Assessing Performance Measurement Indicators for Ship Manufacturing Industry through Value Engineering and Risk Assessment (VENRA) Model

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ABSTRACT: Selecting attributes for shipyard performance measurement remain essential as the dynamic changes occur in manufacturing technology and future ships products. The present study provides the Value Engineering and Risk Assessment (VENRA) approach as the performance measurement model for ship manufacturing. Existing criteria similarity and applicability, in shipyard industry, have been examined through a thorough critical review. A number of performance criteria have been identified, including technical, business, external, and safety/risk groups as part of the VENRA model. Subject experts provide the relevant scoring of the model through a dedicated Likert Scale to assess the weighted criteria. The result shows shipyard facility and capacity are the most critical main criteria, while launching/docking facility and welding machine facility are the top two crucial sub-criteria. The case study of one Indonesian shipyard shows the model's effectiveness, suggesting shipyard examine their existing facility and capacity as part of the technical performance.

1 INTRODUCTION

The challenge of future built ships globally is related to reducing ships' emissions to achieve zero-emission by 2050. The 2020 sulphur regulation imposes new conditions for the whole marine industry. The fuel onboard should not be more than 0.5% of sulphur (earlier, the limit was 3.50%), as reported by the International Chamber of Shipping in collaboration with Ricardo (International Chamber of Shipping, 2021). Ricardo and the team, in this report, has identified the possibility of using alternative greener fuels for the ship engine, such as ethanol, ammonia, hydrogen, and biofuel, to minimise GHG emissions. The possible way to achieve the near target is by installing scrubbers for existing ships, reducing the sulphur content, or consuming low sulphuric fuel oil, which reduces emissions although escalating the operational cost.

Many shipping companies prefer to consume low sulphur fuel or install scrubbers, but some companies such as NYK prefer to apply for LNG-fuelled ships (NYK Line, 2021). Concerning the strict demand on reducing emissions in the maritime industry, the shipyard manufacturing sector (including shipbuilding, ship repair and ship conversions/modifications) needs to have a more efficient strategy to fulfil the need for the future demand of ship manufacturing. One of the tools used in developing this strategy is by applying a performance measurement framework adjusted to the current needs of the maritime sector.

Overall, performance measurement works as a benchmark, which is critical in evaluating an industrial plant capacity and effectiveness in order to be more agile and competitive. A number of criteria are included affecting the performance measurement process and impacting their competitiveness ranking. In this case, key criteria are selected for the performance measurement process, also critically supporting the decision-making process. Crucial factors in performance measurement should be carefully selected to suggest what companies should evaluate (Harbour, 1999). In this respect, the uniqueness of the shipyard industry needs careful examination as it cannot be compared to the general industrial sectors due to their specialisation in technology, business, internal and external resources.

One of the most powerful tools for developing a strategy for improvement is a performance measurement approach. Performance measurement is used in shipyards to compare shipyard competitiveness and improve shipyard strategy shipyard selection, which will eventually develop a new 'green' shipyard. The above process requires indicators or criteria to be developed and included in the measurement process to fulfil the future product's specification demand. With this regard, assessing performance measurement indicators for future ship manufacturing is crucial.

Shipyard productivity is the initial parameter used in shipyard performance for shipbuilding activity. Man-hour/CGT (Compensated Gross Tonnage) is used commonly, considering the labour needs per hour and the Gross Tonnage of the ship size considering the work content of different ship types. The CGT is calculated based on OECD 2007 version formula (OECD, 2007). Data Envelopment Analysis (DEA) model has also been applied to measure shipyard competitiveness and efficiency, involving the output and input analysis involving output and input analysis, one of which is from Chao & Yeh (2020). Another performance model used is the criteria model, categorised into specific dimensions such as the balanced scorecard which is assessed through experts' multicriteria decision making (MCDM) approach. The latter provides flexibility in selecting the criteria included in the performance measurement model. However, this flexibility needs to address upcoming challenges since future ship technology changes and adapt to existing technological needs. In addition, experts' background, education and experience should also be considered related to the shipyard industry.

Following the above, this paper aims to present a performance measurement indicators framework for ship manufacturing through the Value Engineering and Risk Assessment (VENRA) model, integrating the value and risk through four categorised dimensions: technical, business, external, and safety/risk. The novelty of the paper is as follows. First, it systematically purposes the method for selecting criteria for ship manufacturing. Secondly, it assesses criteria through the VENRA model under experts' opinion and implements them in one of the shipyard case studies. The structure of the rest of the paper is as follows. Section 2 discusses the literature review, including the performance measurement model for ship manufacturing in shipbuilding, ship repair, and ship modification. The methodology framework of VENRA is shown in section 3, while section 4 presents the results and discussion and eventually, the last section provides the conclusions and future work.

2 LITERATURE REVIEW/BACKGROUND

2.1 *Background*

Shipyards and ship manufacturing, including shipbuilding, ship repair and maintenance, and ship modification/ship conversion, are unique due to their speciality in technology, business, and internal and external resources. They have different manufacturing strategy applications for each activity (new building, repair or modification) considering the ship type, effectiveness, shipyard capacity and capability, cost and delivery time. From the business point of view, they seem to be similar to general sector industries; however, the knowledge in finance, payment terms, and bank involvement has special treatment and should integrate with technical knowledge. Internal and external resources involved in the process should also include a high level of speciality and expertise. The workers, engineering design and production, and quality control are internal resources involved in the manufacturing process, which should have particular capabilities in handling ship manufacturing. Producing ship hulls or assessing the dry-docking process requires ship design and construction knowledge. Similarly, external resources such as bureau classification, vendors, or suppliers have also knowledge and speciality about ship manufacturing. In this regard, the performance measurement for ship manufacturing industries remains essential be assessed.

Performance measurement for industries, as the benchmark, is critical for evaluating industries to be enhanced and more competitive. The appropriate measurement criteria affect the performance process and impact the competitiveness ranking. In this case, selecting the proper measures for the performance measurement process remains critical as it assists the shipyard decision-making process. Crucial factors in performance measurement should be chosen to explain what companies should evaluate (Harbour, 1999).

2.2 *Shipyard Performance Measurement*

Two factors should be considered in performance measurement within shipyards. The first one is related to the output factors which are commonly used; quality, cost and delivery aspects (Pires & Lamb, 2008; Pires et al., 2009). The second one is the influencing factors: the sources used or included in the manufacturing, repair and modification process in the shipyard. Concerning the output part, some researchers use it to measure shipyard competitiveness, such as suggested by (Pires & Lamb, 2008; Pires et al., 2009; Krishnan, 2012; Chao & Yeh, 2020) by using the Data Envelopment Analysis (DEA) tool. However, not all the output is included. These studies (Pires & Lamb, 2008; Pires et al., 2009) have the delivery time (keel laying to delivery time) and cost of production only (which use labour cost as it is appropriate to compare the shipyard case study). Krishnan (2012) recommended using the Compensated Gross Tonnage (CGT) and shipyards' effort to build a ship using Work Breakdown Structure (WBS) to estimate realistic total productivity using the DEA technique. Chao & Yeh (2020) compare productivity in shipyards using the DEA model, considering changes in productivity values in different years. Roque & Gordo (2021) proposed a systematic and holistic approach for measuring productivity using man-hour based on cost, considering the complexity of the ship based on actual data. Sahin (2021) suggested using the improved fuzzy AHP method for shipyard selection based on game theory while also conducting the shipyard criteria importance based on interviews in his study.

On the other hand, some researchers have tried to determine the factors that are sometimes intangible. Pires et al. (2009) analyse some influencing factors, including the shipyard capacity, technology level index, Industrial environment index, productivity, building time, and quality. The erection area represents the shipyard capacity. In contrast, the technology level index is represented by four groups of activities: fabrication and assembly, erection and outfitting, product and processing engineering, organisation and management, which are assessed by grading between 1 and 5. The industrial environment referred to the prevalent conditions in the country or region, covering production chain organisation, workforce, and shipbuilding policies with some subcriteria of each activity and was assessed using Analytical Hierarchy Process (AHP). The productivity itself is represented by using the CGT measurement by OECD 2007, representing the level of work content in building the ship and using the series factor in building the ship in series (more than one ship), including building time, excluding the quality due to data subjectivity.

Modelling the criteria selected needs the appropriate process or approach. The performance criteria model commonly used is the Balanced Scorecard (BSC). Gavalas et al. (2021) used BSC for shipbuilding performance indicators, while Dincer et al. (2019) applied it in the performance results of the European policies in energy investment, and Dincer et al. (2017) evaluated the performance of the European airlines. BCS combines the financial, customer, internal business, and innovation and learning perspectives (Kaplan & Norton, 2005). However, Dror (2008) argues that BSC has no basic guidelines for selecting performance measures and has complex feedback from the financial perspective to the customer and process perspectives. Moreover, the BSC model does not include the technical criteria as part of the framework. In this regard, establishing the methodology for selecting the performance measures should be performed systematically.

With the uncompleted criteria dimension in the balanced scorecard model in performance measurement, another model can cover the business dimension of measures and the value and risk dimension integration. The integration of Value and Risk dimensions for the performance measurement has been proposed by (Shah *et al.*, 2012, 2016, 2017; Vernadat *et al.*, 2013) in the product development process using embedded risk in the value of quality, cost, and time process. Many researchers applied the term Value Engineering/Value Management integrated with risk assessment/risk management as the project management tool enhancement (Dell'Isola, 1997; Mootanah, 1998; Abd-Karim et al., 2011; Ahmed et al., 2012; Feili et al., 2012; El Khatib, 2015; Golabchi et al., 2016; Sabzkohi & Pourrostam, 2016). However, integrated value and risk have not been implemented in shipyard manufacturing industries (shipbuilding, ship repair, ship modification). The development of VENRA as the performance measurement in shipyards has been established by Baihaqi et al. (2021), purposing the four combined group criteria as the performance parameters. This paper assesses the proposed VENRA (Value Engineering and Risk Assessment) model using the Likert scale to provide the weighted factors score and evaluate the performance model to improve their effectiveness as shipyard industry performance measurement models. The technical part will be examined using the proposed method as it is still ongoing progress. The rest of the business, safety/risk and external criteria will be examined shortly.

3 METHODOLOGY

The development of the VENRA methodology has been initially proposed by Baihaqi et al. (2021), suggesting a number of attributes affecting shipyard performance and integrating the technical, business, external and safety/risk. This paper applies the assessment to the technical group as part of the VENRA model.

In applying the above framework to evaluate the shipyard performance, the VENRA model has grouped the criteria into technical, business, external, and safety/risk, as shown in Figure 3.1.

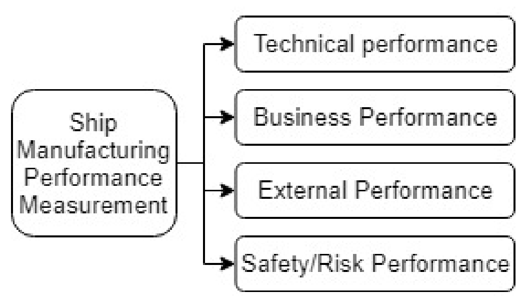

Figure 3.1 VENRA model group attributes

Figure 3.2 shows the flowchart of methodology in this study. It begins with defining the criteria based on the technical group criteria as part of the VENRA model. The next step is modelling the Likert Scale, which refers to Baso et al. (2020), as shown in Table 3.1. The Likert Scale is enhanced by considering the experts' education level, practical shipyard experience and academic experience, which the weighted percentage are shown in Table 3.2. The expert preferences then provide the Likert scale judging (importance level) to the main group criteria and sub-criteria on each main group. The score was normalised based on the total score on the main criteria and each sub-criteria in every main criterion. The final step is to calculate the relative attribute weights by multiplying each group's main and sub-criteria weights. The final weight score was then applied to shipyards data. The justification to grade the shipyard data is based on the grading developed by the authors. The score is given as part of shipyard performance in the technical group part.

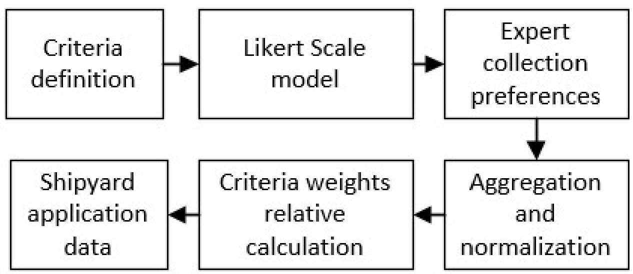

Figure 3.2 Methodology flowchart.

Table 3.1. Likert Scale model used.

Word Expression	Code	Weighted
Strongly Important	SI	0.503
Very Important	VI	0.26
Important	I	0.134
Less Important	LI	0.068
Not Important	NI	0.035

Table 3.2. Expert level consideration model.

Level of education (15%)		Experience (in years), (70%)		Academic Experience (in years), (15%)	
High School	25%	<5	35%	<5	35%
Diploma (Pre-University)	35%	5-10	60%	5-10	50%
Bachelor (S1)	60%	11-14	85%	11-14	70%
Master (S2)	85%	>=15	100%	>=15	90%
Doctoral/PhD (S3)	100%				

4 APPLICATION OF VENRA FRAMEWORK

4.1 *Case study*

Having the weighted criteria in the final model in place, these are applied in the shipyard case study. This shipyard located in Indonesia is active in ship newbuilding, ship repair and maintenance, and offshore building maintenance. It is also involved in navy ships. Overall, there was limited access to data due to confidentiality reasons, and therefore a partial application of the VENRA framework is presented next.

4.2 *Technical attributes of VENRA*

Figure 4.1 shows the main technical criteria and sub-criteria model as part of the VENRA. It consists of six main criteria, which each have some sub-criteria. For example, "manufacturing strategy" is the main criteria as part of the technical group of VENRA. It has four sub-criteria: construction method, pre-outfitting, modules, and make or buy strategy.

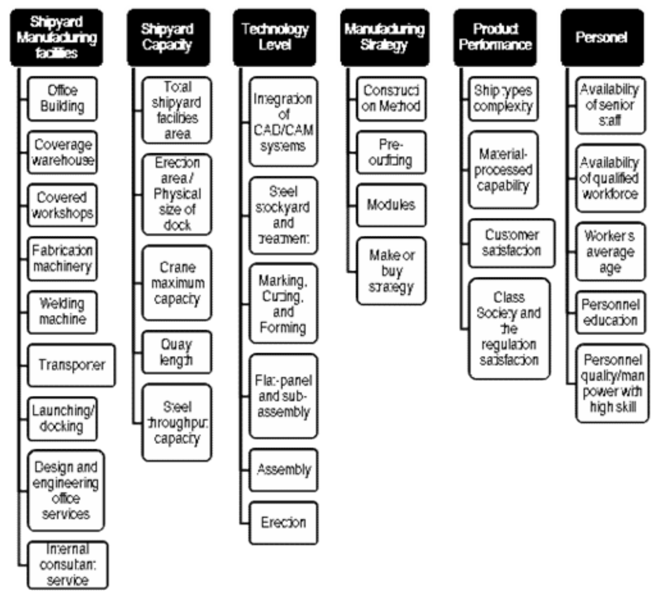

Figure 4.1 Technical group of VENRA model.

Each main criteria has its definition to get the same expert thought before providing the judgment. The main criteria, shown in Table 4.1, are the description of the main criteria which has six criteria.

Table 4.1. Technical group main criteria

No	Main Attribute	Description
1	Shipyard Manufacturing Facilities	The existence/availability of buildings, equipment & tools, and services provided for ship manufacturing activities, considering their quantity, condition and size/capacity.
2	Shipyard Capacity	The ship's maximum size and quantity, based on the ship's main dimensions, deadweight, or Gross Tonnage, which can be built, repaired or modified by the shipyard
3	Technology Level (Degree of Automation and Robotics)	The level of technology, based on the applied degree of automation and robotics, used in a shipyard includes design and production engineering, steel stockyard, fabrication, sub-assembly, assembly and erection

No	Main Attribute	Description
4	Manufacturing/ Building Strategy	Manufacturing/building strategy used to produce/repair or modify the ship, considering the hull construction, outfitting, modules, and make or buy scenario.
5	Product performance (complexity, material, quality, and satisfaction)	Refer to the product performance output of the shipyard or the building capability in producing a range of products with rigorous standards and supervised by top-rank international IACS classification
6	Personnel	Personnel availability, qualification, ages, education, and quality-expertise

As the main criteria have some sub-criteria, they should also be defined. In this paper, the sub-criteria description is provided for shipyard capacity as the example shown in Table 4.2. The detailed description for these criteria includes the total shipyard area, erection area, crane capacity, quay length, and steel throughput.

Table 4.2. Sub-criteria description for shipyard capacity.

No	Sub-Criteria	Description
1	Total shipyard facilities area	The total area of the shipyard (including design office, warehouse, production facility) in square meter / the whole building birth and or docking area in square meter (building berth, slipway, dry dock/graving dock)
2	Erection area / Physical size of the dock	The physical area size to erect new building construction and dock/undock ship repair & maintenance or ship conversion
3	Crane maximum capacity	Crane capacity (in ton) for erection process (newbuilding), lifting equipment/plate for (ship repair and conversion)
4	Quay length	The length of quay (in meter) for installing deck equipment (newbuilding) or floating repair process (ship repair & conversion)
5	Steel throughput capacity	The capacity of fabricated steel or welded panel-assembled construction per period (ton/day, ton/week, ton/month, ton/year)

4.3 *Criteria assessment*

Seven experts provide their opinion, judging the score of the model of criteria developed in the technical group. The criteria and sub-criteria tabulated assessment for the expert opinion are demonstrated in Table 4.2 and Table 4.3. The former shows the main evaluation for the main criteria and the latter in the sub-criteria assessment for shipyard capacity as an example. For example, Main-1 is referred to the total Shipyard area, which exp1 refers to the first expert respondent, which gives SI (Strongly Important) judgement. Exp2, up to Exp7, is referred to the 2nd to 7th expert preferences.

Table 4.3. Main criteria assessment.

Criteria	Expert No						
	1	2	3	4	5	6	7
Main-1	SI	SI	VI	I	SI	SI	VI
Main-2	VI	SI	VI	VI	LI	SI	VI
Main-3	I	SI	I	LI	I	VI	VI
Main-4	VI	SI	I	I	I	I	VI
Main-5	I	SI	I	VI	I	I	VI
Main-6	VI	SI	VI	I	I	VI	SI

Table 4.4 shows the sub-criteria example for the technical capacity part. Tech.Capa1 refers to the total shipyard area, while Tech.Capa2 refer to the erection area. Similar to Table 4.3, there are seven experts involved in the study.

Table 4.4 Sub-criteria assessment for shipyard capacity.

Criteria	Expert No						
	1	2	3	4	5	6	7
Tech.Capa1	VI	SI	I	I	VI	VI	VI
Tech.Capa2	SI	VI	VI	VI	VI	VI	VI
Tech.Capa3	VI	SI	VI	I	LI	VI	VI
Tech.Capa4	I	I	I	I	I	I	VI
Tech.Capa5	I	SI	I	I	I	I	I

5 RESULTS AND DISCUSSION

5.1 *Criteria weighted and ranking.*

The data should be checked statistically, and in this study, the Alpha Cronbach approach adopted from Baso et al. (2020) is implemented using the Microsoft Excel data process. The result shows that the main criteria and sub-criteria scores were 0.844 and 0.811, respectively. A range between 0.8-0.9 is considered good when using the Likert Scale.

Figure 5.1 shows the percentage of the main criteria based on the technical VENRA part. Shipyard manufacturing facilities and capacity dominate with 22.5% and 18.5%, followed by personnel 17.9%, while technology level is considered the lowest score accounted with 12.8%. Product performance has a slightly higher percentage than product performance, accounting for 14.6% and 13.8%, respectively.

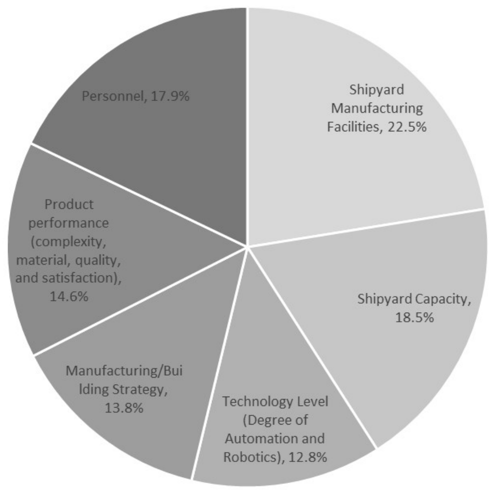

Figure 5.1. VENRA technical group main criteria weighting.

The above results are validated when compared to the existing literature (Sahin et al., 2021), suggesting that the shipyard facility is also the most critical component. Shipyard capacity and personnel sub-criteria importance are proven to be essential factors, as also indicated by (Pires & Lamb, 2008; Pires et al., 2009)

The technology level is accounted for the lowest score. This could be considered the questionnaire is unclear enough about the ship type built. The respondents could assume that the higher level of technology is not the priority in shipyard performance. Pires & Lamb (2008); Pires et al. (2009) suggest that the most competitive shipyard is the one that includes a lower level of technology but produces the highest output considering the CGT (the ship size and type).

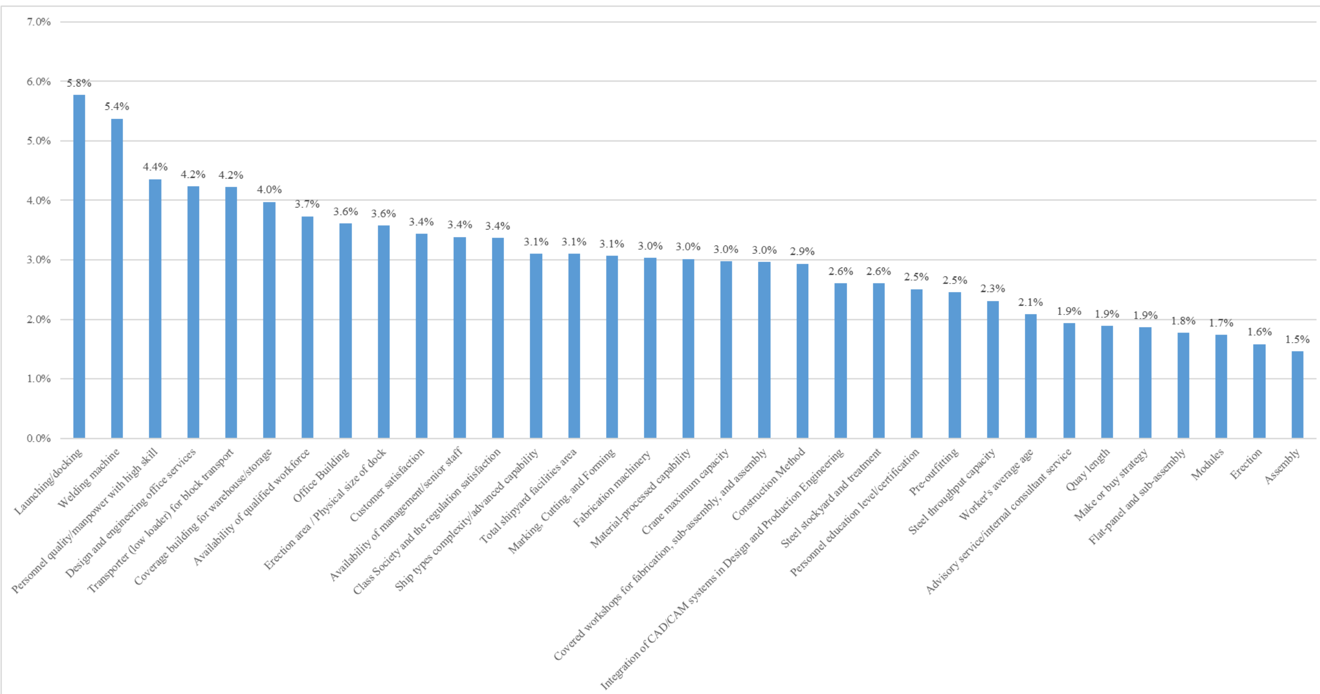

Figure 5.2. Global normalised ranking of criteria.

Based on Figure 5.2, the most crucial sub-criteria for the shipyard performance is the launching/docking facility, which accounted for 5.8% in the global ranking, followed by the welding machine and personnel quality/manpower with high skill, accounting for 5.4% and 4.4%, respectively.

5.2 *Shipyard case study.*

The partial criteria included in the case study are the erection area, fabrication machinery, welding machine and the maximum crane capacity. In this case study, each data collected is analysed considering their efficiency, effectiveness, or capacity needed. For example, the erection area limits the ship size that can be built or repaired; fabrication machinery measures the steel cut or formed output; welding machine performance measure the quality and quantity of joining output, and the crane capacity measures the operational effectiveness.

5.2.1 *Erection area / physical size of a dock*

This shipyard has the capacity of erection area up to 50.000 DWT using graving dock type with the size of length, breadth, and depth: 200m, 32m, and 10.5 m. The dock is used to build merchant ships in general. The shipyard has a quite big erection area for a merchant ship, either new building or ship repair. However, the length and breadth of the erection area ratio should be rechecked considering the working space for shipyard workers in the field. The primary dimension ratio of ship population could be regarded as part of the measurement.

5.2.2 *Fabrication machinery*

Fabrication machinery is considered a vital machine in the shipyard. It handles the steel cutting process, the piece part before the first fit up to build the ship part construction. Based on the case study, the shipyard has three CNC, one of them are plasma cutting underwater. Only one machine operates normally, while the other machine needs retrofitting for the software updates. The cutting data has not been recognised, and during an interview with the staff, they also cannot identify the speed. However, based on the size of the CNC cutting, it can handle plates up to 12 meters long with breath up to 2.4m. The need for fabrication machinery considers the capacity in the new shipbuilding. There is no information regarding measuring the CNC needed for a shipyard. With the available CNC, the shipyard can cover the cutting process for about 1000 tons/month.

5.2.3 *Welding machine*

The welding machine is one of the vital machines to process joining between plates and profiles. This shipyard has a total of 98 units of welding machine with many types such as SMAW (Shielded Metal Arch Welding), FCAW (Flux Core Arc Welding), and SAW (Submerged arc welding). The shipyard has not applied robotic welding in its facility. The welding machine output or welded join depends on the machine types, welding position, type of materials welded, and the machine duty cycle. The thickness of material and type of join also impact the speed of the welding process.

5.2.4 *Crane maximum capacity*

The performance of maximum crane capacity is also should consider the effectiveness and efficiency of the applicability. Based on the interview with the shipyard staff, the high 300 ton capacity of the goliath crane owned by the shipyard said that the actual maximum capacity allowed is 240 tons. Considering the crane's age, which is more than 20 years, the safe working load could be less than 240 tons. Other than that, the actual working load for this crane should be investigated further. If the block or the ring block lifted (the average, in tonnes) is less than 240, then the actual performance of the shipyard is below the maximum. For example, if the average block lifted by the crane is only 150 tonnes, then the average performance of the maximum crane capacity is only 150/240 (based on SWL), or around 60%.

6 CONCLUSION AND FUTURE PLAN

This paper includes the presentation of the VENRA framework and a demonstration of a case study suggesting the model's effectiveness through expert preferences weighting using the Likert scale. The model presented is a part of the overall VENRA framework. In this respect, the shipyard facility, capacity, and personnel are the main criteria to be considered in measuring the shipyard's performance.

The case study shows that the shipyard's performance depends on the ship type built. The performance of each sub-criterion should also consider the ship targeted. The case study shows that the shipyard has a quite large facility and capacity. On the other hand, the history of the actual ship built in the commercial division has not been informed yet. Thus, by assuming it can build the maximum one, the shipyard capacity based on fabrication machinery and maximum crane should be improved.

Steps for future research would include developing and applying the VENRA framework for the remaining major shipyard group attributes. The methodology for the assessment can utilise the hybrid fuzzy approach to achieve the more natural way and improved scoring system to achieve further results.

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