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Study on PLM and Big Data Collection for the Digital Transformation of the Shipbuilding Industry

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Abstract: With the smartization and autonomous navigation of vessels through ICT (Information and Communications Technologies)—combining IoT, artificial intelligence (AI), and Big Data—changes in the shipbuilding industry will progress quickly; we must acquire superior technology and vessel quality to partake in the revamped shipbuilding industry. This paper aims to research the means of collecting and managing big data in shipbuilding to suit a variety of data types and communication methods in the shipbuilding industry, as well as ways of utilizing the aforementioned big data in order to respond to rapidly progressing changes in the industry. Additionally, the model proposed in this paper is research based on the Asian shipbuilding industry.

Keywords: shipbuilding; smart factory; PLM; Big Data collection; data link

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1. Introduction

The global population is being affected by a disaster-like impact due to changes in the global environment, and the world—serving as the infrastructure for mankind—is changing rapidly [1]. Currently, there is increasing damage occurring around the world due to changes in the climate and environment, and the damage caused by viruses such as COVID-19, diseases, hurricanes, tsunamis, and storms is increasing consistently. Such disasters have a significant impact on shipbuilding businesses, and customers are demanding or applying designs that are capable of carrying unit loads for over 100 years, instead of the past criteria of a lifespan ranging between 30 and 50 years for marine vessels and structures [1,2]. Subsequently, it can be expected that various activities will take place to minimize and prevent the damage caused by changes in the climate and environment [3].

To collect and analyze significant amounts of data from various manufacturing processes within the shipbuilding industry, the data must be collected in real time according to standardized equipment protocols such as HSMS through IO, PCS, facilities, devices, and equipment in shipyards, vessels, and manufacturing locations, and shipbuilding IoT infrastructure technology based on an SW platform is necessary to provide service functions for the control and management of data based on the results of data collection. Various standardized and non-standardized data in real time and non-real time generated throughout the life cycle of the shipbuilding industry regarding plans, order placements, designs, logistics, production, safety management, release and delivery, and post-vessel delivery management should be collected, and through the construction of a shipbuilding Big Data system—which can provide analytical and forecast functions—smart ships and smart yards must be implemented in order to achieve a digital transformation of the shipbuilding industry [4,5].

This paper will suggest a Big Data collection architecture based on PLM for the digital transformation of the shipbuilding industry and will research plans for the utilization of this architecture.

2. Related Research

The general strategy for the manufacture or production of a product involves a plan for determining its design, production, and supply by forecasting the product demand and consumer demand; this is determined based on the development and production strategy, the CODP (Customer Order Decoupling Point), and the business environment. On the other hand, the manufacturing or production strategy for the shipbuilding industry is the ETO (engineer to order) strategy. The ETO strategy consists of customer requirements and issuing RFIs and RFQs suitable for these requirements. Proposals are made according to the applicable requirements and orders are placed based on an evaluation of said proposals. Then, the design/development, facility environment, production, quality, and shipment will be executed depending on the requirements and technical specifications of the product order placed by the customer. Additionally, the automobile battery, construction, civil engineering, shipbuilding, and marine plant industries fall under the category of ETO industries. In other words, product design, quality criteria, logistics, and production will proceed according to customers' requirements, and the design, purchase of materials and parts, production, etc., take place simultaneously [6].

Additionally, the shipbuilding industry has the characteristic of having no prototypes due to the nature of the industry (one-of-a-kind products). Therefore, preliminary construction and manufacturing (production) take place before the design is complete most of the time. Due to having such a nature of manufacturing within the shipbuilding industry, there is a tendency to proceed with projects using inaccurate data regarding the purchase or production of facilities and devices or manufacturing, and the industry as a whole inherently has a lot of information that changes during design and production compared to other manufacturing industries.

Additionally, the auto and shipbuilding industries—which are the largest manufacturing industries in the world—have many differences, from the initial phase including the order placement method, product planning, and production quantity calculations to the completion phase. First of all, the auto industry is a CODP (Customer Order Decoupling Point) industry. Although the auto part industry is closer to being an ETO industry, it still remains, overall, a CODP industry that requires the forecasting of general consumer demands. On the other hand, the shipbuilding industry is an ETO industry. Additionally, the auto industry requires the systemic management of changes in options for each variant—while in general, the shipbuilding industry places much more emphasis on the management of a single project due to its nature of manufacturing a single large product at a time. Furthermore, the auto industry expands after reviewing suitable new production facilities and factories, lines, etc., following the development of a prototype, but the shipbuilding industry carries out product development and design simultaneously. In other words, the development and design of a product is directly connected to the manufacturing of the product since there is no prototype. From a mutual cooperation perspective, the auto industry has hundreds of material suppliers directly/indirectly participating in product design—which results in the close-knit sharing of product information as well as an emphasis on the management of changes following changes in the design of some materials or parts, while the shipbuilding industry places more emphasis on sharing product information between design departments [7].

Shikha Singh and Subhas Chandra Misra have studied causal factors for success after reviewing the factors for success in PLM performance in 2018. They studied the key matters required for large manufacturing companies such as marine shipbuilders to use cloud PLM in 2021, and offered a new perspective for the migration of a large manufacturing company into cloud PLM [1].

Tiago M. Fernández-Caramés [8] studied the useful IAR application programs available for, and the architecture of, industry 4.0 shipyards using PTC Windchill PLM. Meanwhile, Laszlo Horvath and Imre J. Rudas [9] analyzed the characteristics of R&D and production activities in relation to the overall product life cycle to study the role and importance of PLM in reinforcing the description and evaluation of manufacturing and other important decisions.

Laszlo Horvath and Imre J. Rudas [10] researched modeling concepts and methodologies for effective communication between engineers, current requirements, and functional/logical/physical (RFLP) abstract-based PLM models. There have been many studies on the distinct characteristics of IT in the shipbuilding industry, and Tom Costello has compared it to the IT of other manufacturing industries to study the characteristics of IT in the shipbuilding industry and plans for future directions [11]. Regarding studies on AI analysis in the shipbuilding industry, Youhee Choi et al. [12] studied objective detection based on deep learning and AI-based safety management for application in the automated monitoring method to effectively manage safety in shipyards that could be dangerous for workers. Meanwhile, regarding CAD/CAM/CAE/CIM/CAL (C5)—which is closely related to PLM in the shipbuilding industry—Burak Omer Saracoglu and Itki Gozlu [13] studied how much of an increase in efficiency occurs in order-production and manufacturing factories when C5 technology is used in the shipbuilding industry, while being managed by the traditional method.

Sehyun Myung [14] categorized the Key Performance Indicators (KPI) for shipbuilding PLM into three categories—consisting of the task review perspective, business division perspective, and corporate management perspective—and correlated the derived KPIs for possible decision making through shipbuilding PLM.

Son, Myeong-jo [15] used the E-COM derived from a PLM-based CAD design with the assumption of a particular vessel composition to calculate costs and referred to similarly constructed vessels to determine material costs, labor costs, and indirect costs—as well as researching an effective prototype for cost calculations by utilizing the MS Structured Query Language Database and E-BOM (AVEVA Marine). Gabrieal A. Burnett and D. J. Medeiros et al. [16] studied "Automating the development of shipyard manufacturing models" and researched the development of customized Flexsim Interfaces and software models for PLM data entry, as well as the possibility of improving model accuracy while simultaneously reducing model development costs. Hwan, Kim Jong and Youn-Kyoung, Joung [17] suggested a methodology and prototype system for product information exchange and integrated management, and also developed a model using ooCBD (object oriented Component-Based Development). They also defined the XML standards for BOM based on PLM services and researched a software module for the exchange of data between PDM and CAD systems from various suppliers. Junming Hou and Chong Su et al. [18] suggested a CAD methodology for design, PDM for product data management, and ERP integration for companywide resource management; he also researched a plan for the consistent revision and maintenance of the design and management model, while also improving management efficiency through integration.

Furthermore, P. Saunders [19] researched the possible collection and reuse of product knowledge through PLM, defined the importance of dimensional measurements that determine the size and shape of the product, and devised a plan for integration. Seung-Hyun Kim [20] studied the four-layer architecture model to build a PLM architecture and system that effectively reflects the nature of the shipbuilding industry, and also researched the capabilities of PLM vessel development in order to develop practical guidelines for developing vessel PLM. Yue, Weihong and Zhang, Qingying [21] analyzed all possible risks and subsequent damages from a material supply network analysis of the shipbuilding industry and researched plans and strategies for controlling them [22].

Additionally, these authors made suggestions and analyzed the form of shipbuilding logistics in consideration of the nature of modern shipbuilding technologies in "Research on the Shipbuilding Logistics System Under Modern Shipbuilding" and researched a plan for the efficient management and operation of Master Production Schedules (MPSs), Material Requirements Planning (MRP), and work site production schedules through a shipbuilding logistics management system based on MRP-II and JIT [23]. Meanwhile, Lim, Jin-Hong [24] analyzed ‘smart ship’, ‘autonomous ship’, ’marine Big Data’, ‘data integration platform’, and ‘ship Big Data’ over the course of a year and studied shipbuilding equipment Big Data integration platforms. Jeong, Ju Hyeon [24] researched a machine learning methodology for the management of shipbuilding master data and researched the application of various machine learning and deep learning algorithms for the assessment of lead time processes—utilizing data on the production, assembly, and manufacturing of vessel blocks. Stanić, Venesa [25] claimed that shipbuilding 4.0—following the trend of industry 4.0—would have a significant impact on the shipbuilding industry, and that smart ships and smart shipbuilding processes are necessary for efficiency, vessel stability, and environmental protection; she also studied the current state and direction of the shipbuilding industry.

3. Characteristics of Product Development and Design in the Shipbuilding Industry

Product development and design in the shipbuilding industry have the following characteristics [25,26]:

First, product design and development take place on-site at the shipyard—thus resulting in no local issues or the necessity of a subsequent risk diversification system. Furthermore, the industry as a whole uses the identical design program (CAD) for product design, so the requirement for criteria for and the standardization of CAD data is not as important.

Second, the shipbuilding industry’s specific designs for particular products increases depending on the building specification’s requirements rather than the initial BOM (first/initial BOM), and BOMs (bill of material) are generated sequentially according to the applicable design. In other words, the shipbuilding/vessel BOM is information that is produced based on blueprints and models, and such blueprints and models serve as the criteria for the design. Main machinery list-BOM (MML), E-BOM, P-BOM, and M-BOM are assessed according to their respective purposes; for the shipbuilding industry, BOM information is very complex, and so automatic generation of BOMs is more important than consistency between BOMs.

Third, the shipbuilding industry must define a product’s structure by considering various pieces of information, including the design, phase, production facility conditions, materials, and production environment—even if it is an identical product to one produced previously. Vessels must be identified by zones, block divisions, and systems, and a product tree must be developed with the combination of these three characteristics. Additionally, the product structure for a vessel must prioritize defining the block division, design phase, built-in system, and relationship with the WBS over a parental relationship structure. Lastly, the industry requires the definition of a product structure that simultaneously reflects block divisions, built-in system trees, and zones, and different product structures must be reflected in each design phase.

Fourth, the design process in the shipbuilding industry is executed through the three phases of basic design, detailed design, and production design, and since an identical vessel is the subject of a design—even though the design outputs may vary—the outputs generated by each phase must be connected for transition into the next phase.

Fifth, the shipbuilding design process begins and proceeds based on the customer’s requirements, and designs are changed by reflecting on the applicable requirements whenever the customer’s requirements change. This is why design, production, etc., are executed simultaneously. For example, design changes based on customer and product-part requests frequently occur, and purchase order placement begins before the entire design is complete. Additionally, multiple departments simultaneously develop a design by dividing the vessel design into the hull, built-in equipment, and facilities onboard. Due to having these characteristics in the shipbuilding industry, product information must be provided in a timely manner—at the point in time desired by the designer—and when there are design changes, the designer and other relevant personnel should immediately deliver the changes to the relevant departments and to the design personnel to prevent any inconsistencies in production and design.

Shipbuilding BOM is divided into the product structure and product information, as shown in Figure 1. The product structure is used in the phases of the basic design and detailed design and is also used in the system-based product structure and production phase, which divides a vessel into functional units. It is also used for the block-based product structure—which divides a vessel based on its production assembly sequence and is used throughout all the design and production phases—and there is also the zone-based product structure, which divides a vessel based on the location of the parts installed onboard. The product information consists of the design information, which includes technical documents and 2D/3D blueprint information generated during the design phase, material/stock forecast information—which forecasts and manages the demand for logistics, materials, equipment, and steel required for production—and the schedule information, which manages the design and production schedule. Depending on the circumstances, shipbuilding BOM can be divided into business BOM, cutting BOM, assembly BOM, POR BOM, and forecast BOM, according to its purpose.

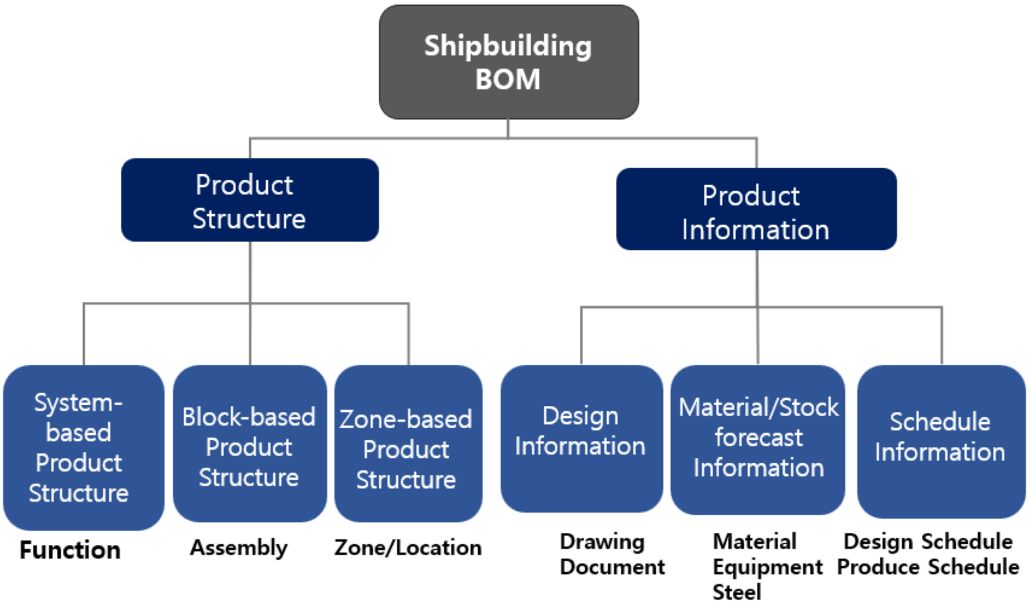

Figure 1. Shipbuilding BOM Structure.

First, the business BOM calculates estimates for major equipment and materials for the sales department. The cutting BOM is a BOM based on the cutting process and is mostly used by the production department. The assembly BOM is also mostly used by the production department and is a BOM generated according to the block assembly sequence. The purchase order request (POR) BOM is a BOM generated for purchasing materials depending on the time of the order placement, the type of order, and the customer. The forecast BOM is a BOM generated for pre-ordering materials that take a long time to be delivered as well as other major materials.

BOMs are very important in shipbuilding, but there is significant amount of data to be managed. For example, the number of parts shown in Table 1 for PLM in non-shipbuilding industries (auto, aircraft, etc.) features a number of parts below 100,000, while the shipbuilding industry PLM features a number of parts well above one million. On the other hand, for non-shipbuilding industry PLM, there is no issue in verifying and processing the validity of changes in and the management of all data throughout the system—

but for the shipbuilding industry PLM, there is much more data to be processed, and this requires a more efficient processing method.

Table 1. Manufacturing Method by Industry.

Category	Shipbuilding	Aviation	Automobile
Number of Parts (Ten Thousand)	250–1000	15–150	0.3–1
Manufacturing Method	Engineer to order (ETO)	Order production	Order production and assembly
Reuse of Information	Low	High	High
Process	Simultaneous execution of design and production	Design and assembly of a prototype	Prototype design and assembly
Key Design Information	Blueprints, BOM	OPTION, blueprints, BOM changes	OPTION, BOM, substitute part changes
System Integration	CAD and production plan	CAD, CAPP	Master Production Schedule

Additionally, due to the shipbuilding industry's nature as an ETO industry, it is difficult to define substitute parts or alternative properties. As a result, BOMs are generally edited and constructed to suit the customer's requirements based on the most similar existing vessel to the customer's order in the shipbuilding industry.

4. PLM and Big Data in the Shipbuilding Industry

The product information, manufacturing process, and supply network for the shipbuilding industry are all becoming more complex, and the material management process—including over 2.5 million parts—is complex and essential, as shown in Figure 2. Designs and customer requirements are growing and becoming more complex by the day. Due to the shipbuilding industry having such a nature, the demand for an "intelligent" platform that allows stakeholders to easily perform analyses and make decisions throughout the vessel manufacturing lifecycle—involving the quality and specifications of parts, designs, production, and customer requirements—will also grow in the future. This would be an opportunity for companies investing in in-depth machine learning to establish a foothold in the future of PLM and AI platforms; digital conversion is an essential factor for the survival of many retail companies and brands.

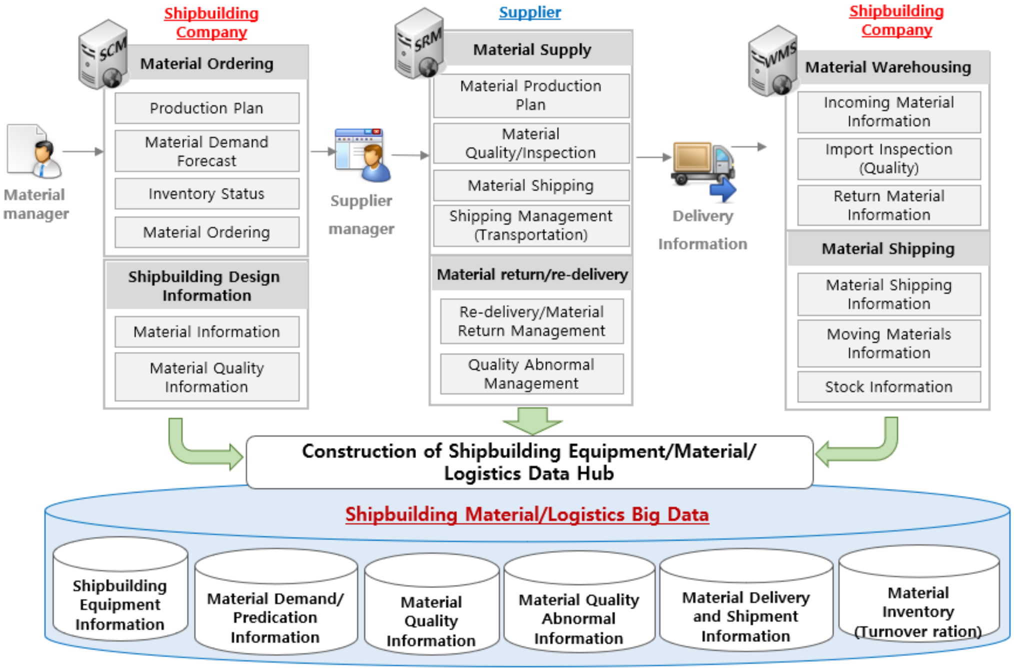

Figure 2. Marine Vessel Material Management Process.

Shipbuilding Big Data collects and stores various pieces of real-time information generated during the vessel manufacturing and inspection process, as well as non-standardized/standardized data generated during design and production within the shipbuilding industry to provide the analytical services and real-time information necessary for the shipbuilding industry. Shipbuilding Big Data collection platforms require base technology for the integration, collection, and storage of Big Data, along with technology for data communication and collection with consideration to the nature of shipyards.

Most of the information generated in PLM is standardized, but information generated on-site during vessel construction is more often non-standardized. To utilize and manage such non-standardized information, decision-making management and NLP technologies can be used together to construct a smart PLM system—although they are not exactly connected. However, smart PLM platform data consists of product attributes such as materials, specifications, and designs. The precise application of this platform relies on maintenance technology for high-quality data. Therefore, the system has very little fault tolerance, and once there is a data problem, it will cause a wide range of product distortions.

5. Big Data Collection based on PLM in the Shipbuilding Industry

Product Lifecycle Management (PLM) is a system that is referred to as one of the top three S/Ws, along with MES and ERP, that have a significant impact on manufacturing. It contains a significant amount of information, and this information comes in variety of forms including planning, design and criteria data, customer details, product disposal data, etc. Additionally, BOM data managed in PLM is managed in a layer structure, along with important design data and data related to design in shipbuilding.

PLM in the shipbuilding industry manages the project from order placement to final delivery, and it fundamentally consists of criteria information, BOM information, blueprint information, design change information, and process management; it manages the overall vessel manufacturing process information in connection with the information systems of ERP, MES, and SCM.

As shown in Figure 3, PLM manages the entire process and history from product planning to final mass production and interfaces (I/F) with various systems including ERP, MES, WMS (logistics), SCM, and QMS (quality) throughout the manufacturing industry; it inevitably involves more I/F development as more systems are developed due to the different development languages for each system, DBMS, and I/F methods.

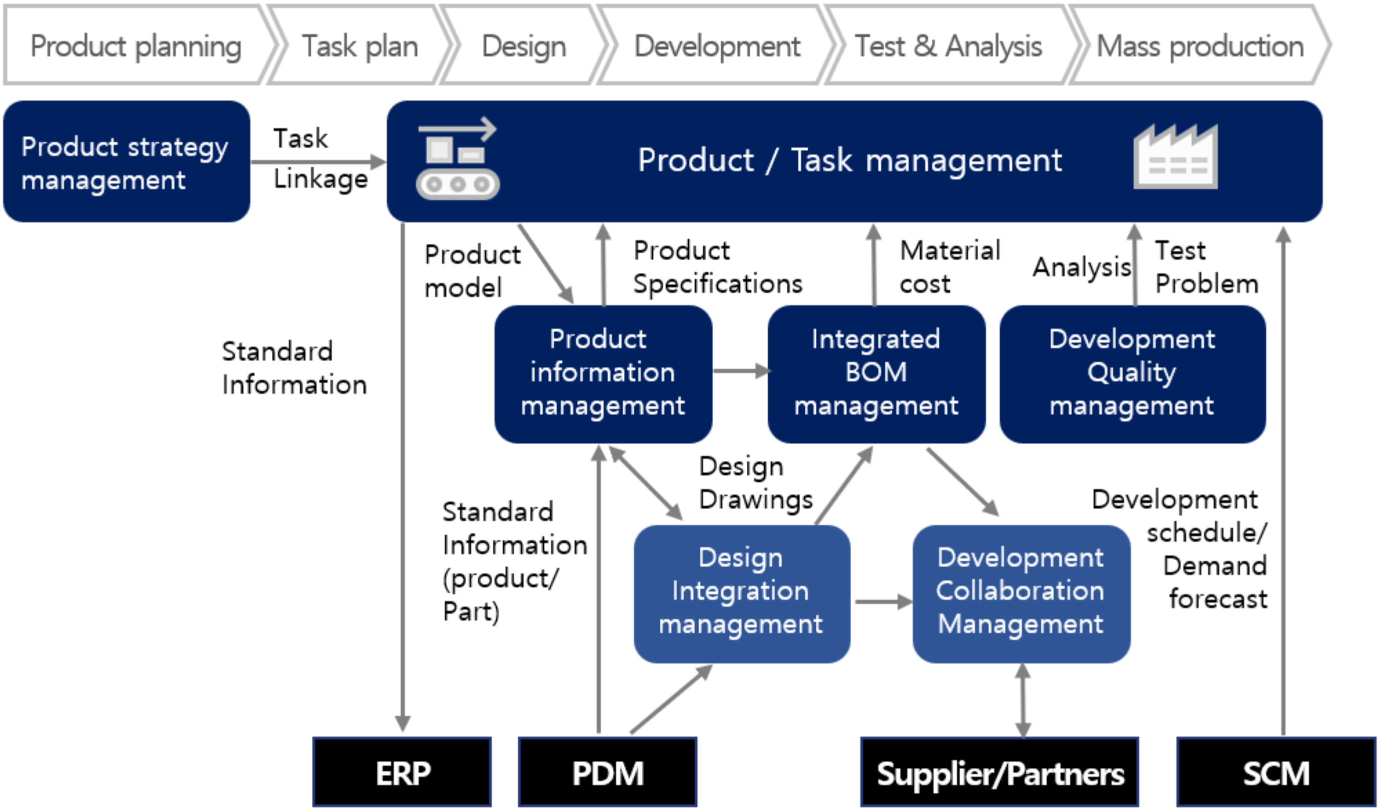

Figure 3. Composition of the PLM System Process.

PLM is connected to multiple systems, as shown in Figure 4, and is divided into the following functions: the Project Management System (PMS), which manages the vessel manufacturing project from order placement to delivery; product design management (PDM), which manages material, design change, vessel, and blueprint information; R&D management, which designs the vessel, selects materials suitable for the order, and generates BOM; requirement management, which manages changes in customer orders and requirements and reflects them in the design, and also determines whether customer's requirements are reflected in the product; and problem management, which manages various problems incurred during the vessel design and manufacturing process.

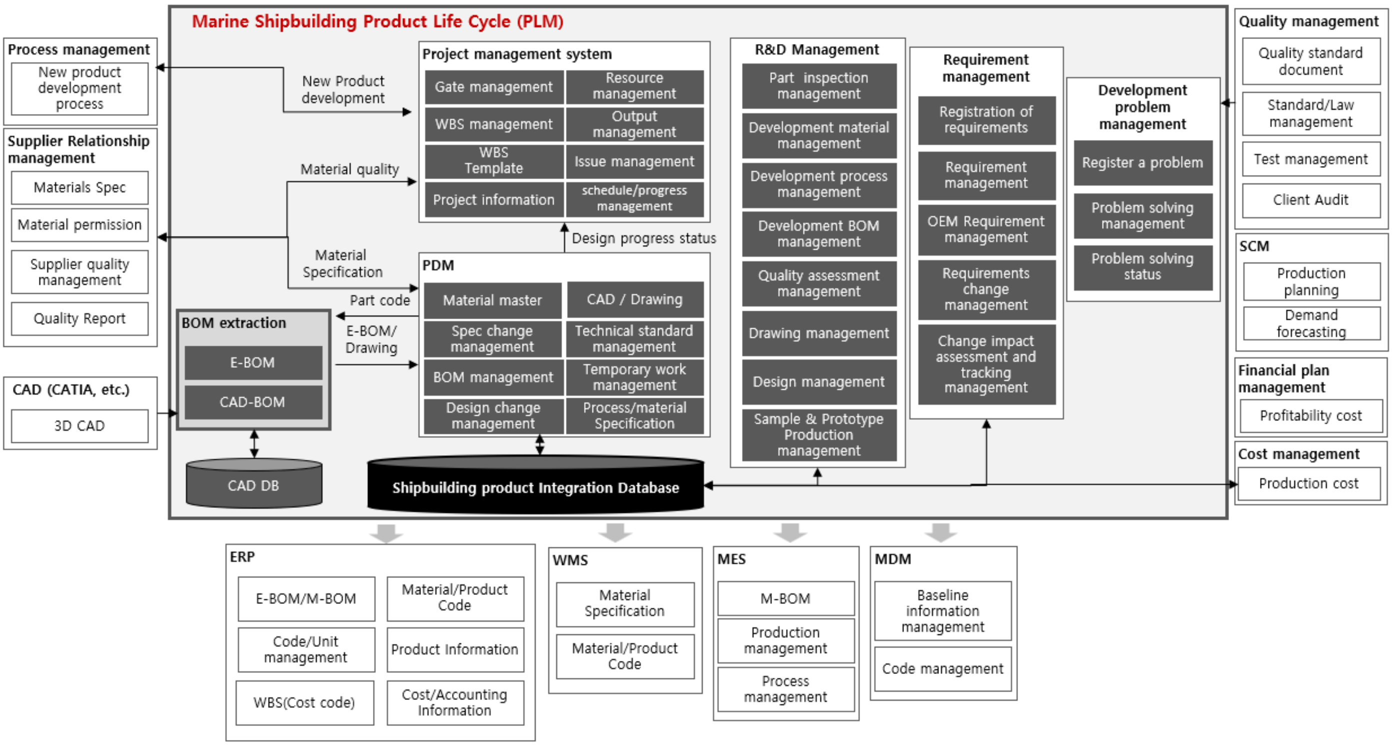

Figure 4. Composition of Product Lifecycle Management (PLM).

Additionally, each function within PLM synchronizes with various systems for CAD design, quality management, logistics management, production management, criteria information management, ERP, etc., to generate and manage data systematically.

There have been a variety of ways proposed thus far for linking PLM with other legacy systems or equipment information [27]. However, such linking is limited to specific legacy systems or protocols such as PLM or ERP for any particular model—subsequently posing difficulties in solving cases in which many different kinds of legacies and protocols are used, such as in the shipbuilding industry [28,29].

It is difficult to standardize all data due to the varying development languages, databases, and communication methods between legacy systems and the abundance of data managed by PLM. To solve this problem, PLM DATA BOX has been developed, featuring the following architecture for the management of the conversion of data between PLM and legacy systems.

Meanwhile, as shown in Figure 5, PLM DATA BOX API provides data through PLM, or—when being provided data or utilizing certain PLM screen functions—provides data through API to improve PLM system security, and utilizes PLM functions even if the relevant system does not have applicable data. If the relevant system has the applicable data, then it automatically converts the data to meet the PLM standards and transmits the data to PLM. Identical standardized data items for APIs appropriate for each language have been standardized for the standardization of data communication between numerous global plants (sites) and legacy systems, as well as to allow standardized data transmission.

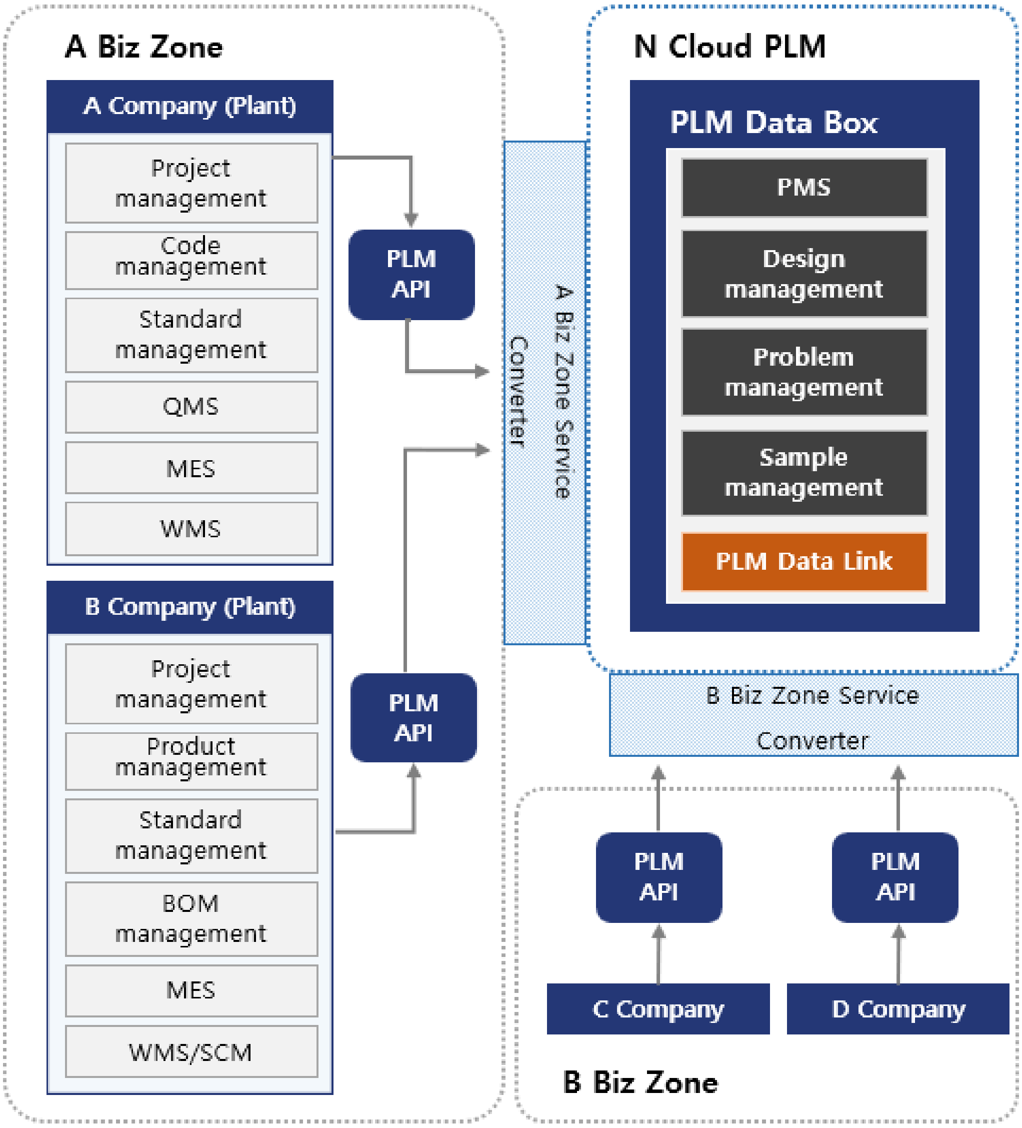

Figure 5. Composition of PLM DATA BOX API.

The advantages of PLM DATA BOX API include its being able to receive search results and the desired data after data processing, and when BOM lists and BOM details are necessary, the necessary window can be accessed through the API without having to develop a separate window. There is also no need for the accumulation and management of data in order to search for the needed windows.

PLM DATA BOX API receives data generated from a legacy system from in-bound PLM or provides data generated by PLM to out-bound PLM, as shown in Figure 6. An API suitable for the varying languages of each legacy system is provided and another API is used for communication. If a PLM DATA BOX API is used as shown above, it can synchronize legacy systems not just from a single site (factory/PLANT), but from multiple sites into a single, integrated form of data.

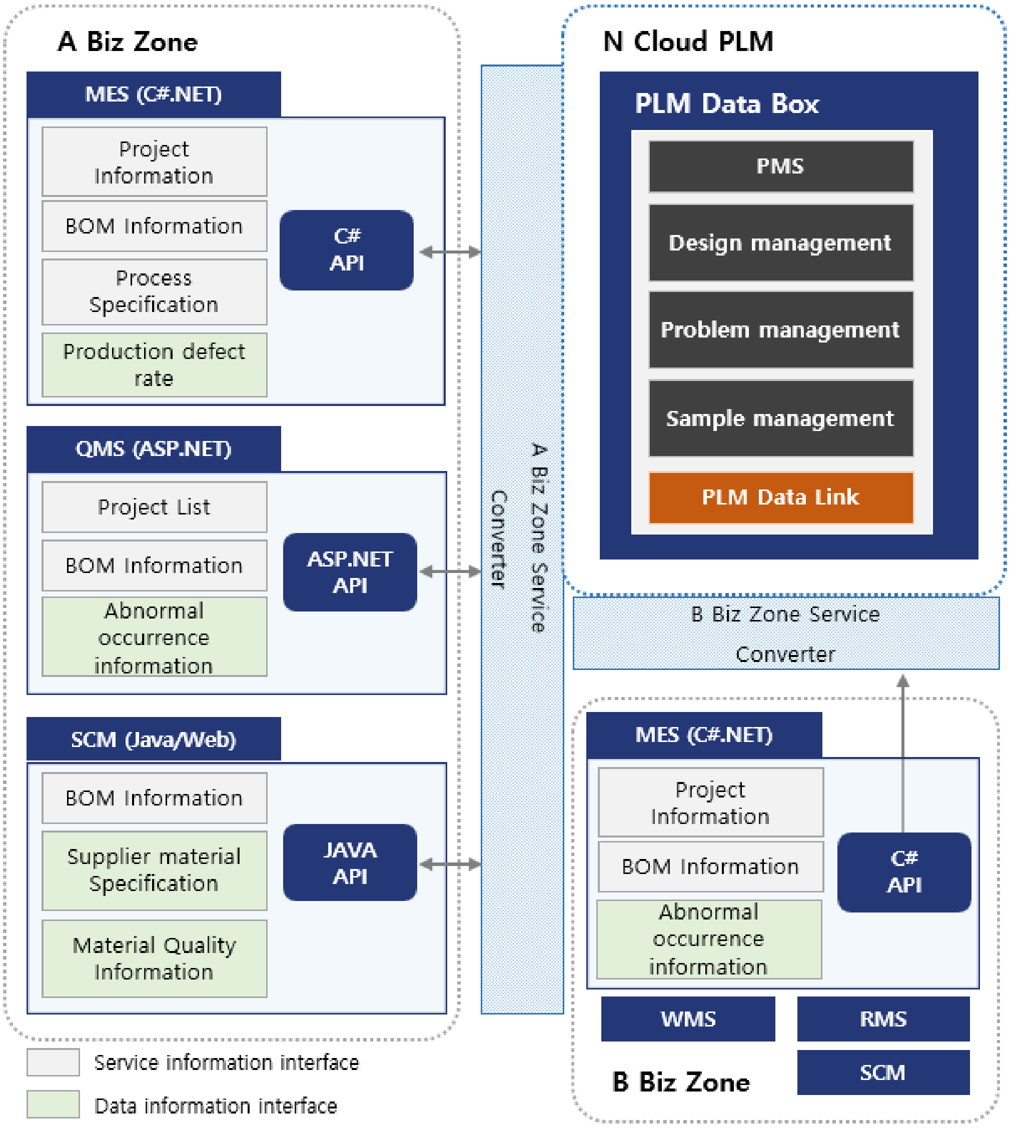

Figure 6. PLM DATA BOX In–Out Bound Interface.

Once data is compiled based on PLM, and when unification of information is achieved, this data can be utilized to collect and manage the various pieces of information related to criteria, designs, and mass production that serve as the basis for Big Data analysis.

PLM DATA BOX configures APIs to suit a particular legacy so that the data collected through PLM DATA BOX may extract diverse data, including standardized data and images extracted from RDBMS and regular texts and analog data from various pieces of equipment.

Most of the information generated in the PLM is standardized, but information generated on-site during vessel construction is more often non-standardized. To utilize and manage such non-standardized information, decision-making management and NLP technologies can be used together to construct a smart PLM system—although they are not exactly connected.

Then, the shipbuilding industry could achieve digital transformation by using machine learning and AI through the collection of PLM Big Data.

For example, information entered by a vessel designer can be used to make suggestions regarding design parameters and input, or design information can be suggested through researching types of materials and vessel designs used often by vessel designers.

Additionanlly, customer requirements and information from past designs and constructed vessels can be analyzed to suggest reusable parts and parts requiring a new design, and design information from the designer can be compared to previous design information to find and suggest ideal design information. Even when the customer places an order, information on the vessel and 3D design can be provided in advance based on the objects designed, depending on customer's requirements.

Figure 7 shows ship a Big Data hub. AI technology without Big Data is useless, so AI technology is fundamentally related to certain systems and Big Data technology, which collects and manages a significant amount of data. PLM systems collect a vast amount of input data and most of the stored data consists of product properties including materials, specifications, and designs; this is closely related to manufacturing Big Data.

However, many designs and types of PLM data are managed internally, and in order to utilize AI technology in PLM as described above, base technology to systematically manage data quality must be first developed.

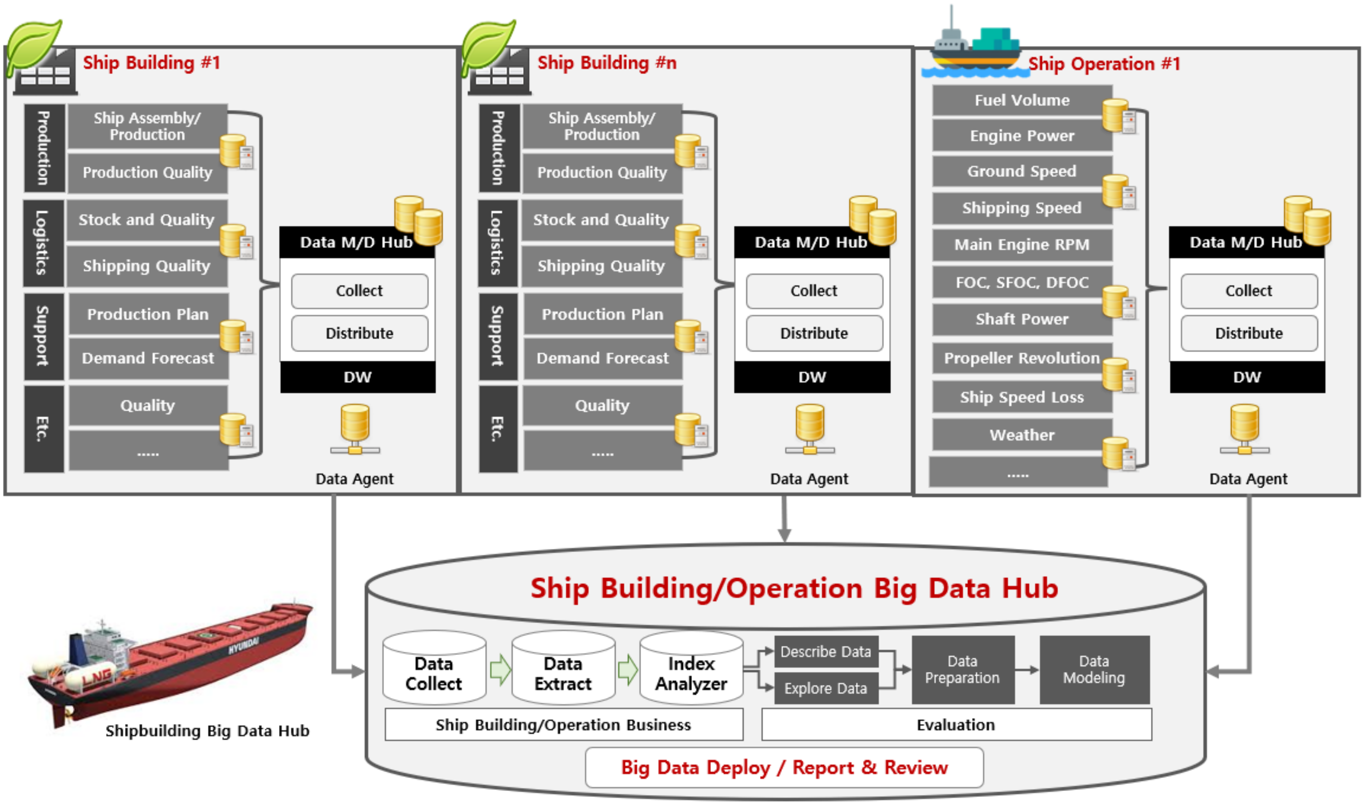

Figure 7. Ship Big Data Hub.

This research, which uses PLM DATA BOX to manage standard information and data centered on PLM, takes the form of collecting and re-interpreting data around PLM; this method differs from existing methods such as EAI and ESB that simply transmit data, as shown in Table 2.

Table 2. Comparison between PLM BOX and the existing methods EAI and ESB.

Category	EAI (Enterprise Application Integration)	ESB (Enterprise Service Bus)	PLM DATA BOX
Concept	Using Middleware (Hub) for integrated, business logic-centered connection among applications within a company	Using Middleware (BUS) for organic, service-centered connection with related systems that serve to support the service	Using API for each development language for PLM-centered linking of services and systems related to PLM
Advantage	Centralized type that integrates systems through a single point of contact; Hub System	Connecting each system through BUS; excellent expandability and flexibility	PLM-centered data management based on product lifecycle, which enables the collection and utilization of refined data
Role	Transmits and links data	Transmits and links data	Manages and distributes data in a PLM-centered manner
Disadvantage	Costs incurred when linking applications due to additional development Hub failure affecting the entire system	In need of additional development based on its connection system and of a different definition in advance of transmission; dependent on network	Additional work needed for linking in case of a system that is not linked to PLM

6. Discussion

This research was conducted by means of collecting data from various legacies and communication protocols through a method called PLM DATA BOX and, through this, Big Data collection architecture based on PLM for the digital transformation of the marine shipbuilding industry. Plans developed for the utilization of this architecture were proposed. Though this paper has proposed the means of collecting data, there may arise issues in standardization and data errors in the utilization phase after collection. To minimize such issues and to utilize high-quality data for analyses, this paper aims to research ways of resolving problems such as pre-processing, standardization, errors, etc., in data.

7. Conclusions

The global market in the era of the Fourth Industrial Revolution will feature consistently increasing demands from customers for data analysis that can provide appropriate insight into Big Data, IoT-based services, and business domains. Market demands are already growing from the simple storage and management of data into data analysis. The shipbuilding industry must also react to changes in the global market through efficiency and innovative productivity and quality and overcome physical limitations by developing new models using Big Data and AI.

The current research work was on the Asian shipbuilding industry and was conducted by means of collecting data in this industry from various legacies and communication protocols through a method called PLM DATA BOX. Through this, a Big Data collection architecture based on PLM for the digital transformation of the marine shipbuilding industry and researched plans for the utilization of this architecture were proposed.

Based on this study, we intend to research an efficient plan (ship Big Data hub) that can collect standardized and non-standardized data generated in vessel construction—as shown in Figure 7—as well as navigation data including vessel navigation along with safety, weather, and topography data from the equipment shown in Figure 8, as well as a plan for improving safety and energy efficiency in vessel navigation, utilizing the data that will be collected in the future.

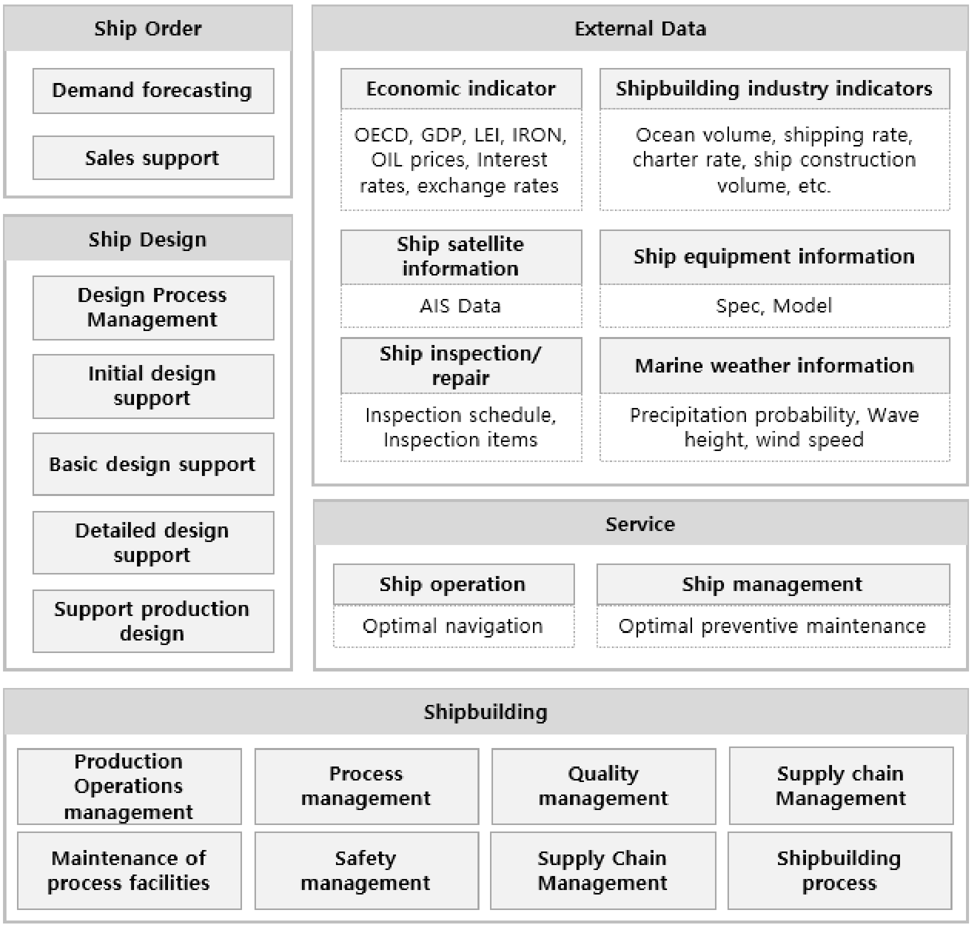

Figure 8. Big Data Model for the Shipbuilding Industry.

Though this paper has proposed a means for collecting data, there may arise issues in standardization and data errors in the utilization phase after collection. Additionally, the model proposed in this paper is based on the Asian shipbuilding industry. To minimize such issues and to obtain high-quality data for analyses, this paper aimed to research ways of resolving problems such as pre-processing, standardization, errors, etc., in data.

Additionally, the model proposed in this paper was that of an real-life researched case, as well as an initial idea model. In order to efficiently collect data in a distributed environment, future research should aim to be conducted by means of collecting grid networking big data based on smart factories through the utilization of Kafka.

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