**Science Research**
2022; 10(2): 45-51
http://www.sciencepublishinggroup.com/j/sr
doi: 10.11648/j.sr.20221002.14
ISSN: 2329-0935 (Print); ISSN: 2329-0927 (Online)

# Cope with the Uncertainty by Systematic Improvement of Lean Supply Chain Management in Shipbuilding

**Chu Niansheng**

Shanghai Waigaoqiao Shipbuilding Company, Shanghai, China

**Email address:**
cns@chinasws.com

**To cite this article:**
Chu Niansheng. Cope with the Uncertainty by Systematic Improvement of Lean Supply Chain Management in Shipbuilding. *Science Research*. Vol. 10, No. 2, 2022, pp. 45-51. doi: 10.11648/j.sr.20221002.14

**Received**: March 22, 2022; **Accepted**: April 7, 2022; **Published**: April 14, 2022

**Abstract:** Based on the same author's previous study, A Systematic Approach of Lean Supply Chain Management in Shipbuilding, this paper presents further analysis on the uncertainty of supply chain management in shipbuilding, clarifies the nature of uncertainty in the supply chain of shipbuilding, and establishes a systematic improvement model of lean supply chain management to mitigate the uncertainty of supply chain in shipbuilding. It refines the systematic approach on the respect of uncertainty and radically improvement of the theory. With the cases study, it is learnt that uncertainty of the supply chain in shipbuilding forces some trivial, particular, and detailed supply to become urgent issues, especially in the later stage when the ship closes to delivery; in these cases, the solution of solving such urgent parts causes the shipyard to pay a much higher cost. Less urgent issues and uncertainty in the supply chain of shipbuilding can not only benefit the total cost of the supply chain but also the efficiency of building processes. In a systematic path, this paper analyzes the root causes of the uncertainty of the supply chain management in shipbuilding in terms of technical specification, standardization ratio, unforeseen damage and defects, and change of demand schedule. The uncertainty of supply chain management in shipbuilding can be mitigated and reduced by means of high-quality design and engineering, higher standardization ratio in the parts and fittings, and proper safety margin on schedule time. After the procedure of LSCM obtained and refined by circulation for perfection, the professional software bund with new technology devices makes digital transformation reality. In the digital LSCM system, all performance measurement results with the original data of LSCM can be calculated and shown for the management. Therefore, the uncertainty of the LSCM in shipbuilding can be easily captured and solved.

**Keywords:** Uncertainty, LSCM, Shipbuilding, Digital Transformation

## 1. Introduction

As the same author defined in the former study of lean supply chain management (LSCM) in shipbuilding, the uncertainty is one of the major characteristics of supply chain management (SCM) in shipbuilding [1]. Although the clients' demand uncertainty and the degree of satisfying the customer desires results in the uncertainty of SCM in most industries [2], there are still many different ways of uncertainty challenge the team of procurement and supply department in a shipyard. Colleagues of SCM in the shipyard often force the suppliers to manufacture a special part to wrap a damaged one day and night, and keep the workers waiting onboard so that they can mount it immediately when the certain product or component arrives the yard in order to catch the delivery date of a ship.

Sometimes the delivery of large ship valued 100 million USD is delayed caused by some minor products or components of machinery maybe cost only several dollars. People get very irritated and upset when a ship comes into the time of delivery; they worry about products or parts damaged caused by some careless operation and wrong behavior, and these new ones need to buy from a factory far away even wait several weeks to produce. The high degree uncertainty of SCM in shipbuilding is caused by its unique processes and client-based technical specification [1]. So reducing the uncertainty of the SCM and demand becomes very important in shipbuilding. From LSCM point of view, there are some possibilities to identify potential risks and mitigate the demand uncertainty in the shipbuilding processes.

The following sections of this paper present the uncertainty of SCM in shipbuilding, analyze the main reason caused such high degree uncertainty, and try to establish LSCM system to cope with the uncertainty. The achievement of LSCM proves that some of the uncertainty can be avoided or mitigated if the LSCM function properly. Based on the deep analysis, the study focuses on the functional procedure to improve the LSCM systematically with practice in shipbuilding. Finally, relationship between the previous study of the same author and this paper is clarified, and the uncertainty of SCM and related questions of this study are discussed.

## 2. The Uncertainty of SCM in Shipbuilding

The high degree uncertainty of SCM in shipbuilding is caused by the major differences from most manufacture industry for example, car manufacturing [3], and can be considered in many aspects similar to construction technology in which the product is special designed and the site itself is a resource [4] and with uncertainty in nature [5]. The processes and production flow differ from those of most manufacturing methods studied in both LSCM and SCM [1].

### *2.1. The Uncertainty in the Detail of Technical Specification*

One of the essential and unique natures of shipbuilding is that the ship or the offshore engineering product is designed, fabricated, and built during the project development stage instead of being ready before the building contract signing. In other mature manufacturing, the material, technical specifications, model, suppliers, and components are decided during the design stage; thus, the new product is trial-manufactured and tested before the real production [1, 6]. Shipbuilding does not include such trial manufacture processes and, is therefore similar to construction projects [4]. The shipbuilding is characterized by the application of project-based approaches for the building of ships and offshore products [7].

Similar to other projects in the engineering industry, ship design is divided into three different stages: basic design, detail design, and production design [8]. Saved for the requirement of the client, the shipbuilding or offshore project normally starts from the basic design stage compared with the complicated final product. The basic design outlines the major technical specification, service performance, key function, and systemic working method. Subsequently, the shipyard signs the contract with the client [6] based on the Specifications, General Arrangement Plan, and Main Structure Plan of the basic design.

Consequently, the shipyard submits the detail design drawings to both the client and the Class Society for approval after the contract becomes effective [8]. The design department of the yard carries out all necessary technical files for the shipbuilding process and each component drawing to tell how to build the ship, which called as production design, after modeling the ship via computer according to the approved detail design drawings.

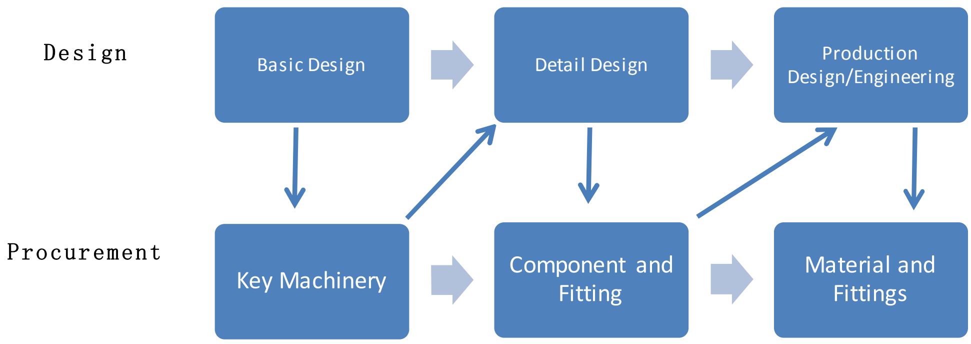


***Figure 1.*** *Design Work Flow.*

The process of design and procurement coordinate in such a way as shown in the figure 1. The key machinery and major fittings shall meet the requirement of the basic design, and the detail specifications of these machineries and standard of component and fittings also shall be input of the detail design and production design [8]. The design engineers from the shipyard will approve the design of the key machinery or give comments if any to the suppliers so that makes coordination of the whole system. The yard can finally decide the very details of raw material and fittings based on the output of production design. In order to achieve the lean building schedule and resource balanced, the shipyard fixes all relevant suppliers in advance. So all relevant parties will have uncertainty in technical specifications based on the preliminary coordination.

### *2.2. Low Standardization Ratio (LSR) Caused Uncertainty in Shipbuilding*

The application of standardized parts and standardized production makes the industrial mass manufacturing possible with the automatic production line combined by digital and automatic machinery, IT solutions, integrated mimic chart. Normally, the standardization ratio (SR) can be simplified calculation for a product as the formula below [10],

SR=Number of standardized parts /Total Number of parts of the product x 100%

In shipbuilding, there are several different definitions to define the parts [11]; hereby the quantity of parts is calculated by the minimum unit of purchasing order of SCM and not included intermediate products in the modeling processes of design and production procedure. By contrast with those of other industrial manufacturing processes, the SR of the material, components, fittings, products in shipbuilding is very low [1, 12].

Firstly, the LSR of shipbuilding is caused by high degree of customization instead of standardization. Except yachts and small ships below 5,000 tons deadweight, most ships and offshore products are not mass-produced. The number of ships with identical designs that are simultaneously or continually constructed doesn't exceed 10 in all the major shipyards worldwide [1].

Secondly, the ratio of standardized raw material is rather low. The major material in shipbuilding is the steel including plates and profile bars, thereby representing approximate 30% of the total cost of shipbuilding. Owing to the development of lean production designs, the three dimensional modelling has been used to simulate all hull structures, machinery, fittings, and major intermediate components with digital model before construction. To increase the utilization and reduce the lightweight of the ship to enable the owner to carry more cargo, the designers determine the optimal steel grade and thickness for each structure; subsequently, the demands of steel plates and profile bars are defined with precise size and grade. As the result, the steel plates and profile bars become non-standard. For example, there are 5500 types of steel plates (which correspond to 14,000 steel plates) for the construction of an FPSO unit approximately 70 thousand tons.

Furthermore, the suppliers of the fittings of piping, passageway, equipment installation, and cable tray fabricate them according to the detail drawings provided by the shipyard. The shipbuilding organization and per shipyard have established a set of standards for almost all fittings; however the standards do not support the standardized production owing to the great number of types and uncertainty demand on the quantity, size, and due date of each fitting type.

The key machinery for the engine, propulsion, deck machinery, power supply, and navigation can be standardized, however the shipyard and the client still have customized requirements in the signed technical specifications. The equipment is normally shop tested with witness of the Class Society, representatives of the yard and the client before the delivery; the installation onboard is followed by commissioning, docking and sea trial.

Based on the analysis above and estimation of typical projects, the SR of shipbuilding is approximately 20% [1]; and the weight of standardized material, components, and mechanical products is only approximately 5% in shipbuilding. This causes problems for the shipyard to prepare safety inventory to prevent the production delay in the event of a failure along the supply chain.

### *2.3. The Uncertainty Caused by Unforeseen Modification*

One of major unforeseen modifications comes from the design of a ship or offshore product. Although the process of ship design coordination as mentioned in Figure 1 is ultimately optimized to reduce the iterative work and/ or mistakes; but technically, the modifications cannot be avoid as shipbuilding of a ship is an unique project; there shall be many technical details had not been solved beforehand, so the minor or significant technical conflicts come forth caused by ignorance or negligence in the later stage and make unprepared condition of SCM in shipbuilding. For example, the alarm points shall be estimated and specified in the technical agreement when the shipyard contracts the automation system with the supplier. The designer estimated as 2500 points (2200 points demand plus 300 points spare) based on his best knowledge and project experiences, but finally it became nearly 3000 when finished all the design. Subsequently, three more alarm panels from the supplier and more space in engine room are needed to accommodate the additional panels. Therefore, one modification will bring series impacts on SCM such as to make the contract with the supplier to be updated with price and may delivery date, plan coordinate with production department, etc.

The client can also require modifications in order to make the ship more competitive in the market when they recognize some up to date technology or demand merged may help during the period ship under construction. Though both owner and the shipyard have an agreement in the contract, under such circumstances, the owner needs to compensate the shipyard loss caused by the modification. Because there are too many factors shall be taken into consideration such as cost, time, and technical consequence etc., it is not easy for the owner to decide quickly and keep the issues pending for a certain time. It adds uncertainty to SCM of shipbuilding as serval alternative solutions of fully change, partly change or no change shall be prepared synchronously.

The International Maritime Organization (IMO) and other state authorities may update relative rules on the basis of legal procedure and cause technical facility change when the ships are under construction or designed to be constructed. As most of the rules change can be foreseen, almost changes caused by Rules updated can be identified and planed considering the enforcement date of each rule during the design stage of the project. The problem often happens in the construction of sister vessels which construction last a period of time. Whether change or not often depends on the result of comparing the milestone date and the applicant date of the Rule. Subsequently, the uncertainty of SCM derives from the match of the shipbuilding schedule and the rules' enforcement and application; in such events, postpone of the schedule can also cause design and SCM modification.

Moreover, the disputes caused by misunderstanding or different understanding of the rules clause also can cause the modification of the ship system and brings uncertainty on SCM. On some technical detail, the ship designers design the system according to their understanding on the rules and the Class also approved the design drawing. Later on the class finds this unconformity, confirms it when questioned by others, even or settles as a dispute under such circumstance, the shipyard also needs to modify the design as the approval of the design doesn't exempt the shipyard's obligation of complying the rules. Most threaten cases happen at the time when the ship is to be delivered; the large ship costs tens millions USD is delayed for delivery just due to a small conductive grating or explosion-proof senses only worth several dollars.

### *2.4. The Uncertainty Caused by Unforeseen Damage or Defects*

A defective component or neglectful damage in the production especially in a later stage of shipbuilding will cause a delay and increase the cost due to the non-standard and complexity. For instance, in a leading shipyard of China, one platform supply vessel had to been brought to a dry dock; the structure was cut in the aft body and the thruster was dismounted for inspection and repairing owing to the leakage during the sea trial of the ship. This additional repair caused a loss of approximately one million RMB and delayed the delivery of the ship for nearly one month [1]. Even the discovery of steel fitting with galvanized defects during check-in inspection might delay the production of the block for at least one week; such event may delay the entire shipbuilding schedule if such the block is on the critical path.

The situation of defective parts identified in delivery state is similar cases as stated in the last paragraph of 2.3, the ship will be waiting for the alternative parts and then can be delivered. For example, the glass of bridge window is damaged caused by welding splash due to improper protection when two workers install the handrails on the bridge top just 3 days before the estimate delivery date. It needs at least one week to fabricate such glass in the supplier's shop and the maker doesn't have such inventory because the size of the window is not standard size. Consequently, the delay of the ship delivery is inevitable.

### *2.5. The Uncertainty in Schedule of Demand*

Similar with most industries, the uncertainty of SCM derives from the uncertain demand forecast [2] which is not caused by the market; the schedule change causes the demand uncertainty. The plan of the processes such as design, procurement, fabrication, construction, commissioning, and test of the shipbuilding project are specified based on the milestone that is developed and refined with the work breakdown structure [9] and based on the required duration of each step by aligning the critical path of the building process [6].

During the designed shipbuilding process, the sequence of meg-blocks (which consist of several blocks) are erected and assembled to build a ship in the dry dock. The schedule of SCM in shipbuilding can be lean with the consideration of the consequence and detail content of each block and meg-block. The raw materials, fittings for hull structure, pipes, outfitting, key components, and machinery must arrive at the shipyard and mounted onboard within the scheduled time frame [1].

The schedule of SCM for a single new building project can be precise and ultimate lean based on the breakdown structure and designated processes, the challenge comes from the balance of working load of per production department and individual project demand. Thus, in most situations the exact building schedule will be dynamic adjust according to the optimized balance between the single project plan and the production load of the shipyard, so do the SCM.

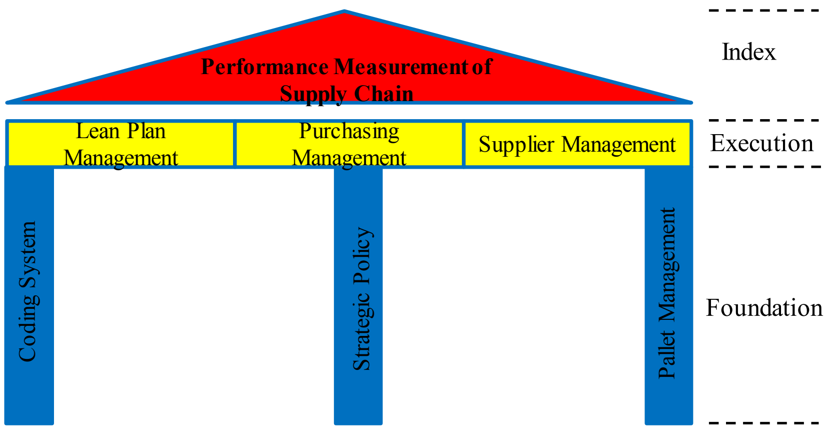


***Figure 2.*** *Frame of LSCM for Shipbuilding.*

## 3. Cope with the Uncertainty by LSCM System

As the conclusion of the same author's previous study, LSCM system is established based on seven sub-systems to integrate all detailed procedures (Figure 2 [1]) in three levels; the first called as foundation level specify the common language and constitute the foundation of the management principles, the execution level includes the operation guidelines on the lean plan, purchasing processes management and the supplier's management, and the index level represents the performance measurement which drives the improvement of the system [1].

With approach of the lean system, uncertainty of SCM in shipbuilding can be mitigated by means of optimizing in both individual process and the integrated LSCM coordinating with the design, engineering, production, commissioning, and inspection. Among these processes, lean design and engineering are most important work in LSCM of shipbuilding [6]. Moreover, the brief information and possibility of technical detail may cause modification of technical specification, size, type, and quantity of material, machinery, and fittings also benefit the supply chain preparation in some early stage.

### *3.1. High Quality Design and Engineering Eliminate Uncertainty*

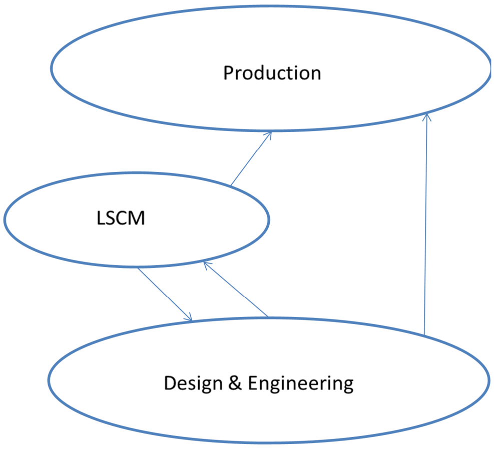


***Figure 3.*** *Logical Flow of LSCM.*

Shipbuilding is a project-based manufacturing industry, SCM derives from the design; design drives all activities in shipbuilding. As shown as Figure 3, design and engineering coordinate with SCM and output the demand of SCM. Thus, high quality design and engineering can eliminate the uncertainty of SCM in shipbuilding; actually it is really a challenge. All the root causes of uncertainty shall be identified, broken-down, taken actions in all processes of the design and engineering [8].

The foundation level of LSCM compact connects with the design and engineering of the ship or offshore products; nominate the coding system starts from engineering and covers all the life cycle of shipbuilding; the category of the commodity based on the complexity and value is defined and taken with different management solution on design and engineering stage; the intermediate parts and pallet also defined and executed in all engineering work. The big amount of input information of LSCM comes from the design and engineering work, LSCM system is also decided by the design and engineering on some aspects.

To obtain good quality design and engineering, two essential aspects shall be considered as below,

1) A qualified design team with good experience and adequate time to make the design perfect. Some leading shipyard sets standard of design process and schedule makes the design team working in order and benefits the production.
2) Deep study on the specialty of ships type. Leading shipyard worldwide forms own product list and seldom to touch the ship type not familiar with. The knowledge they studied and lesson learnt makes them into a big team of experts in this shipbuilding field, and benefits the LSCM and production with higher efficiency. Some other shipyards always jump among different ship types, confront challenges on both knowledge and experience, and cause the SCM performance poor.

### *3.2. Safety Margin of LSCM*

On the way of pursuing for lean production, some people misunderstand JIT as zero inventories which are against the essential spirit of production flow and value flow [13], to some extent, the just-in-time philosophy is yielding to a just-in-case mindset [14].

In the practice of LSCM, some uncertainty caused by unforeseen defects and schedule adjust cannot be avoid completely which is decided by the characters of shipbuilding; in this case, to set a safety margin on the schedule can give space and time to solve these problem. In the previous study [1], we conclude the priority of effectiveness for supply chain performance in shipbuilding and set the index of efficiency based on the balance of facility resource and the real performance.

Margin on the schedule shall be carefully specified based on the operation of LSCM. For example, there is about one week margin for the fitting pallet for per block as we set the turnover of pallet is 5 times [1].

### *3.3. Increase the SR in Shipbuilding*

The SR of shipbuilding can be increased by means the following two ways,

The first is to design the standard ship type with competitive performance and cost-efficiency, and collect the fixed suppliers on main machinery of the ship; thus, the shipyard can produce identified design for sister vessels. The particular parts can be borrowed from the inventory of sister vessel which is delivered lately, the waiting time for certainty spare parts can be saved. Thus, the uncertainty of supply parts will be mitigated.

The second is to increase the SR of components and parts of shipbuilding, particularly reduce the number of types and sizes of outfitting. Consequently, the manufacturers of outfitting can organize their production in a standardization way, assembly the pallet, and the ship to the shipyard. The production will be not delayed by one or two certain fittings.

There is a conflict on the lean design and cost increase caused by such the lean. Thus, to achieve more precise on one aspect without balance of total cost and efficiency is not good LSCM. The leading shipyard, Shanghai Waigaoqiao Shipbuilding Company (SWS) re-estimate the granularity of the standard for the fittings such as pipes, handrails, ladders, cable tray, etc.

## 4. Systematic Improvement of LSCM

### *4.1. Recirculation for Perfection*

The LSCM procedure can be executed step by step, as shown in Figure 4 [1]. As our practice in SWS, the seven sub-systems coordinated with the processes and management principles in the shipyard is prepared to specify detailed procedure and all staff involved are trained for execution, and then collect all operation data. Based on the performance data, the performance measurement is carried out on the two categories of effectiveness and efficiency according to the measurement model as shown in the Table 1 [1].

***Table 1.*** *Index of LSCM for Shipbuilding.*

| Category | Index | Mean Rating | Weight |
|---|---|---|---|
| Effectiveness | Plan match ratio of arrival V1 | >98% | Health index |
| | Quality: passing rate of first inspection V2 | >95% | |
| | Claim of service V3 | 0 times | |
| | Liquidate damage V4 | 0 times | |
| | Safety conformity V5 | Yes | |
| Efficiency | Inventory cycle of steel plate C1 | 55 days | 0.30 |
| | Monthly turnover of fitting pallet C2 | 3 | 0.25 |
| | Plan match ratio of checkout for production C3 | 85% | 0.25 |
| | Yearly Cost reduction C4 | 3% | 0.20 |
| | Management improvement conformity C5 | Yes | Bonus point |

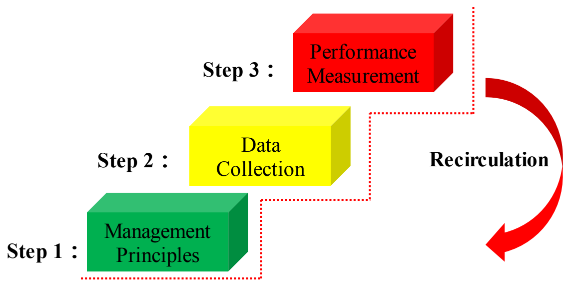


***Figure 4.*** *Execution of LSCM for Shipbuilding.*

As the spirit of Lean Thinking [13], recirculation in the current system works in two distinct ways: it improves the performance on the incremental path, particularly the Group C parameters. Afterwards, when the root cause of the poor performance has been identified, it is mitigated or eliminated on the radical path to improve and refine the system [8]. With the circulation of the LSCM, the uncertainty and its root cause can be identified and analyzed. In particularly, the margin of schedule, SR will be evaluated on the basis of total cost and efficiency.

### *4.2. Digital Transformation of LSCM*

Similar to many other industries, the digital transformation affects the SCM much in shipbuilding. As stated by Morgan Swink and Nada Sanders, a digital supply chain integrates technologies that automate and illuminate all processes including data capture, communication, analyses, decision-making, transactions, and transformations [15]. The ERP system of a shipyard enables supply chain to finish all purchasing procedures in one software from design order, suppliers selection, price decision, check-in inspection, check-out from the warehouse, and final payment to the suppliers. With the support of QR print and scan technology, all material, fitting, and intermediate product are identified, recorded, and traced with quality condition in the system, enable them flow into production line properly. Thus, the uncertainty caused by man-made fault and mistakes can be eliminated.

In SWS, design team of the shipyard can coordinate with suppliers for detail design and productions in the Suppliers System; after signing the technical specification, the suppliers submit their design drawing for yard's approval, and the designers approve it or give comments on the platform; for these suppliers to fabricate fittings according to yard's design, they also can download the drawings from the system and then report the fabrication condition on a basis of weekly.

Specialized software of LSCM will be developed based on IT technology, business procedure, and the ERP system of the company. As mentioned in the book Three-Body Intelligence Revolution and Refactoring: The Logic of Digital Transformation, the system can be designed and applied after the operation procedure has been fixed and the business model is mature [16-17]. In this system, the all performance measurement result with the original data of LSCM can be calculated and shown for the management. Therefore, the poor performance and weakness of the SCM can be easily captured, and uncertainty in LSCM can be mitigated accordingly.

## 5. Discussion

Uncertainty is a key topic and brings challenge to SCM in almost every industry. For most manufacturing, the uncertainly comes from the uncertain demand from clients and imprecise forecast of demand from market [2], moreover Dr. Lapide thinks the demand planning always deals with uncertainty of SCM [18]. As analysis above, uncertainty of SCM in shipbuilding derives from the nature of the industry instead of market. According to Aslesen and Sigmud [19], "The available literature on implementation of lean in shipbuilding environment is quite restricted due to novelty and the restriction of the concept. Lean shipbuilding is very specialized one and its application is considered to be one of the extensions beyond lean construction".

The previous study [1] presents a systematic approach includes detailed management principles and radical and incremental improvements for LSCM first time in literature. As uncertainty is a major factor of SCM in shipbuilding, in a systemic thinking [20], study and manage uncertainty well can benefit LSCM. On the other hand, the uncertainty of SCM in shipbuilding can only be coped with by improvement of LSCM and high quality design.

As smart manufacturing applicant with AI method improves decisions and processes within industrial manufacturing environment [21], digital transformation now contracts the attention of enterprises and experts. The special issue 2021 summer of Harvard Business Review focuses on the topic: How to build your digital intelligence; experts mainly talk about the ability to marshal data to make smarter decisions, to build the trust of a far-flung team, and to lead-and to withstand –change [22]. The logic of digital transformation by Xiaopeng An [17], the automatic flow of data can cope with the uncertainty of complicated manufacturing system, so the foundational engineering is the precondition of digital supply chain [23].

# 6. Conclusion

Uncertainty is the nature of shipbuilding, and can be mitigated and reduced with the systemic operation of LSCM by means of high quality design and engineering, higher SR in the parts and fittings, and proper safety margin on schedule time. The systematic improvement of LSCM can be obtained and refined by circulation for perfection on both radical and incremental path. With the circulation of the LSCM, the uncertainty and its root cause can be identified and analyzed. In particularly, the margin of schedule, SR will be evaluated on the basis of total cost and efficiency.

With the digital transformation, the e-LSCM system automates, integrates and illuminates all processes including data capture, communications, analysis, decision-making, transactions and transportation [15]; all performance measurement results with the original data of LSCM can be calculated and shown for the management. Therefore, the uncertainty of the LSCM in shipbuilding can be easily captured and solved.

# References

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

[2] Chopra S, Meindl P (2013) Supply Chain Management: Strategy, Planning, and Operation. Pearson Education ASLA Ltd and Tsinghua University Press Limited, Chapter 2.

[3] Sharma S, Gandhi PJ (2017) Scope and Impact of Implementing Lean Principles & Practices in Shipbuilding. Procedia Eng 194: 232-240.

[4] Kristoffersen S (2012) Nextship-Lean Shipbuilding, Report 1214, ISSN: 0806-0789.

[5] HUANF Baocheng (2010) On the uncertainty and coping strategies of the supply chain management in construction projects, Project Management Technology. 08 (9): 39-42.

[6] Chu NS (2019) Coordination in the Supply Chain Management of a Complicated EPCC Projects. PMI Knowledge Shelf.

[7] 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.

[8] Chu NS (2018) The Execution of FMEA in Risk Management of a Project. PMI Knowledge Shelf.

[9] Project Management Institute (PMI), Inc (2018) A Guide to the Project Management Body of Knowledge (PMBOK guide), 6th edition.

[10] Geng J, Gao P. Optimal Calculation of Product Standardization [J]. Aeronautic Standardization & Quality, 2020 (02): 12-14+35.

[11] Zhou CY (2006) Shipbuilding Modeling 2.0 of China State Shipbuilding Corporation, Beijing.

[12] Wu XF, Yue H, Shi Y, Wang J (2016) Current Status and Development Trend of Smart Manufacturing Technology and Standardization of China's Shipbuilding Industry. Ship Science and Technology 38 (09): 1-6.

[13] Womack JP, Jones DT (2003) Lean Thinking. Simon & Schuster, UK.

[14] Tyagarajan T (2021) Artificial Intelligence- the Sixth Sense for Supply Chain Risks? Harv Bus Rev Special Issue Summer: 133-143.

[15] Swink M, Sanders N (2020) Want to Build a Digital Supply Chain? Focus on Capacities, Supply Chain Manag Rev November 12-21.

[16] Hu H, Zhao M, Ning Z, et al (2016) Three-Body Intelligence Revolution, China Machine Press.

[17] An XP (2019) Refactoring: The Logic of Digital Transformation, Publishing House of Electronics Industry.

[18] Lapide L (2021). Decision-making Under Uncertainty, Supply Chain Manag Rev March/April.

[19] Sigmud A (2007) Lean Shipbuilding, Lean Construction Beyond Lean/ In EGLC-5, OSLO, Norway.

[20] Senge P (2006) The Fifth Discipline: The Art and Practice of the Learning Organization. Random House Books.

[21] Kronberger G, Bachinger F and Affenzeller M (2020) Smart Manufacturing and Continuous Improvement and Adaptation of Predictive Models [J]. Procedia Manufacturing 42: 528-531.

[22] Editors (2021) Harv Bus Rev Special Issue Summer.

[23] Walters N., Hewitt J., and Piccarreta M. (2020) what's Really Slowing Your digital Transformation? Supply Chain Manag Rev March/ April: 60-62.