**Science Research**
2023; 11(3): 72-79
http://www.sciencepublishinggroup.com/j/sr
doi: 10.11648/j.sr.20231103.14
ISSN: 2329-0935 (Print); ISSN: 2329-0927 (Online)

# A Novel Approach of Performance Measurement of Shipbuilding Supply Chain by AHP-FCE Model

**Yongjun Wu, Niansheng Chu*, Jiang Xu, Jianyang Guo**

Shanghai Waigaoqiao Shipbuilding Company, Shanghai, China

**Email address:**
cns@chinasws.com (Niansheng Chu)
*Corresponding author

**To cite this article:**
Yongjun Wu, Niansheng Chu, Jiang Xu, Jianyang Guo. A Novel Approach of Performance Measurement of Shipbuilding Supply Chain by AHP-FCE Model. *Science Research*. Vol. 11, No. 3, 2023, pp. 72-79. doi: 10.11648/j.sr.20231103.14

**Received**: May 20, 2023; **Accepted**: June 6, 2023; **Published**: June 20, 2023

**Abstract:** As an ETO industry of shipbuilding, supply chain management is very important in a shipyard. Based on the analysis of shipbuilding production mode, the characteristics of shipbuilding supply chain management, the real problems, and the operation requirement of supply chain in a shipyard, this paper generally introduces the performance measurement driven lean supply chain management system and its mechanism of circulating for perfection of the same team's previous study. This study carries out further research on the methodology of the performance measurement of supply chain in shipbuilding and proposes a novel method to evaluate the performance of supply chain in shipbuilding by the model combined the Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) based on the operation of lean supply chain management system. The AHP-FCE model for the supply chain performance measurement (SCPM) in shipbuilding is achieved by the steps of the indexes analysis, deciding the relative weights by the AHP method, and then evaluating the effectiveness of these indexes with the input of experts' opinion and calculation accordingly. The calculation results show that these performance indexes and their weight work functionally and properly, and the performance measurement driven lean supply chain management system can be self-improved based on functionally operation and circulation for perfection.

**Keywords:** Shipbuilding, SCM, Performance Measurement, AHP-FCE Model

## 1. Introduction

As the nature of that shipbuilding is an Engineer-to-Order (ETO) industry in which a new ship is designed and built after a contract signed and enforced between a shipyard and a ship owner [1], the supply chain management (SCM) in shipbuilding is a very important and fundamental activity to enable the shipbuilding contract realizing effectively and efficiently [2]. However, SCM of shipbuilding is a real challenge because of its intrinsic and essential characteristics of short chain, low standardization ratio (LSR), complexity, and uncertainty caused by the nature of shipbuilding as the same author earlier studied [3]. Therefore, the performance and supply chain performance measurement (SCPM) in shipbuilding becomes critical for the productivity of a shipyard.

In order to measure the effectiveness and efficiency of supply chain, researchers and practitioners take varies methods to evaluate SCM performance based on frameworks, models, approaches, and techniques [4]. According to literature review carried out by Jagan Mohan Reddy K et al's [4], the majorities of researchers have used Balanced Scorecard (BSC) approach and Supply chain operations reference model (SCOR) to assess SCM performance. There are also some researchers to combine the features of the SCOR and BSC models to develop a performance measurement system for the cases of small and medium enterprises of different industries [5-7]. However, both BSC and SCOR are not suitable for the performance measurement in the industries with high complexity [8].

The analytic hierarchy process (AHP) is designed to quantitatively determine the weight of each different evaluation factor inherent in the multi-objective and multi-standard sets [9]. This technique may be useful for analyzing and organizing complex decisions by considering mathematics and psychology [4]. It also can be used to decide the indexes of the SCPM combined with other techniques for example SCOR as Ikhsan Bani Bukhoria did in a slaughter house [10].

The fuzzy comprehensive evaluation (FCE) method is one of the most basic fuzzy mathematics methods, which is used for multiple indicators of under the level of comprehensive evaluation. In manufacturing industries, engineers always confront decision-making issues, in which the object being judged is influenced by various factors and contains fuzzy characteristics. Fuzzy refers to these concepts whose boundaries are unclear and ambiguous, e.g., the relative goodness or badness of the building material [11].

The AHP–FCE model combines AHP's capabilities of multi-object and multi-rule decision with FCE's advantages in uncertainty processing and analysis of complex problems [12]. Some researchers and experts use this model to deal with complex and uncertain problems in industry such as risk assessment and achieve good results [13, 14]. The SCPM in shipbuilding also comes with the characteristics of high complexity and uncertainty [3, 15]. This study tries to build an AHP-FCE model to measure the performance of supply chain in a shipyard based on the unique nature of shipbuilding to solve the problem of low efficiency.

The following sections of this paper presents a background analysis of SCPM in a shipyard, represents the status quo in main shipyards of this industry, lists the crux problems of shipbuilding supply chain. Based on these, an AHP-FCE model is built and calculated accordingly. Finally, the key points and important problems of this study are discussed, and its contributions are summarized.

# 2. Research Background of SCPM in Shipbuilding

## *2.1. The Main Processes of Shipbuilding*

As an ETO industry, the essential and unique nature of shipbuilding is that a ship or an offshore product is designed, fabricated, and built together with the project development instead of being ready before the shipbuilding contract signing. In other mature manufacturing industries, the raw materials, technical specifications, suppliers, components, and machinery models are decided during the design stage; thus, the new product is trial-manufactured and tested before the real product being produced [16]. There are not such trial-manufacture processes in shipbuilding; therefore, the shipbuilding is characterized by the application of project-based approaches [17].

The shipbuilding plan is to be carried out in a shipyard based on work breakdown of the ship or offshore product to coordinate the main hull fabrication processes together with the paint and outfitting work. As shown in the figure 1, the ship is built on the path of initiated from the shop premier of steel profile bars and steel plates, cutting in the workshop, assembled into sections or small assembly, transported to block fabrication, erected blocks into meg-blocks, and then erected in the dock of the shipyard [18], launched into water; finally, the ship is delivered after outings installation on the wharf, tested and trialed according to the requirement of technical specifications.

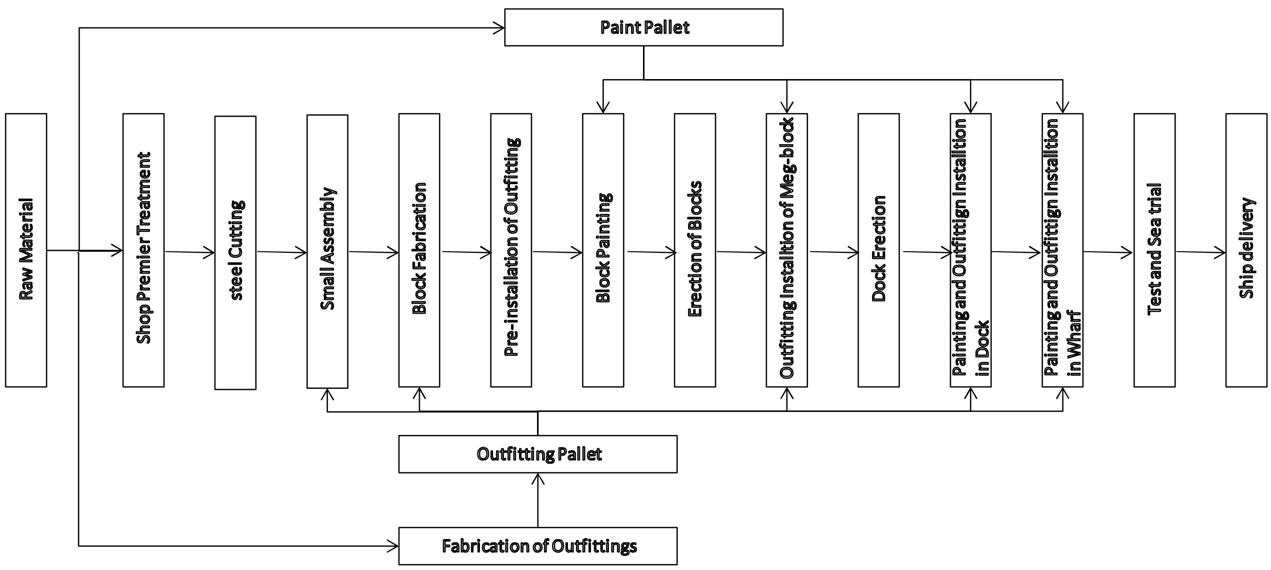


***Figure 1.*** *Main Processes of Shipbuilding.*

The outfittings including pipes, pipe supports, cable fittings, and steel fittings are to be installed during sections, blocks, meg-blocks, and dock erection stage. These outfittings are organized, fabricated, and transported on the basis of pallets respectively [3]. In shipbuilding, the sections, blocks, meg-blocks and relevant outfitting pallets become the basic units of intermediate product. The shipyard manages a shipbuilding project through handling these intermediate products.

Similar in other ETO industry, the SCM of shipbuilding becomes very complex as almost all raw materials, components, interim products, key machinery are produced and purchased based on the detail and specific production design [3, 19]. The work scope of SCM in shipbuilding is in accordance with the structure as shown in figure 2, on the requested time specified by the lean production plan.

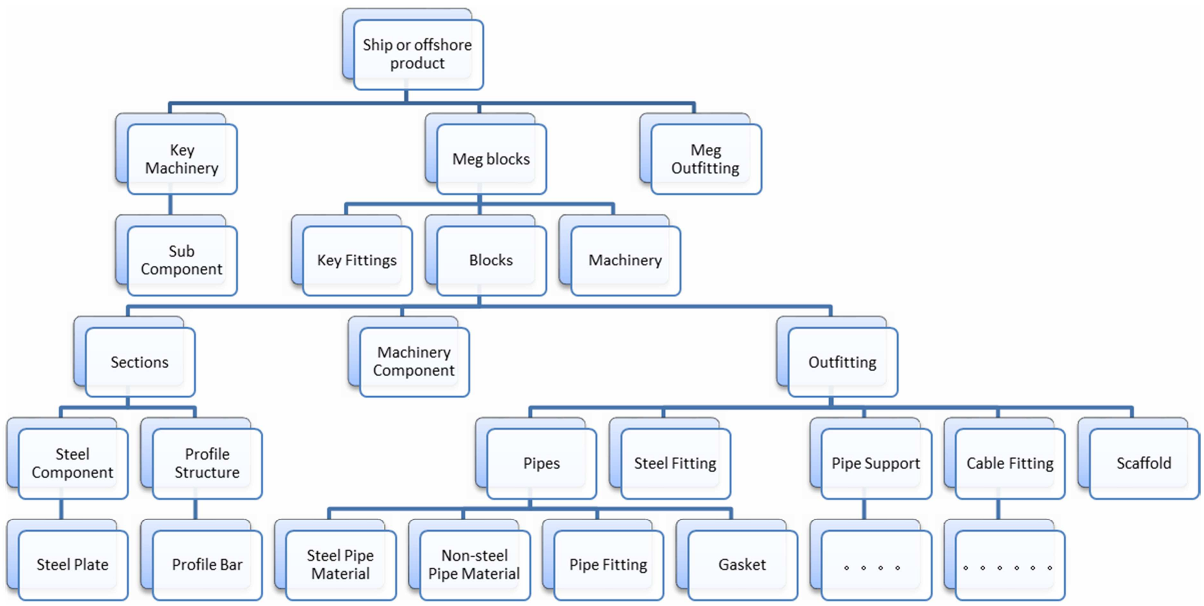


***Figure 2.*** *SCM structure in Shipbuilding.*

### *2.2. Requirement of Shipbuilding Supply Chain*

As an ETO industry, the SCM of shipbuilding has a very LSR at approximate 25% in quantity and only occupied the 5% weight of shipbuilding material [20]. The common practice to take a higher level of inventory to compensate for unforeseen greater uncertainty and complexity [2] would not work in supply chain of a shipyard. The task of SCM shall enable all related raw materials, components, interim products, and machinery arrive aligned with the lean plan of shipbuilding in the shipyard otherwise would cause a failure of supply chain and then insufficient production in the shipyard [3, 21].

The LSR results that there is no real inventory in shipbuilding. The stuff in the warehouse of a shipyard is just waiting for production instead of common inventory. So the main purpose of quality control is to ensure that no defective product enters the production line and the production flows without mistakes or defects. A defective product in the production will cause a delay and increase the cost owing to the LSR and complexity [3].

The cost of supply chain is more than 50% of total production cost in most manufacturing industries, part of them would reach 70-80%, supply chain cost in shipbuilding varies more or less than 60% depends on different ship types [3]. The optimal supply chain cost plays very important role in the business performance of a shipyard.

Most experts and professionals in shipbuilding industry would like to consider the production of ships and offshore products as a project due to its nature of ETO and SCM are just an amount of activities in the project. The same author insisted the applicative of SCM theory in shipbuilding and carried out a systematic way called lean supply chain management (LSCM) in shipyard as shown in figure 3 and circulating as shown in figure 4 [3]. In the LSCM process, the operational data of SCM and suppliers in the shipyard are timely collected, monitored, and analyzed, and then the weaknesses in the supply chain are identified through performance measurement and eliminated by improvement. With this approach the entire shipbuilding supply chain can be continuously optimized and controlled.

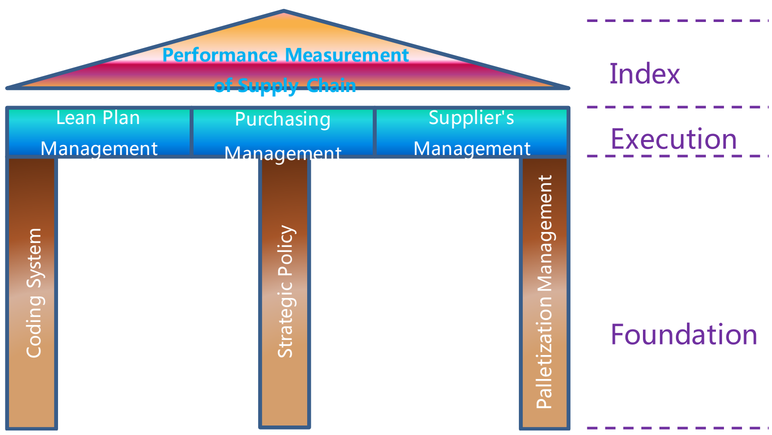


***Figure 3.*** *Frame of LSCM for Shipbuilding.*

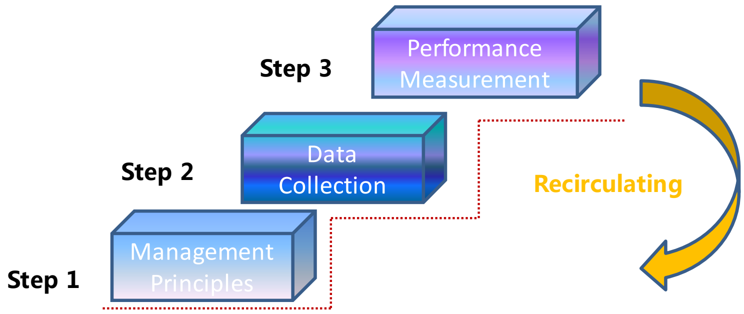


***Figure 4.*** *Execution of LSCM in Shipbuilding.*

### *2.3. The Key Problems of SCPM in Shipbuilding*

The common knowledge consensus on definition, systematic method, and performance measurement of SCM in shipbuilding is not reached yet [3]; the experts and managers in shipbuilding industry prefer to use the methodologies and tools of project management to manage the processes and activities of shipbuilding [1]. Some scholars did local and fragmentary study of SCM improvement in shipbuilding, but it is seldom to use the professional knowledge of SCM to manage the supply chain in a systematic way [3, 22].

Supply chain in a shipyard focuses on the aspects of production ensuring and cost saving instead of a systematic and holistic way; the indexes used for performance measurement of supply chain in a shipyard derive from these two aspects. It is a basic and fundamental way to combine proper method, procedure, and data analysis into a performance measurement system [23], but there is no evidence and literature shown shipyard to execute SCPM in such a way. However, performance measurement shall operate and execute to dig out root causes for poor performance and improve accordingly [3].

## 3. Build SCPM Methodology by AHP-FCE Model in Shipbuilding

### *3.1. Establishment of the Weight Value for the Performance Indexes by AHP*

#### *3.1.1. AHP Model of SCPM in Shipbuilding*

Such as in most measurement and evaluation solution for SCPM in other industries, the performance measurements of SCM in shipbuilding still fall into two broad categories: effectiveness and efficiency [2]. The effectiveness of SCM in shipbuilding is to make sure the shipbuilding production effectively, namely all the raw material, component, interim products, and key machinery being ready at the specific time and with good quality; the efficiency of SCM in shipbuilding represents how fewer cost of the shipbuilding supply chain, thus less inventory, less waiting time, and less waste of production risks the supply chain caused; therefore, the performance of shipbuilding supply chain is the highest efficiency based on the effectiveness [3]. Therefore, the performance measurement AHP model of shipbuilding supply chain is as shown as figure 5 based on the shipbuilding experts' survey and previous study [3].

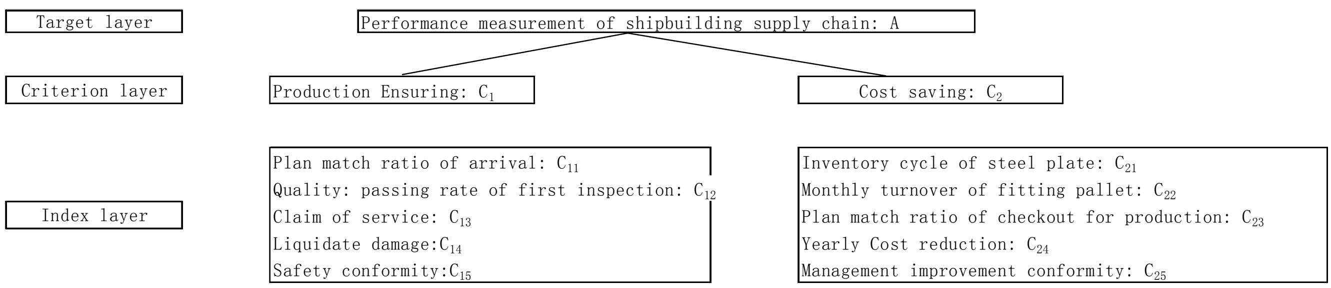


***Figure 5.*** *AHP Model Performance Measurement of Shipbuilding Supply Chain.*

#### *3.1.2. Construction of the Judgment Matrix*

The AHP method is used to justify the relative importance of each factor at the same level [14]; however, it will be some diverse judges in experts' mind when confront complex industry environment; in this paper, the judgement matrices are obtained by the survey of selected 12 shipbuilding experts' opinion on the relative importance of these supply chain factors.

On the criterion layer, there are only two factors: production ensuring $C_1$ and cost saving $C_2$; the experts reach a consensus that $C_1$ is much more important than $C_2$ and decided the relative score as 2, the weight calculation shown in table 1.

***Table 1.*** *Judge matrix and weight calculation for the criterion layer.*

| Factor | $C_1$ | $C_2$ | Weight, W |
|---|---|---|---|
| $C_1$ | 1 | 2 | 0.67 |
| $C_2$ | 0.5 | 1 | 0.33 |
| (Consistency check: $\lambda max$=2; *CI*=0; *RI*=0.58; *CR*<0.1, acceptable) | | | |

On the index layer, we set five different grades to indicate the importance of the performance indexes for each two factors in the same group, normal, slight important, important, very important, and extremely important, which are scored as 1, 3, 5, 7, and 9 in sequence as shown in table 2. The average scores are calculated and used to give the priority order of the indexes and calculate the index weight. The survey results are shown in table 3.

***Table 2.*** *Judgment matrix scales and explanation.*

| Importance level | The value of $C_{ij}$ |
|---|---|
| $C_i$, $C_j$ are equally important | 1 |
| Ci is slightly more important than Cj | 3 |
| Ci is significantly more important than Cj | 5 |
| Ci is strongly more important than Cj | 7 |
| Ci is extremely more important than Cj | 9 |
| The intermediate level of adjFCEnt judgement | 2, 4, 6, 8 |

***Table 3.*** *Survey result for importance level of indexes.*

| Survey result for importance level of indexes $C_1$ | | | | | | Survey result for importance level of indexes $C_2$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{25}$ |
| $C_{11}$ | 1.00 | 2.02 | 7.58 | 6.05 | 4.12 | $C_{21}$ | 1.00 | 2.85 | 3.84 | 7.25 | 8.75 |
| $C_{12}$ | 0.50 | 1.00 | 3.86 | 3.23 | 2.04 | $C_{22}$ | 0.35 | 1.00 | 2.08 | 3.96 | 5.84 |
| $C_{13}$ | 0.13 | 0.26 | 1.00 | 0.47 | 0.32 | $C_{23}$ | 0.26 | 0.48 | 1.00 | 2.06 | 3.75 |
| $C_{14}$ | 0.17 | 0.31 | 2.15 | 1.00 | 0.60 | $C_{24}$ | 0.14 | 0.25 | 0.49 | 1.00 | 1.82 |
| $C_{15}$ | 0.24 | 0.49 | 3.08 | 1.89 | 1.00 | $C_{25}$ | 0.11 | 0.17 | 0.27 | 0.55 | 1.00 |
| Sum | 2.03 | 4.08 | 17.67 | 12.64 | 8.08 | Sum | 1.86 | 4.75 | 7.67 | 14.82 | 21.16 |

### *3.1.3. Determination of Evaluation Weight*

By normalization method as Eq. (1), the relative weights of the factors are calculated based on survey result as shown in table 4.

$$W = \frac{A_{ij}}{\sum A_{ij}} \tag{1}$$

***Table 4.*** *Determination of judgment matrix C.*

| Determination of judgment matrix $C_1$ | | | | | | | | Determination of judgment matrix $C_2$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | weight W | AW | | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{25}$ | weight W | AW |
| $C_{11}$ | 0.49 | 0.50 | 0.43 | 0.48 | 0.51 | 0.48 | 2.46 | $C_{21}$ | 0.54 | 0.60 | 0.50 | 0.49 | 0.41 | 0.51 | 2.60 |
| $C_{12}$ | 0.24 | 0.25 | 0.22 | 0.26 | 0.25 | 0.24 | 1.24 | $C_{22}$ | 0.19 | 0.21 | 0.27 | 0.27 | 0.28 | 0.24 | 1.23 |
| $C_{13}$ | 0.06 | 0.06 | 0.06 | 0.04 | 0.04 | 0.05 | 0.26 | $C_{23}$ | 0.14 | 0.10 | 0.13 | 0.14 | 0.18 | 0.14 | 0.69 |
| $C_{14}$ | 0.08 | 0.08 | 0.12 | 0.08 | 0.07 | 0.09 | 0.44 | $C_{24}$ | 0.07 | 0.05 | 0.06 | 0.07 | 0.09 | 0.07 | 0.35 |
| $C_{15}$ | 0.12 | 0.12 | 0.17 | 0.15 | 0.12 | 0.14 | 0.70 | $C_{25}$ | 0.06 | 0.04 | 0.03 | 0.04 | 0.05 | 0.04 | 0.22 |

Combining the table 1 and table 4, the relative measurement weight for per index is shown in table 5.

***Table 5.*** *Combined Relative Weight for Factors.*

| factor | Weight for criterion layer | Index | Weight for index layer | Combined weight |
|---|---|---|---|---|
| | | $C_{11}$ | 0.48 | 0.32 |
| | | $C_{12}$ | 0.24 | 0.16 |
| *$C_1$* | 0.67 | $C_{13}$ | 0.05 | 0.03 |
| | | $C_{14}$ | 0.09 | 0.06 |
| | | $C_{15}$ | 0.14 | 0.09 |
| | | $C_{21}$ | 0.51 | 0.17 |
| | | $C_{22}$ | 0.24 | 0.08 |
| *$C_2$* | 0.33 | $C_{23}$ | 0.14 | 0.05 |
| | | $C_{24}$ | 0.07 | 0.02 |
| | | $C_{25}$ | 0.04 | 0.01 |

### *3.1.4. Consistency Check of the Judgment Matrix*

The consistency implies the rational judgement on the regard of the decision maker. The consistency measure, known as the consistency ratio (CR), is used to judge whether the judgment matrix is available and consistent (Eq. (2)), where $\lambda_{max}$ is the maximum eigenvalue (Eq. (3)) and RI is the random index based on table 6. The maximum characteristics root (CI) is used as indicator for measuring the deviation from the consistency of judgment matrix in Eq. (4) [14].

$$CR = \frac{CI}{RI} \tag{2}$$

$$\lambda max = \frac{\Sigma[AW]i}{nWi} \tag{3}$$

$$CI = \frac{\lambda max - n}{n-1} \tag{4}$$

When CR<0.1, the judgment matrix has the acceptable consistency.

***Table 6.*** *RI of the judgment matrix.*

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

The calculation results for $C_1$ and $C_2$ respectively in this paper are all positive as shown in table 7.

***Table 7.*** *The calculation results.*

| Consistency check | | $C_1$ group | $C_2$ group |
|---|---|---|---|
| $\lambda max = \Sigma[A\omega]_i / n\omega i$ | = | 5.07672 | 5.054734 |
| CI=(λ-n)/(n-1) | = | 0.01918 | 0.013683 |
| RI | = | 1.12 | 1.12 |
| CR=CI/RI | = | 0.0171 | 0.0122 |
| Result | pass | | |

### *3.2. The AHP-FCE Model of SCPM in Shipbuilding*

The comprehensive evaluation result obtained is expressed as B=W.R (Eq. (5)), where is generalized fuzzy operation; W is the matrix based on the AHP method, and R is the fuzzy evaluation matrix based on the FCE method [14]. In this paper, as calculation above, $W_1$= (0.48, 0.24, 0.05, 0.09, 0.14), $W_2$= (0.51, 0.24, 0.14, 0.07, 0.04), and W= (0.67, 0.33) as shown in table 4.

$$B = W.R = \{W1, W2, \ldots Wn\}\begin{bmatrix} R11 & R12 & \ldots & R1n \\ R21 & R22 & \ldots & R2n \\ \ldots & \ldots & \ldots & \ldots \\ Rn1 & Rn1 & \ldots & Rnn \end{bmatrix} \quad (5)$$

$$S = B * V^T \quad (6)$$

#### *3.2.1. Questionnaire Survey Process and Results*

In order to collect the information of effectiveness for these index factors, we invite 14 experts in shipbuilding and shipbuilding supply chain to fill the questionnaire; they are all experienced shipbuilding experts in which 5 from production departments, 4 working in the area of plan management, 3 supply chain managers, and 2 for cost management. The effectiveness level is set as very poor, poor, normal, good, and very good (V= 1, 2, 3, 4, 5), calculation results as shown in table 8.

***Table 8.*** *Evaluation Results of Effectiveness of Indexes.*

| Index | Very poor | Poor | Normal | Good | Very good |
|---|---|---|---|---|---|
| $C_{11}$ | 0.0000 | 0.0000 | 0.1429 | 0.5000 | 0.3571 |
| $C_{12}$ | 0.0000 | 0.0714 | 0.2143 | 0.4286 | 0.2857 |
| $C_{13}$ | 0.0000 | 0.2143 | 0.3571 | 0.4286 | 0.0000 |
| $C_{14}$ | 0.2143 | 0.2857 | 0.5000 | 0.0000 | 0.0000 |
| $C_{15}$ | 0.1429 | 0.2857 | 0.4286 | 0.1429 | 0.0000 |
| $C_{21}$ | 0.0000 | 0.0000 | 0.1429 | 0.4286 | 0.4286 |
| $C_{22}$ | 0.0000 | 0.0000 | 0.2857 | 0.4286 | 0.2857 |
| $C_{23}$ | 0.0000 | 0.0714 | 0.2143 | 0.4286 | 0.2857 |
| $C_{24}$ | 0.1429 | 0.4286 | 0.2857 | 0.1429 | 0.0000 |
| $C_{25}$ | 0.0000 | 0.5000 | 0.3571 | 0.1429 | 0.0000 |

#### *3.2.2. FCE-Based Effectiveness Evaluation*

Based on the results shown in Table 8, a secondary specific evaluation matrix is developed as below,

Evaluation matrix for the indexes of production ensuring,

$$R_1 = \begin{bmatrix} 0.0000 & 0.0000 & 0.1429 & 0.5000 & 0.3571 \\ 0.0000 & 0.0714 & 0.2143 & 0.4286 & 0.2857 \\ 0.0000 & 0.2143 & 0.3571 & 0.4286 & 0.0000 \\ 0.0000 & 0.2143 & 0.3571 & 0.4286 & 0.0000 \\ 0.2143 & 0.2857 & 0.5000 & 0.0000 & 0.0000 \end{bmatrix}$$

Evaluation matrix for the indexes of cost saving,

$$R_2 = \begin{bmatrix} 0.0000 & 0.0000 & 0.1429 & 0.4286 & 0.4286 \\ 0.0000 & 0.0000 & 0.2857 & 0.5000 & 0.2143 \\ 0.0000 & 0.0714 & 0.2857 & 0.3571 & 0.2857 \\ 0.14290 & 0.4286 & 0.2857 & 0.1429 & 0.0000 \\ 0.0000 & 0.5000 & 0.3571 & 0.1429 & 0.0000 \end{bmatrix}$$

#### *3.2.3. Fuzzy Evaluation of Index Layer*

Based on Eq. 5, calculation is shown as below,

$B_1=W_1*R_1$= (0.0382, 0.0925, 0.2416, 0.3866, 0.2411)

$B_2=W_2*R_2$= (0.0098, 0.0609, 0.2163, 0.4041, 0.3089)

Based on the maximum membership degree principle, the two aspects of measurement effectiveness for the supply chain management in shipbuilding are evaluated.

Of production ensuing aspect in criterion layer, the best effectiveness is the value of 0.3866 which in the field of "good". As S= $B*V^T$ =3.7001, the fuzzy evaluation result belongs to the area between "normal and good" and close to good.

Of cost saving aspect in criterion layer, the best effectiveness is the value of 0.4041 which in the field of "good". As S= $B*V^T$ =3.9413, the fuzzy evaluation result belongs to the area between "normal and good" and close to good.

#### *3.2.4. Fuzzy Evaluation to the Overall Performance of the System*

Based on the fuzzy evaluation results on the criterion layer, the target layer fuzzy evaluation can be carried out accordingly. The fuzzy evaluation matrix comes from the results of $B_1$ and $B_2$ as below,

$$R = \begin{bmatrix} 0.0382 & 0.0925 & 0.2416 & 0.3866 & 0.2411 \\ 0.0098 & 0.0609 & 0.2163 & 0.4041 & 0.3089 \end{bmatrix}$$

$$B = W * R = (0.0287, 0.0820, 0.2331, 0.3924, 0.2637)$$

Based on the maximum membership degree principle, the comprehensive measurement effectiveness for the supply chain management in shipbuilding is evaluated. The best effectiveness is the value of 0.3924 which in the field of "good". As S= $B*V^T$ =3.7805, the fuzzy evaluation result belongs to the area between "normal and good" and close to good.

Therefore the final result of FCE evaluation for performance measurement of shipbuilding supply chain is achieved in the field of "good" as shown in table 9.

***Table 9.*** *The results of FCE.*

| Dimension | Effectiveness | Efficiency | Total |
|---|---|---|---|
| Scores | 3.7001 | 3.9413 | 3.7805 |

## 4. Discussion

The steps of performance measurement analysis for shipbuilding supply chain includes identification of performance factors, questionnaire surveys, data collection, and calculation of the weight coefficient of evaluation indexes based on AHP, evaluation of effectiveness of these indexes based on FCE. Therefore, the joint model of AHP-FCE is achieved based on these two processes if the FCE results are positive.

The demand of SCM in a shipyard is to ensure the shipbuilding production operation going smoothly and continuously based on the lean plan system and then try to save the total cost of supply chain at the minimum. Detail factors for these two dimensions of production ensuring and cost saving are analyzed based on the real shipbuilding processes and their characteristics as shown in figure 5.

Among these factors of SCM performance in shipbuilding, the plan match ratio of arrival ($C_{11}$, 0.48) and inventory cycle of steel plate ($C_{21}$, 0.51) achieved the highest relative weight respectively, and then passing rate of first inspection ($C_{12}$, 0.24) and monthly turnover of fitting pallet ($C_{22}$, 0.24) followed. It is because all the stuff for shipbuilding should arrive at the shipyard on time otherwise will interrupt or harm the shipbuilding processes as the LSR of shipbuilding [3] and steel plate occupied the biggest part of the total supply chain cost; then defects of supply also harmed the production and fitting pallets played very important role in shipbuilding as analysis in the back ground part. Therefore, managers of SCM in shipyard shall pay much more attention and carry out detail management policies and principles on these factors.

The evaluation results of AHP-FCE model can be varied with some fluctuation in different shipyards due to their lean level of comprehensive production management and facilities resource [24]. The lean level of production management is key capacity of operation in a shipyard; it can also influence these indexes of SCM. For the shipyards with poor lean production management, the delay of design drawings can cause the postpone of supply and then impede the fabrication of ship component as well, thus, the poor plan match ratio of arrival ($C_{11}$); The poor plan match of production will cause poor performance of inventory cycle of steel plate ($C_{21}$) and monthly turnover of fitting pallet ($C_{22}$) accordingly [15]. For the shipyards with good facility resources, the inventory cycle of steel plate ($C_{21}$) and monthly turnover of fitting pallet may be not the same importance as the shipyards with not so good facilities.

# 5. Conclusion

With the AHP-FCE model and detail analysis of the nature of shipbuilding and shipbuilding supply chain, this paper establishes a performance measurement method for SCM in a shipyard based on the LSCM system operation. Then the results of performance measurement drive the system circulating for perfection when the root causes were eliminated.

This method is also applicable to performance measurement in other kind of complex industries, especially the ETO types; the detail assessment indexes shall be replaced based on the actual situation.

The final result of FCE assessment in this study as “good” means the performance measurement for shipbuilding SCM still can be further studied and improved especially with development of digital transition and lean production.

# Conflicts of Interest

The authors declare no conflict of interest.

# Acknowledgements

The authors acknowledge support from 20 shipbuilding experts who completed the survey in the research work.

# References

[1] Choe Sung Won and Lee Jong Moo et al. (2021). Development of production planning system for shipbuilding using component-based development framework. International Journal of Naval Architecture and Ocean Engineering.

[2] Handfield RB, Monczka RM, et al (2009) Sourcing and Supply Chain Management, 4th ed., Cengage Learning Asia Ltd. and Tsinghua University Press Limited, Chapters 6, 8, 16, and 19, Singapore.

[3] Chu, N., Nie, X., et al (2021) A systematic approach of lean supply chain management in shipbuilding. SN Appl. Sci. 3, 572. https://doi.org/10.1007/s42452-021-04562-z.

[4] Jagan Mohan Reddy. K, Neelakanteswara Rao, et al. (2019). A review on supply chain performance measurement systems. Procedia Manufacturing, 30 pp. 40-47.

[5] J. Thakkar, A. Kanda, et al (2009), Supply chain performance measurement framework for small and medium scale enterprises, Benchmarking An Int. J. 16 702–723.

[6] Yuniaristanto et al (2020). Performance measurement in supply chain using SCOR model in the lithium battery factory. IOP Conf. Ser.: Mater. Sci. Eng. 943 012049.

[7] I S Fauziyah et al 2020, Food production performance measurement system using halal supply chain operation reference (SCOR) model and analytical hierarchy process (AHP). IOP Conf. Ser.: Mater. Sci. Eng. 909 012074.

[8] Anjomshoae Ali et al. (2022). A systematic review of humanitarian supply chains performance measurement literature from 2007 to 2021. International Journal of Disaster Risk Reduction, 72.

[9] Haixia Pu, Kunli Luo, Shixi Zhang,(2018), Risk assessment model for different foodstuff drying methods via AHP-FCE method: A case study of “coal-burning” fluorosis area of Yunan and Guizhou Province, China, Food Chemistry, Volume 263, Pages 74-80.

[10] Ikhsan Bani Bukhori, Kuncoro Harto Widodo et al, (2015), Evaluation of Poultry Supply Chain Performance in XYZ Slaughtering House Yogyakarta Using SCOR and AHP Method, Agriculture and Agricultural Science Procedia, Volume 3, Pages 221-2252.

[11] Zeyu Zhang, Pengfei Liu et al (2021), A fuzzy comprehensive evaluation method to select the optimal mineral filler for optimization of the performance of asphalt mastics, Construction and Building Materials, Volume 298.

[12] Weiliang Wang, Chunling Dong, et al (2016), The design and implementation of risk assessment model for hazard installations based on AHP–FCE method: A case study of Nansi Lake Basin, Ecological Informatics, Volume 36, Pages 162-171.

[13] San He, Huilan Xu, et al, (2022) Risk assessment of oil and gas pipelines hot work based on AHP-FCE, Petroleum.

[14] Xinghui Zhang, et al (2018), Optimal study of the rural house heating systems employing the AHP and FCE methods, Energy, Volume 150, Pages 631-641.

[15] Chu Niansheng (2022), Cope with the Uncertainty by Systematic Improvement of Lean Supply Chain Management in Shipbuilding, Science Research. Volume 10, Issue 2, April, pp. 45-51.

[16] Chu NS (2019) Coordination in the supply chain management of a complicated EPCC projects. PMI Knowledge Shelf.

[17] Diaz R, Smith K, Landaeta R, Padovano A (2020), Shipbuilding supply chain framework and digital transformation: A project portfolios risk evaluation. Procedia Manuf 42: 173-180.

[18] Jan Sender, Steffen Klink & Wilko Flügge. (2020). Method for integrated logistics planning in shipbuilding. Procedia CIRP (C). doi: 10.1016/j.procir.2020.05.022.

[19] Tarek Fatouh, Nazaré Rego (2023), Shipbuilding Engineer-To-Order supply chain: a systematic literature review, Procedia Computer Science, Volume 219, Pages 1868-1876.

[20] Chu Niansheng, Shi Mingliang et al (2022), Concept and analysis of shipbuilding standardization ratio, Ship Standard Engineer, 55 (01): 35-37. DOI: 10.14141/j.31-1981.2022.01.006.

[21] Sharma S, Gandhi PJ (2017) Scope and impact of implementing lean principles & practices in shipbuilding. Procedia Eng 194: 232-240.

[22] Ramirez-Peña M, Abad Fraga FJ, Sánchez Sotano AJ, et al (2019) Shipbuilding 4.0 index approaching supply chain. National Library of Medicine 12 (24).

[23] Bernardin, H. John (1989). Increasing the accuracy of performance measurement: A proposed solution to erroneous attributions R. human resource planning. New York: 12 (3): 239-250.

[24] Vahid Nazari-Ghanbarloo (2020) A dynamic performance measurement system for supply chain management, International Journal of Productivity and Performance Management.