Most researchers agreed that the current man-hours development is predicted using conventional method by those who performed by shipyard expertise. Hur (Hur et al., 2013) proposed the man-hours prediction system for shipbuilding and have decided to use the MLR, and CART models. In the beginning, the initial data collected is an actual man-hour from shipbuilding processes estimated by shipyard expertise based on experience. They discussed man-hour prediction methodologies in detail, which is normally predicted by experts at shipyards. New proposal of system that can predict man-hours was introduced for shipbuilding application. The numerical concept is not linked to detailed WBS of shipbuilding construction. Data collection of three months is somewhat short to encompass the production process of the whole shipyard. It may require greater period of historical data to reduce error in estimating using computer software.

Expertise prediction may raise concerns regarding error or inaccurate results. Liu (Liu & Jiang, 2005b) stated and also agreed that the conventional method to estimate man-hour based on weight factor is inadequate. They obtained 28 samples of actual data predicted by Shipyard experience and introduced SLR, MLR as well as ANN model to predict global ship man-hours. 28 man-hours data, which was collected randomly based on dimension and weight, was not grouped into ship structure types i.e. stiffeners, plate, etc. The data was then analysed, which proved that ANN is better than MLR method analysis. The analysis only shows different error analysis between MLR and ANN without linking to WBS and ship product. Man-hours, historical or actual for all ship parts, is required to be further analysed in respect to their model. Result then need to be compared with actual ship construction man-hours for validation.

Mei (Mei et al., 2015) used the interim product of shipbuilding for research on OKP man-hours optimization using MRCGA method and dynamic programming. This author also required actual man-hours data for their man-hours optimization analysis and they took the data from actual shipyard experience. Most analysis uses the samples of man-hours that are linked to PWBS and their prediction is only based on mathematical model rather than actual project. It can be concluded that the man-hour reference based on expertise estimation and
A Review of Work Breakdown Structure and Man-Hours Estimation Method used in Shipbuilding Production

historical data can be generated and analysed for optimization. Unfortunately, no validation was done by Mei (Mei et al., 2015) with respect to actual project.

Other software produced by Proteus Engineering from U.S known as Smart Product Model (SPM) (J. Ross, 2002; J. M. Ross, 2004; J. M. Ross et al., 2002) has been specially designed for SWBS method for cost estimation. This software is capable to calculate cost during concept design, preliminary design and contract design. As this software is not available to the public, the details of methodology cannot be traced. Mitsubishi from Japan also introduced CIM system that is capable to integrate all planning data and costing into CAD system. The CIM system is able to semi-automatically define the hull block assembly and calculate the cost, time and weight for production information. However, while this system is only applicable for welding cost estimation, it is valuable for automatic definition of smaller assemblies. This software is still not applicable at Malaysia shipyard, and to use it, Malaysia shipyard expertise is required to provide data input based on Malaysian Shipyard properties into this software as the base for historical data analysis.

Spon’s Fabrication Norms, a handbook for the oil, gas and petrochemical industries (Andrews, 1992) introduced detailed breakdown of the labour content for fabrication of offshore structures and pre-assembled units. It resulted in the compilation of actual data drawn from a wide range of projects by one of the leading consultancies in the offshore industry and the book will be an essential industrial reference. This book will act as part of validation that can be used by all researchers of man-hours either in shipbuilding or offshore industries.

4. CONCLUSION

The literature review in this paper clearly defined the types of WBS for shipbuilding project including Program Work Breakdown Structure, Contract Work Breakdown Structure (CWBS), Ship Work Breakdown Structure (SWBS), SFI Group System, Product Work Breakdown Structure (PWBS) and Zone Work Breakdown Structure (ZWBS), which are comprised of Hull Block Construction Method (HBCM), Zone Outfitting Method (ZOFM), and Zone Painting Method (ZPTM).

A critical review has been discussed and it can be concluded that the SWBS methodology is not suitable to further use in man-hours development. The PWBS is the best methodology that is widely used in the shipbuilding industries for schedule and cost estimation development. The PWBS will act as foundation in future research in developing man-hours for shipbuilding.

This chapter also discussed the man-hours calculation method in shipbuilding which is comprised of expertise methodology such as using historical data of weight factor and other methods such as Single Linear Regression Model (SLR), Multiple Linear Regression Model (MLR), Classification Regression Tree (CART) models, Artificial Neural Network (ANN), which mostly use mathematical models to predict man-hours in shipbuilding. There is also matrix real-coded genetic algorithm (MRCGA) methodology used to further optimize shipbuilding man-hours estimation. Shipbuilding cost estimation is also related to man-hours since without man-hours, the cost cannot be calculated. Program models such as Smart Product Model (SPM), Mitsubishi CIM system, and Simulation all have the same objective, which is to define man-hours and cost.

A critical review of this man-hours development methodology shows that most researchers still depend on conventional expertise estimation to develop their data analysis. No mathematical model can be made without shipyard expertise data and it can be concluded that the expertise data is still valuable in this shipbuilding industry. One of the historical data
available currently is the Spon’s Fabrication Norms Handbook that breaks down offshore structures like Topside and Jacket in terms of man-hours. This valuable data can be act as foundation for validation by all researchers of man-hours, either in shipbuilding or offshore industries.

The development of man-hours for shipbuilding is always complex and difficult to predict if the initial WBS elements are not known. PWBS is one the best methods to use in Shipbuilding production which is widely used in the shipyard at the present time. Labour man-hours is easy to identify by using PWBS, which uses product oriented compared to SWBS methodology that uses system oriented. Further man-hours development for Shipbuilding Project by using PWBS method must be studied.

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A Review of Work Breakdown Structure and Man-Hours Estimation Method used in Shipbuilding Production


