Journal of Ship Production and Design, Vol. 34, No. 2, May 2018, pp. 168–179
http://dx.doi.org/10.5957/JSPD.170006

Shipyard Block Logistics Simulation Using Process-centric Discrete Event Simulation Method

Yong-Kuk Jeong,* **Philippe Lee,†** and **Jong Hun Woo‡**

**Department of Naval Architecture and Ocean Engineering, Seoul National University, Seoul, Korea*
†PLM Laboratory, XINNOS, Seoul, Korea
‡Department of Naval Architecture and Ocean Systems Engineering, Korea Maritime and Ocean University, Busan, Korea

In recent years, shipyards have conducted various studies to accurately investigate their production capacities and improve the accuracy of their production plans. Nevertheless, frequent delays in schedules inevitably occur at production sites. Simulation-based techniques are used in various fields to solve similar problems, especially those related to predicting loads on facilities and upgrading production planning by considering various constraints. Process-centric simulation modeling techniques are used in shipyards because the shipbuilding process has different characteristics from the general manufacturing process. Conventional resource-oriented modeling techniques are inadequate to construct a simulation model to analyze the logistical behavior of shipyards. In this study, a process-oriented simulation modeling method is applied and improved through the identification and development of additional modules needed to simulate the behavior of shipyard logistics. The core of the simulation is improved using a logistic token that can analyze the physical movement effected by each process. Moreover, such process modeling modules as the geographic information system, the route search module, and the spatial arrangement module are developed and integrated into one solution.

Keywords: shipyard; logistics; DES; process centric

1. Introduction

THE SHIPBUILDING industry in South Korea was affected by the recent global financial crisis. It has since suffered from a decline in global freight volume that has led to massive losses in all areas of commercial shipping and offshore plants since 2010. The shipbuilding industry in South Korea, especially large shipbuilders, received a large number of orders by competing in the market while reorganizing its business structure around the growth of offshore plants. This move was prompted by the flooding by Chinese shipbuilders of the local market with general merchant vessels (Fig. 1), as well as by prospects for the growing offshore plants' market due to crude oil depletion and high oil prices.

However, the industry has suffered astronomical deficits in recent years due to unexpected losses, and the three major shipbuilders in South Korea are experiencing high operating loss and debt-to-equity ratio (Fig. 2), leading to fears of insolvency. Additional losses are expected due to large backlogs in orders for offshore plants.

Despite these pessimistic stats and market prospects, it has been predicted that the shipbuilding industry in South Korea can overcome this crisis because the global shipbuilding industry has witnessed cycles of boom and bust at relatively regular intervals since the development of steel vessels. Moreover, the industry is expected to increase its competitiveness by restructuring and developing new technologies.

To overcome the current crisis in the shipping industry in Korea, the government is providing support in the form of research tasks projects. However, these are focused on the development of products and equipment. Investment to strengthen supply capabilities, such as production, logistics, and procurement, remains insufficient.

Representative ways to enhance profitability in the face of fierce competition in the worsening shipbuilding market include

Manuscript received by JSPD Committee April 3, 2017; revised manuscript received April 4, 2017.

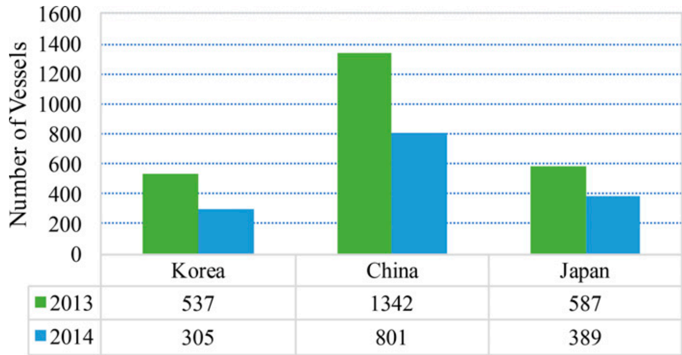

Fig. 1 Comparison of orders booked among Korea, China, and Japan

developing high-quality products and strengthening supply capacity. The smart factory strategy, which has been driven strongly by the government for several years, strengthens supply capacity. This strategy is gradually being implemented while spreading to the upper and lower supply chains of related industries, with the automobile and the electronics industries taking the lead, and is contributing to improvements in the health of the manufacturing industry. Smart factory technology, which is part of Industry 4.0 strategy (Kagermann et al. 2013), focuses on strengthening supply capacity, and is expected to become a new growth engine for the shipbuilding industry by combining information and communications technology with traditional manufacturing industries.

Research and development of factory simulation technology, which is one of the key elements of the smart factory, has been being constantly conducted for the prediction of behavior of target manufacturing system. Factory simulation technology is evolving as Cyber Physical System (CPS) nowadays (Table 1). The CPS methodology is identical to virtual and digital manufacturing basically, but focuses on a practical perspective for quick and efficient feedback concerning the results of simulations rather than on the modeling (Kagermann et al. 2013). Therefore, agile modeling and simulation, and quick feedback are emerging as the core competitive features of the simulation as opposed to features such as three dimensional (3D).

For rapid modeling and feedback, two major barriers must be resolved (Woo et al. 2017): 1) for simulation-based decision-making, a set of guidelines for a series of processes, including goal setting, identification of key performance indicators (KPIs) as a result of the simulation, identification of additional add-on components, and a requirement engineering system for KPI identification, are required. In this regard, a systematic shipyard simulation framework is proposed (Woo et al. 2017), using which a shipyard block logistics simulation system is developed in this study. 2) A flexible development environment is then needed. Many existing factory simulation studies have been conducted by using commercial simulation solutions developed by Dassault Systemes (DELMIA QUEST, http://www.3ds.com/), Siemens (Plant Simulation, www.plm.automation.siemens.com), Rockwell (Arena, https://www.arenasimulation.com/), and so on. These general-purpose commercial simulation solutions provide wide-ranging features for general simulation engineers. To implement CPS concepts, such as agile modeling and feedback, a lightweight and flexible simulation modeling environment is required. In this study, features required for the simulation of shipyard block logistics are loaded on and integrated with the ShipyardOne™ (http://s1.xinnos.com/) kernel, which was developed and distributed by Xinnos (www.xinnos.com).

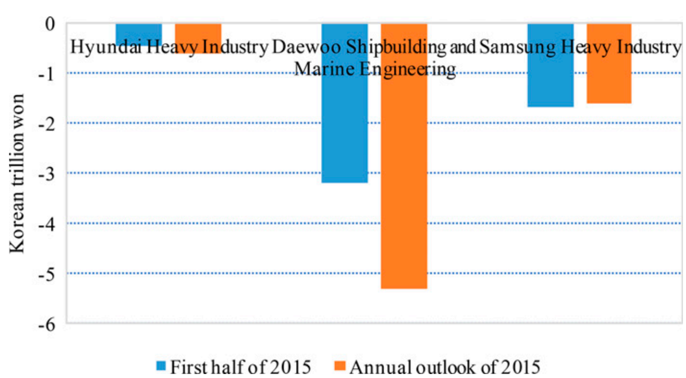

Fig. 2 Operation profit and outlook for 2015 (Foreign economy lab of the export import bank of Korea)

2. Research review

Frensberg shipyard of Germany has been conducting a research for the simulation project for application to the shop floor since 2003, and simulation toolkit for shipbuilding was developed. There came out a practice for the fabrication process (Kaarsemaker & Nienhuis 2006) and one for the block assembly process planning system (Steinhauer & Meyer-Konig 2006). Also, there are several papers those presented simulation research with shipbuilding case (Mclean & Shao 2001; Steinhauer 2003; Ljubenkov et al. 2008). These researches have their own significance in focusing on the advancement of planning and prediction capability with the factory simulation to the actual ship production planning apart from traditional simulation approach in ivory tower.

Meanwhile, biggest and most complex shipyards such as Hyundai, Samsung, or Daewoo are in Korea at present. So, latest significant researches about shipbuilding are being announced and published in Korea. So, research review is going to be focused on Korean shipbuilding industry during the last 15-year period.

The first case of shipyard simulation research using an advanced concept of digital manufacturing in Korea was "Integrated Digital Shipbuilding Technology for Development of High Value-added Ship" (Project no. 00,016,038), which was carried out from 2001 to 2004 with the support of the Ministry of Trade, Industry, and Energy of South Korea (Lamb et al. 2006, Han et al. 2008; Hwang et al. 2010; Lee et al. 2007, 2009). In this project, with Samsung Heavy Industries Co., Ltd. as the target shipyard designated by Seoul National University, digital models were constructed for all processes of the shipyard using 3D kinematic simulation and discrete event simulation (DES) software DELMIA QUEST (Dassault Systemes of Paris/France). For the panel line, fabrication factory, and outdoor-yard production processes, a system was developed to interact with the production management operations of the shipyard. This project was highly significant because it was the first to present the direction of research in advanced digital shipyards of the future by establishing digital models for all relevant processes derived from the various use cases.

The next shipyard simulation project was "Simulation-based Production Technology for Ships and Offshore Plants" (Project no. 10,035,331), from 2010 to 2015. It targeted Hanjin Heavy Industry

Table 1 Changes in DES trend

	Computer simulation	Virtual factory	Digital factory	Smart factory
Period (year ± 5)	"60–"85	"85–"95	"95–"10	"10–"current
Significance	Modeling using computer	3D virtual modeling	Virtualization of information	Feedback from simulation model to real manufacturing system
Focus	Focus on scenario-based what-if simulation	Focus on maximization of physical visibility through the 3D modeling of real factory	Focus on operational information by simulation rather than 3D virtualization	Focus on agile feedback from simulation model to real manufacturing system before the problem is recognized
Object	Investigation of production index (throughput, utilization, WIP, etc.) based on various simulation scenarios	Transition of real manufacturing system into virtual model using 3D Computer Aided Design and digital mock-up technology	Same as early stages in "60–"85 (scenario-based simulation)	To secure management competency by agile decision-making system based on simulation, which originated from the concept of the digital factory
		Minimization of physical rework by preventing interference and collision among physical entities	The difference is hardware and software enhancement, which allows simulation engineers to extend the scope and detail of modeling	Prompt action with respect to simulation requirements and consideration of given status of target manufacturing system through monitoring is crucial
Keyword	What if	3D	Digital	Cyber Physical System

and Construction Co. Ltd., and was supervised by the Korea Research Institute of Ships and Ocean Engineering (KRISO, formerly MOERI) (Heo et al. 2013; Hwang 2013; Lee et al. 2014b; Ruy et al. 2015). The goal of this project was the localization of simulation kernels, which constitute the basis of simulations, to acquire source technology related to the production simulation. Through this project, simulation kernels were developed for crane lifting, process planning around quays based on a geographic information system (GIS), transporter logistics, and shipbuilding planning validation. On the basis of these kernels, applications required for the workshops of Hanjin Heavy Industry and Construction Co., Ltd. were developed and applied. However, many shipyards were unable to participate in this project due to the sudden depression in the shipbuilding business. Hanjin, the only participating shipyard, could not invest much effort and interest in the research and development of this project for the same reason.

A recently launched national research project in the shipbuilding area by the government of South Korea is "Development of Simulation-based Production Management System for Middle-sized Shipbuilding Companies" (Project no. 10,050,495). This project is intended to strengthen supply management competency and production management competency of middle-sized shipbuilding companies in South Korea that have been struggling to survive since 2010. The goal of this project is to establish a DES system that can be used to develop shipbuilding APS (advanced planning and scheduling) for planning and to verify the plans. The DES part involves upgrading features and systems based on kernels developed in the shipbuilding planning validation simulation of the Project no. 10,035,331.

Other notable projects (those are related above projects) conducted to meet the needs of shipyards include a study on the simulation of production plan verification for the block assembly process (Lee et al. 2012), a study on the development of a simulation module for the construction of an integrated logistics control system for shipyards (Woo et al. 2010), and a study on the design of simulation-based assembly factory design and finite capacity production planning (Song et al. 2009).

3. Research target

In this study, a shipyard block logistics simulation system is developed to improve the mid- to long-term block logistics of D Shipbuilding Company in South Korea. The block logistics at the shipyard encompass a series of processes, including the transportation of blocks to the stockyard using transporters between outdoor processes and subsequent processes. There are limitations on the number of transporters that can be used for logistics movement and the area of the stockyard where the blocks are stacked, which act as constraints. In this paper, we propose a technology to analyze the logistics generated in the shipbuilding process by using simulations based on a DES. Figure 3 shows a flow diagram of the shipyard block logistics researched in this study.

4. Logistics module added to process-centric DES kernel

To perform the simulation, a modeling process that accurately simulates real objects must be available. It has been reported that due to its nature, process-centric modeling is more appropriate for shipbuilding management than resource-oriented modeling (Lee et al. 2014a). ShipyardOne™, which is the developmental basis of this study, features a process-centric modeling environment. This modeling methodology offers the advantage of simulating the shipbuilding process based on the plan activities, but has a limitation whereby it cannot define the logistics between activities because it is modeled according to activities defined in the production planning stage. Therefore, to define and simulate the logistics of blocks, additional features must be developed to

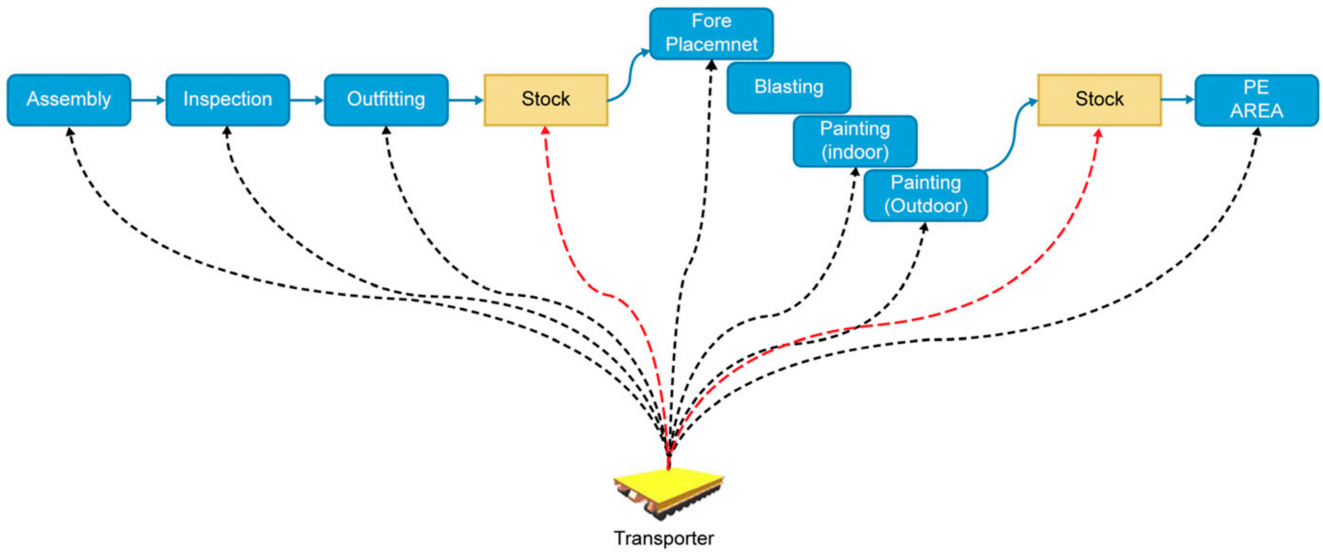

Fig. 3 Coverage of shipyard block logistics simulation

allow the definition of logistics in the existing process-centric modeling methodology.

4.1. Process-centric modeling

In manufacturing, where most processes are produced by a flow, such as in the automobile and the electronic industries, the locations of facilities and the workers are fixed and products follow a predefined route. In the case of a factory where production occurs in this way, once the location of the facility is determined, its facility and routes of products remain largely unchanged thereafter. Therefore, it is appropriate to create a simulation model based on the facility. Commercial software applications that, such as DELMIA QUEST and Plant Simulation of Siemens, are generally used for production simulation are based on resource-oriented modeling.

However, products produced in the shipyard are not uniform in form and size, and their moving routes are not fixed. Therefore, the process-centric modeling method is appropriate for simulating the shipbuilding process; our research team has been studying this topic (Back et al. 2016). The key to this process-centric modeling method is to create processes, rather than resources, where each process in the method is composed of five detailed logics—approval, stock, process, transition, and delivery—as shown in Fig. 4. Furthermore, this method allows the expression of process constraints in terms of products and facilities.

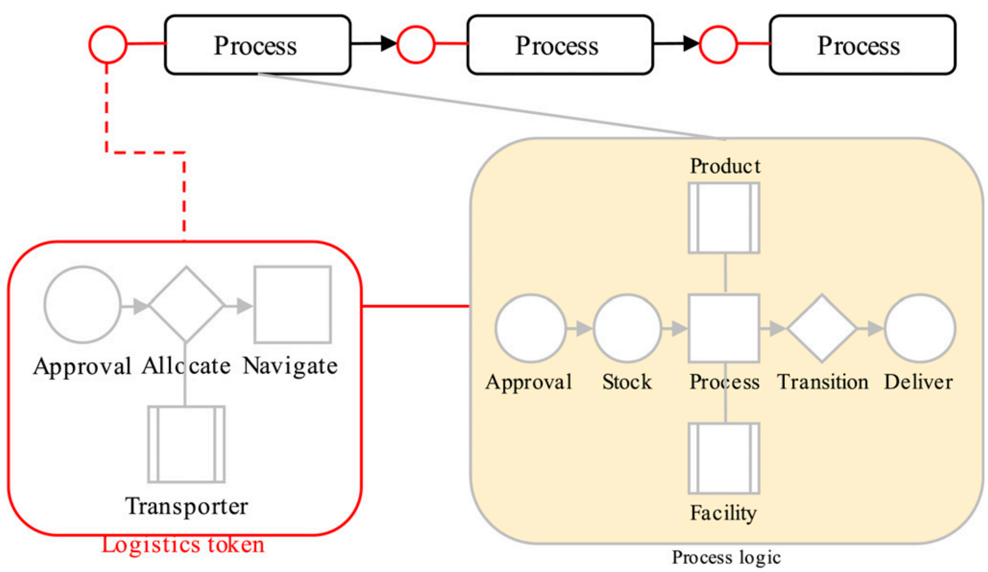

Fig. 4 Improvement in process-centric modeling method for logistics (left: basic process-centric model scheme; right: advanced process-centric model scheme with logistics token)

4.2. Extension of process-centric modeling to logistics

The process-centric modeling method has been researched for use in shipyard simulations through application to the midterm schedule verification of shipyards, loading simulations, and other applications (Jeong et al. 2016). However, in the block logistics simulation in shipyards, which is the subject of this study, there is a limitation in expressing the simulation model only using the existing modeling method. In this study, therefore, we extended the existing modeling method and added a logistics token to define logistical phenomena as shown in Fig. 4.

In this study, block logistics in the shipyard are defined as the process flow and the movement of blocks between processes defined in the production plan. In general, the production plan for a shipyard consists of schedules for value-added production processes, such as assembly, painting, outfitting, and erection, but does not include the flow of such logistics as the movement of blocks and stocking on the stockyard. Therefore, to execute the block logistics simulation, expressions for the movement and stocking of blocks must be added to the existing modeling method, and each step must be specified in detail and expressed as a logistic. For the sake of implementation, this feature is expressed as a logistics token, and approval, allocate, and navigate are set up as detailed logistics logics.

The logistics logic implemented in the logistics token verifies whether it is possible to execute the logic in the given logistics situation through the "approval" step, which checks whether the logic is executable, as shown in Fig. 4. If the logistics is executable, the "allocate" step, which allocates transporters required for the logistics, is executed. If there are several candidate transporters, the transporter logic, a logic which determines rate, is used. Once the transporter is allocated, the "navigate" logic is applied to move the products to the factory. If the target factory is a temporary stockyard, the logistics logic is executed again after a certain time. If the products have been moved to a factory where it is possible to work, the process logic is used.

5. Module development

5.1. KPI identification

In this study, we aim to identify the results of the simulation such that they can be verified through block logistics simulation by referring to a preliminary study on a comprehensive framework for simulation-based production management of shipyards (Woo et al. 2017), where series of processes was proposed to derive KPIs using a performance pyramid and a value driver tree. In this paper, the KPI areas to be derived were classified using the performance pyramid proposed by Woo et al. (2017) and the management items through interviews with field workers. By choosing the four areas of delivery, work in process (WIP), time, and cost, and excluding customer area, and the utilization items calculated by time and WIP shown in Table 2, the appropriate indices for logistics analysis were selected. For example, in the case of WIP, it must

Table 2 Identified KPIs for shipyard block logistics simulation

Category	KPI	Description
Delivery	Timely supply rate to the following process (timely support quantity, deviation of delay date, etc.)	The delivery time is not for the final product, but refers to the relationship between the preceding and following processes for semifinished goods Timely supply rate of members/blocks between processes considering logistic flow
WIP	Block stocking quantity (workshop + stockyard), time series stocking status by stockyard (quantity, occupancy area, etc.)	Assess the impact of the plan on the operational strategy scenario for the stockyard (adjustment of the available stock of the stockyard)
Time	Time series lead time for process sequence by block, and quantitative time required for auxiliary work in the logistics part	It is possible to establish a plan by performing a simulation with only duration and precedence information, ignoring the start/finish time from the aspect of strategic review. Furthermore, we can examine the possibility of improving the existing plan by comparing the plan established through the simulation with the reference schedule.
Cost	Logistics cost (Transporter operation cost = transporter utilization rate×movement distance (loading/unloading division), stockyard operation cost = stockyard occupancy rate×stockyard occupation cost)	It is possible to predict changes in the preexisting process time series for indirect cost (auxiliary work) through logistics simulation.
Utilization (WIP/time)	Area occupied by workshop or stockyard, programming ratio (operating ratio) of transformer, load on the road	In block logistics, the target of resource analysis can be divided into transporter, space (workshop/stockyard), and road. The efficiency of the workshop is determined by the production plan, but the load on the workshop can also be observed from the viewpoint of logistics simulation. The schedule compliance rate (e.g., ±5 compared to the plan) can be determined by the timely supply rate to the following process depending on the operation of the stockyard or transporter, if the logistics activity relative to the standard plan is considered.

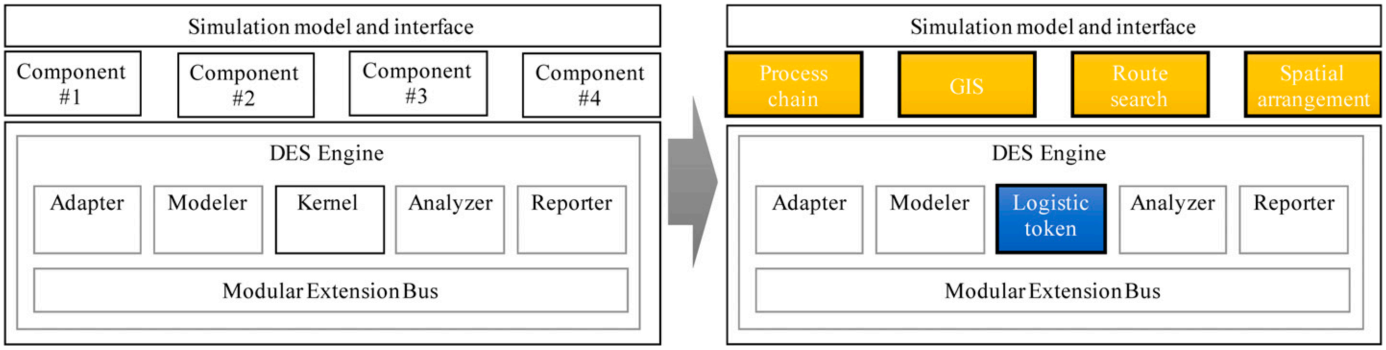

Fig. 5 Configuration of additional modules of ShipyardOne™

be possible to verify the number of blocks in process for the entire shipyard and those in process at the workshop or the stockyard by a time series. In the utilization area, it must be possible to verify not only the area occupancy of the workshop and stockyard, but also the index of the transporter carrying the blocks and the frequency of use of main roads. In this case, WIP is used not only to represent this number, but also the frequency of movement of the transporter or that of use of the road.

5.2. Module identification

As analyzed in the previous section, functional elements are required in addition to the basic modeling environment of ShipyardOne™ to derive a target KPI. The development environment of ShipyardOne™ is flexible so as to be customized easily (Fig. 5) (Woo et al. 2017). Logistical tokens that should be reflected at the kernel level are shown in Fig. 5. Furthermore, four additional modules are needed in the case of features required by KPI analysis. As shown in Fig. 6, we must develop a process modeling module that can identify the logistical process by the input of a reference schedule, a GIS module for obtaining the physical location and road information of the workshop or stockyard in the yard space, a route search module for searching a route and between points, and a spatial arrangement module for determining the arrangement of the stockyard space. Finally, an integration step capable of shipyard block logistics simulation is performed by mounting these modules on the DES kernel.

5.3. Process modeling module

As mentioned earlier, the shipyard block logistics simulation system constructed in this study defines the model required for simulation by transforming shipyard planning data and geographical information. These shipyard planning data are used to identify and define the logistical process, which requires a series of processing steps. The production plans in the shipbuilding industry have a hierarchical structure according to the period and degree of detail of the plan (Nam et al. 2016). In this study, based on the master production plan in shipyards, we identified the logistical process by using a production plan in the work package unit, which allows the identification of the start and the end dates of each activity. The production plan data classified by activity were redefined based on the products, and the logistics process chain was defined by identifying the activities in which the logistics actually occurred. The logistics process chain refers to the identification and definition of only activities that occur in the production process of each product. It is possible to define an integrated logistic process chain by identifying and combining situations where the same logistical process occurs even if the products are different. This process is illustrated in Fig. 7.

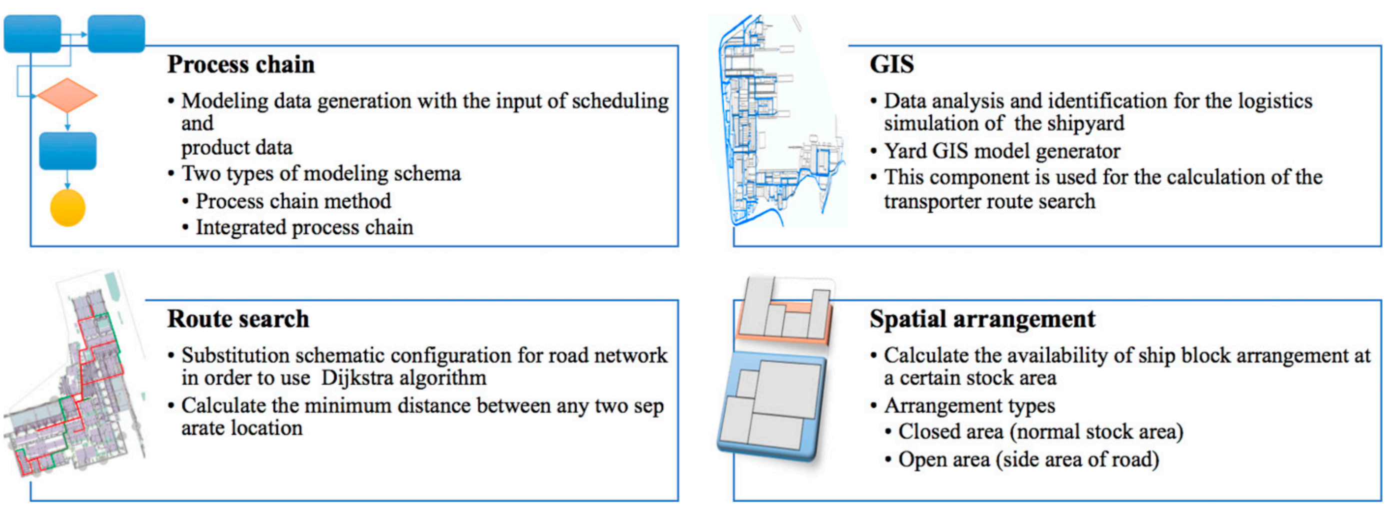

Fig. 6 Development of additional modules for shipyard block logistic simulation

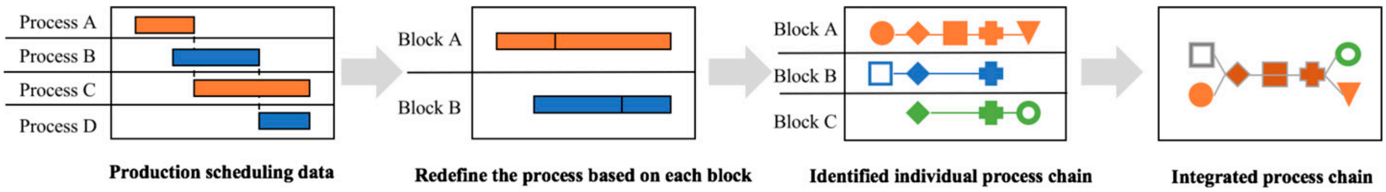

Fig. 7 Generation of logistics process chain by master production plan

The logistics simulation process model generated from the master production plan is shown in Fig. 12. The user interface of ShipyardOne™ consists of a product list, a factory list, attribute information, a process model, and a process chain list. The product list contains products generated from the data conversion process. The factory list is a tree structure consisting of factory models and facilities assigned to the factor models created through the GIS conversion module. The process model is where the logistic process chain is identified through the process shown in Fig. 7. In this model, the configuration and precedence relations of detailed processes and their attributes can be controlled. The process chain list includes the logistical processes selected for the given model, and shows the names for managing the process chain and the percentage of products that follow the process chain. The list of process chains is a kind of process mining output that provides insights for analyzing the logistical characteristics of the master production plan in the presimulation stage.

5.4. GIS module for logistics simulation

The shipyard GIS data of the shipyard are a de facto standard (Esri 2012). To analyze the logistical flow by using the movement of transporters, additional attributes and a hierarchy are required in addition to the standard attributes. The GIS module developed in this study plays the function of converting GIS data managed by the shipyard for use in ShipyardOne™. The logistics simulation is carried out using information concerning workstage and stock, size and shape, location, roads on which transporters move, and so on, which is automatically converted by the GIS module. GIS module loads the map information of target shipyard as input, and generates the hierarchical shipyard geographic model, space information for each working area, and stock area.

For this purpose, a schema for the structure of spatial information was defined as shown in Fig. 8, and a function for creating a GIS model for the shipyard block logistics simulation was developed according to this schema. The structure of spatial information is designed to store area, location, and road information. The area element was defined so that information concerning the working and stock area. The road element was defined so that road information can be saved, on which such transportation facilities as transporters can move. Finally, the location element in the schema was defined to represent a point with a specific role within the yard. For example, the place where the transporter is waiting may be expressed as a point indicating a specific location. Thus, location is defined such that point information can be stored under the location to represent a point.

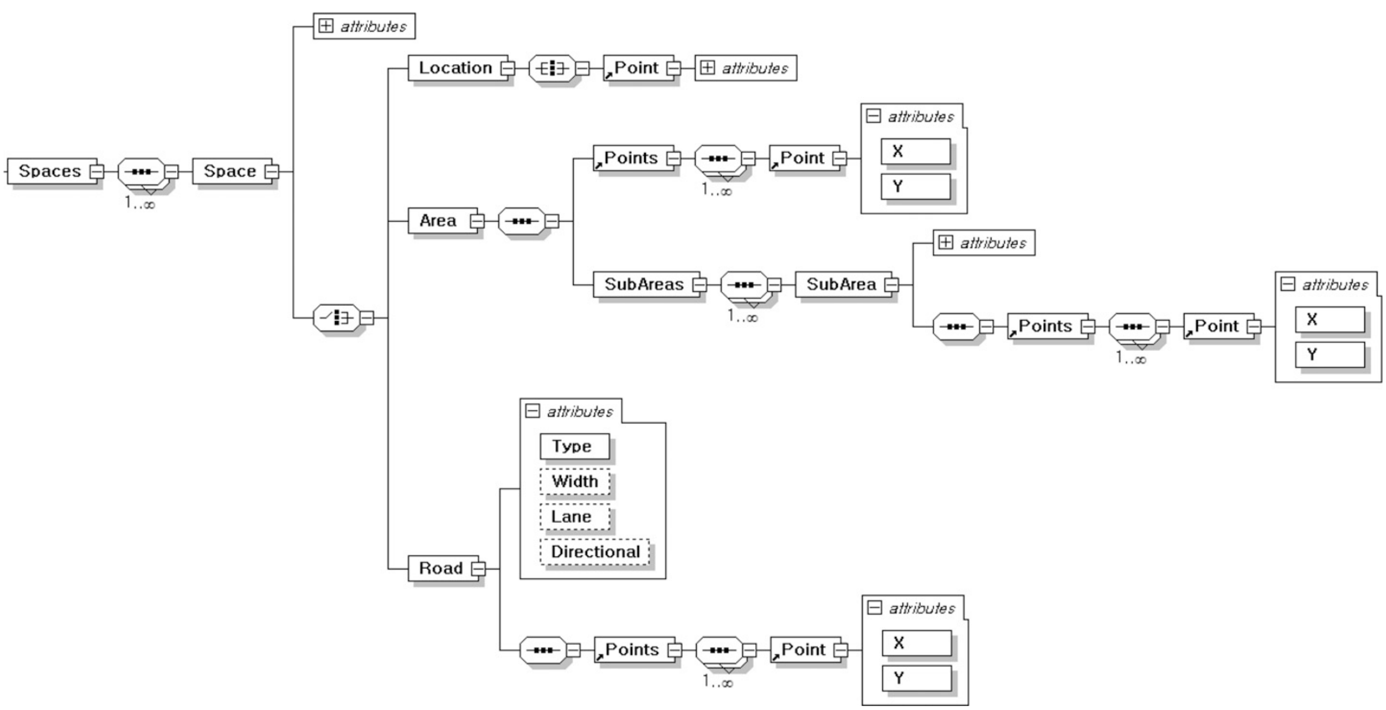

Fig. 8 Schema for spatial information structures

5.5. Route search module

In this study, an algorithm developed by Moon et al. (2016) is used to find the optimum route for transporters. In the study, the authors claimed and verified that the Dijkstra algorithm is the best algorithm for finding the shortest route in real time. In this study, we applied the algorithm and, to this end, the spatial information of the shipyard was transformed into graphical notation, as shown in Fig. 9, to calculate the shortest route between any pair of nodes. However, the route search algorithm was simplified by moving through the shortest route without considering the case where a different route must be searched, since a specific location cannot always be passed when moving a transporter.

5.6. Spatial arrangement module

The spatial arrangement module is called during the execution of the simulation. It is used when determining whether a product can be arranged in a space (workshop or stockyard), when deciding the actual arrangement location, and when delivering the product from the located space. As shown in Fig. 10, two types of arrangement algorithms have been implemented according to arrangement type, and can be divided into closed area and opened area arrangements.

The closed area arrangement type arranges blocks in multiple rows. It is applied to relatively large stockyards, and location is determined by a bottom-left-fill algorithm, which fills the lower and left sides of the space first (Chazelle, 1983). On the other hand, the opened area arrangement type arranges blocks in a single row, and is often applied to stockyards located along roadsides. In this case, the arrangement algorithm is constructed by judging whether to overlap only along the width of the relevant ship block.

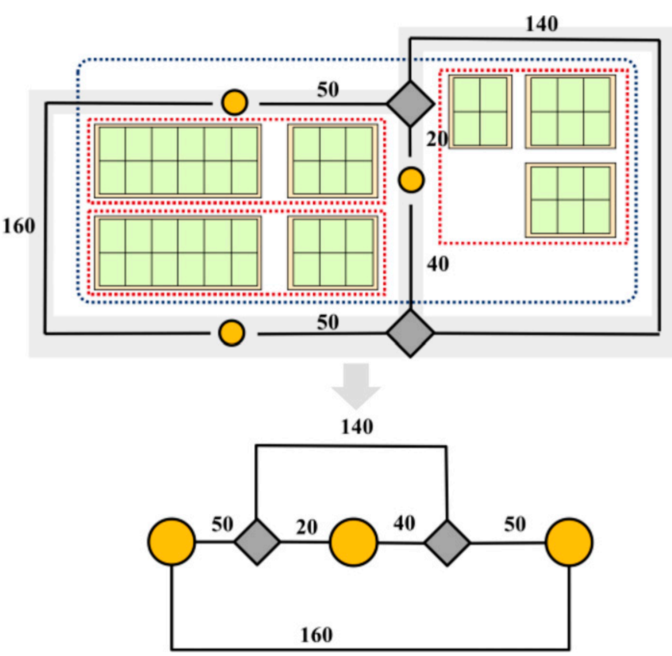

Fig. 9 Graphical notation transformed from spatial information of shipyard

6. Integrated logistics simulation

ShipyardOne™ not only includes the DES kernel feature mentioned earlier, but is also used for the easy development and integration of modules for various functions. Of the four modules described earlier, the process modeling and the GIS modules function as adapters for data conversion, and the route search and spatial arrangement modules are called and used in real time during the execution of the simulation.

6.1. Use cases of the simulation modeling module

The process modeling and GIS modules are simulation modelers that implement functionality through a data adapter. The process modeling module contains a function to generate a process chain for each route by analyzing the master production plan. The GIS module generates the geographical model of a hierarchical shipyard, containing such information as lot number and road, by using a geographical model of the shipyard as input.

6.2. Simulation use cases of the simulation executing module

The route search and spatial arrangement modules communicate directly with the simulation kernel during the simulation. They are called and used when searching for the route of a transporter, or arranging blocks at the workshop or stockyard during the simulation. To apply these modules to the simulation, the logistics and route searching logics must be set in advance. If the corresponding module is prepared, the route search and spatial arrangement can be checked in the logic selection screen, as shown in Fig. 11. These features are used by calling the functions defined in each module during the creation of the detailed process logics.

6.3. Operation of shipyard block logistics simulation system

Once the shipyard block logistics simulation system is defined as shown in Fig. 12, the block logistics simulation is executed through a series of processes when a block is inserted according to the master production plan, and the results of this process are recorded in a log file. As shown in Fig. 13, when the blocks defined in the plan are entered, the process corresponding to the simulation date is carried out first. In Fig. 13, the painting process is illustrated as the first process. When this process is completed, the logistics token is called and a transporter that can transfer the block is searched. For the search condition, we first consider the weight of the block and then search for an available transporter. When a transporter is selected, the route is searched using the positions of the preceding and following processes as inputs. If the workshop corresponding to the following process is available and

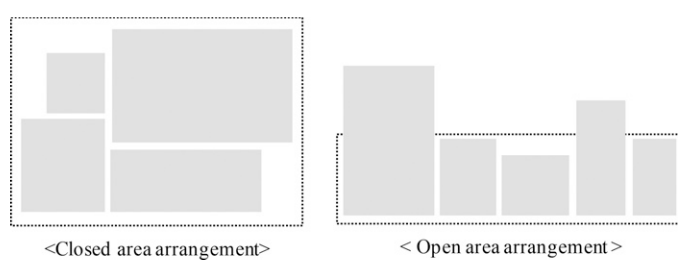

Fig. 10 Arrangement types of closed and opened areas

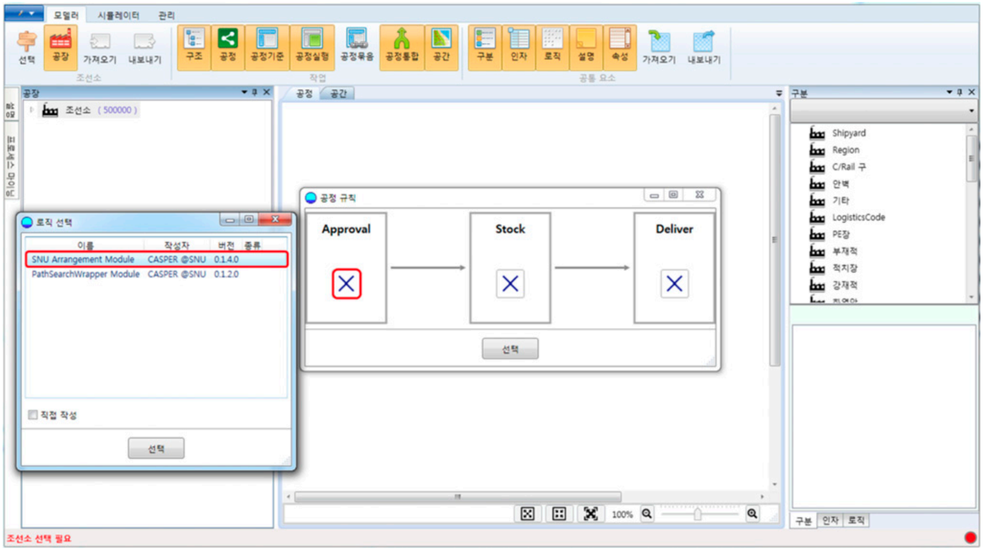

Fig. 11 Route search and spatial arrangement module integration method

matches the date on the plan, the next workshop is selected directly. If the start date of the following process is further ahead in time than 3 days from the given day, an available stockyard is searched and allocated. At this time, the route search function is called. In case the following location is a stockyard, whether the products are stocked is determined based on the possibility of the spatial arrangement. If it is not possible to stock the products in the stockyard, the process of selecting the stockyard with the next highest priority is carried out. The blocks that have been stocked are then taken out and moved to the corresponding workshop on the next workday.

The simulation is carried out by repeatedly applying the earlier process to all corresponding blocks. All events during the simulation process are recorded as logs with such attributes as product, process, location, time, and resources.

7. Report module of the simulation system

The report module of the block logistics simulation system is divided into product, process, facility, space, worker, and schedule attributes based on the six-factor shipyard information model constituting the shipbuilding system, as shown in Fig. 14. The result recorded in the simulation system was reinterpreted from the viewpoint of each factor so that it could be checked. In the simulation system, the results of simulations were recorded based on schedule, facilities, factories, and products. The results for the number of blocks of each working area are shown in Fig. 15. Figure 16 shows the raw data of results in terms of schedule, product, space, and facility.

Figure 17 shows the difference between the simulation result and the field record in terms of the total number of blocks in the yard.

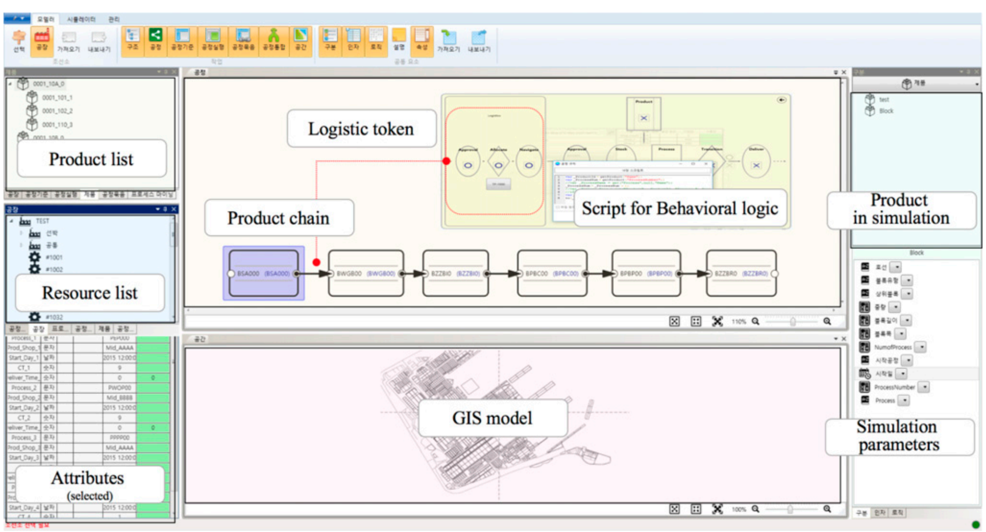

Fig. 12 Configuration of shipyard block logistics simulation system

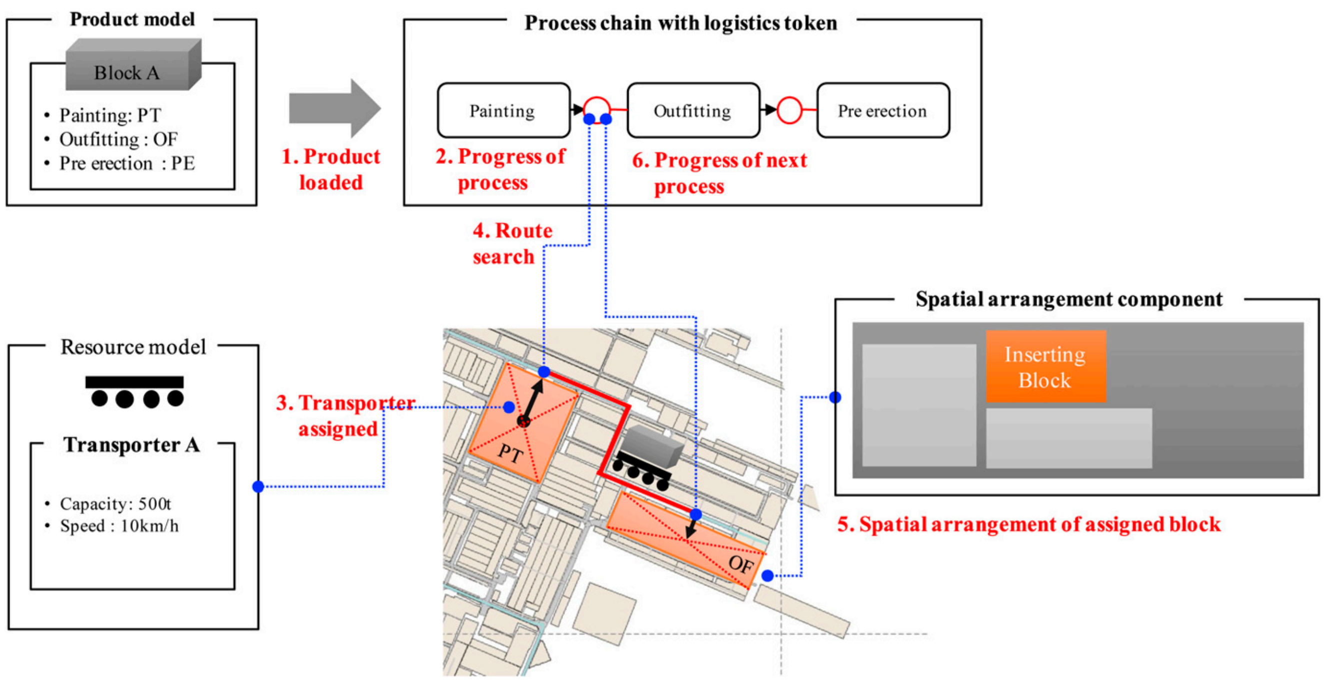

Fig. 13 Operation of shipyard block logistic simulation system

The gap between the simulation and the actual field was due to the outsourcing block. The outsourcing of a block to another constructor was not considered in the simulation model. The gap of approximately 10% between the simulation and the actual field data were due to the outsourcing of blocks. The outsourcing of blocks was not considered in the simulation model. However, this discrepancy corresponded with planned block outsourcing. Hence, the overall behavior of our simulation model was normal. Detailed validation, including the movement of each transporter, daily working load of each shop, and stock, is currently underway.

8. Conclusions

In this study, we investigated simulations to actualize CPS, which is part of the industry 4.0 strategy, to strengthen the internal competitiveness of shipyards. The production activities include value-added processes such as processing and assembly, and nonvalue-added processes such as logistics. The shipbuilding industry is facing difficulties in logistics management, which is a nonvalue-added process. In particular, the industry needs preemptive forecasting for the production plan because the fluctuation in

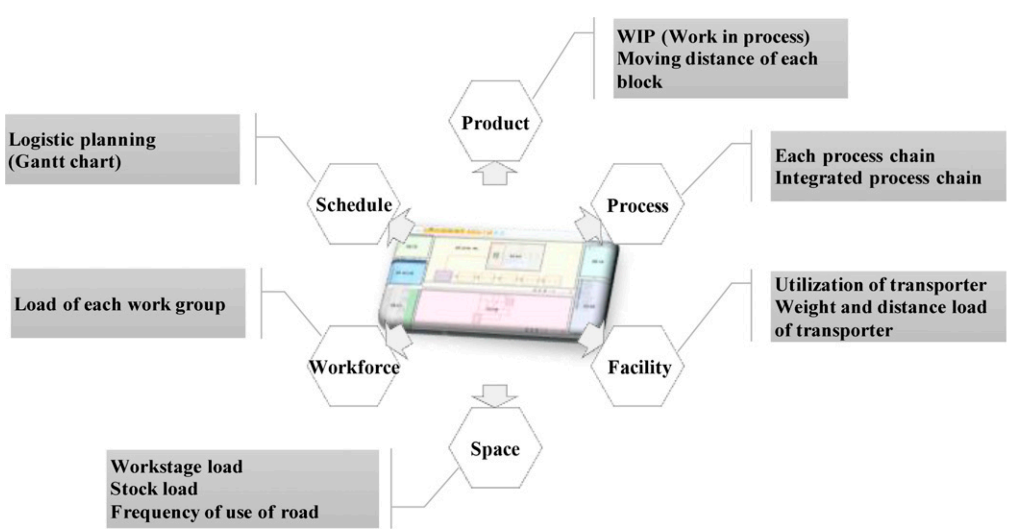

Fig. 14 Six-factor shipyard information model corresponding to the results of block logistics simulation

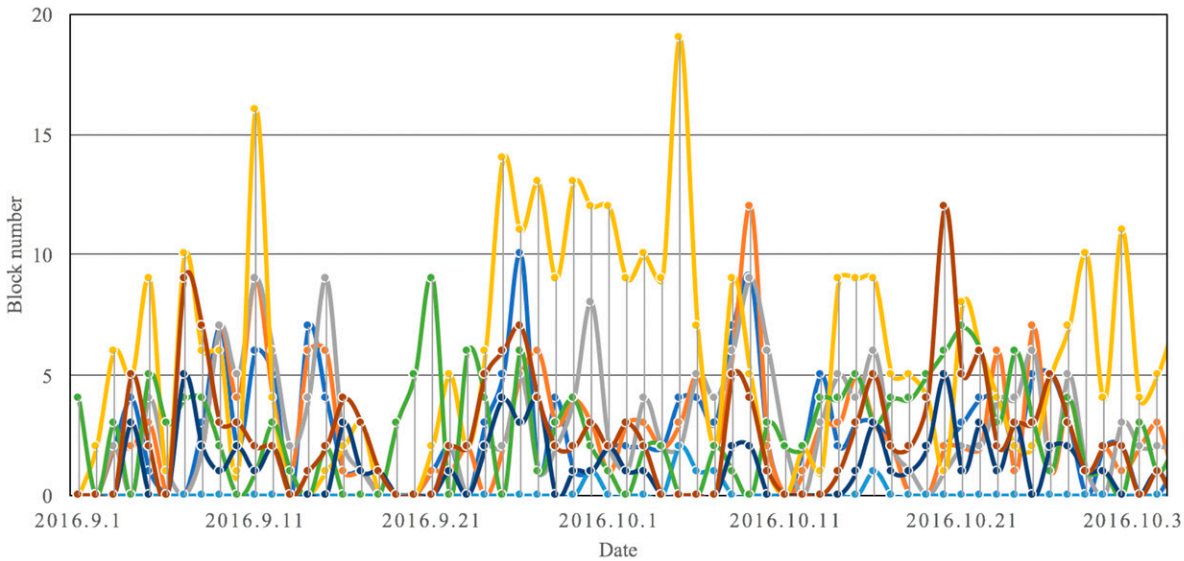

Fig. 15 Number of stock of each area (period: September 9, 2016 to November 10, 2016)

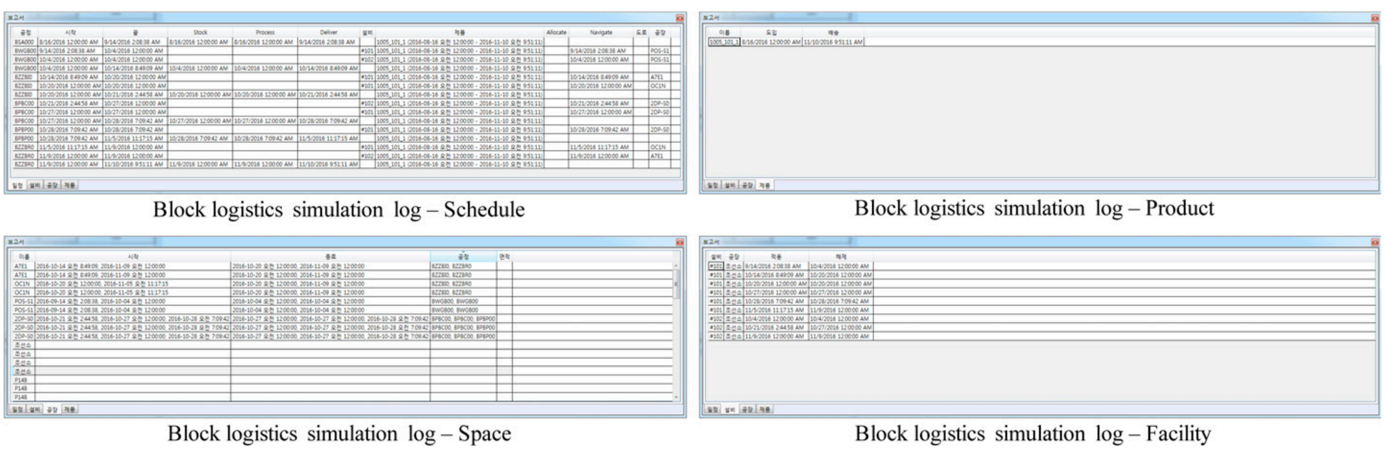

Fig. 16 Number of transporter call-outs within the given period

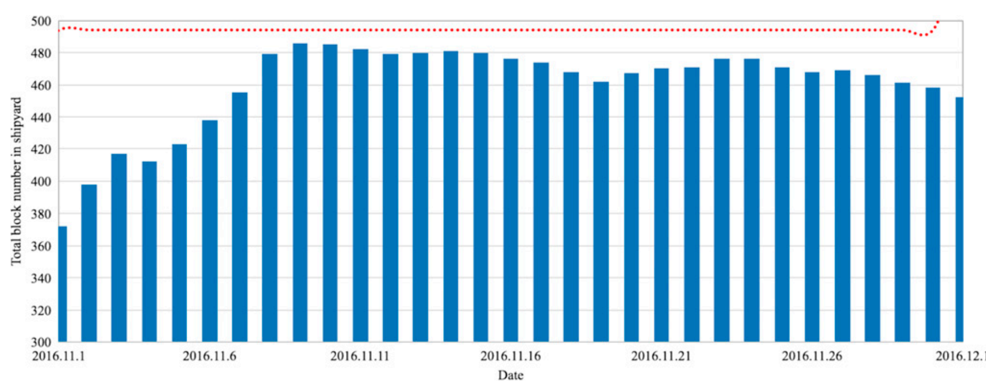

Fig. 17 Validation by comparison with the field record (bar: Simulation results for total number of blocks; red dotted line: field record)

logistics management is large due to changes in the internal and external environments.

To predict the behavior of shipyard block logistics, a block logistics process modeling function, a shipyard geographic modeling function, a shortest route search function, and a spatial arrangement function based on the DES kernel were developed as independent modules and loaded into the self-developed ShipyardOne™ kernel. In this way, we developed a system capable of simulating block logistics for shipyards.

We are now in the process of validating the effectiveness of the simulation results through comparison with the actual number of shipments and transportation performance from real shipyard and production plan data. We are also developing a feature to visualize the results for users by analyzing log files to improve the capacity of shipyard block logistics management.

Acknowledgments

This research is a result of a project ("Development of the Simulation-based Production Management System for Middle-sized Shipbuilding Companies," No. 10050495) supported by the Industry Core Technology Development Business of the Ministry of Trade, Industry and Energy (www.motie.go.kr). The National IT Industry Promotion Agency (www.nipa.kr) funded, and is supporting, a project ("Production Strategy and Execution Simulation Technology Development for the Optimization of Offshore Plant Production Cost," No. S1106-16-1020), which supported this work.

References

BACK, M. G., LEE, D. K., SHIN, J. G., AND WOO, J. H. 2016 A study for production simulation model generation system based on data model at a shipyard, *International Journal of Naval Architecture and Ocean Engineering*, **3**, 496–510.

CHAZELLE, B. 1983 The bottom-left bin-packing heuristic: An efficient implementation, *IEEE Transactions on Computers*, **100**, 8, 697–707.

ESRI. 2012 *GIS for National Mapping*, New York, NY.

HAN, S. D., RYU, C. H., SHIN, J. G., AND LEE, J. K. 2008 Modeling and simulation of ship panel-block assembly line using petri nets, *Transaction of the Society of CAD/CAM Engineers*, **13**, 36–44.

HEO, Y. J., CHA, J. H., CHO, D. Y., AND SONG, H. C. 2013 Optimal block transportation path planning of transporters considering the damaged path, *Journal of the Society of Naval Architects of Korea*, **50**, 5, 298–306.

HWANG, H. J. 2013 Simulation technology for production processes of ship and offshore plant building, *Communications of the Korean Information Science Society*, **31**, 1, 33–39.

HWANG, I. H., NOH, J., LEE, K. K., AND SHIN, J. 2010 Short-term scheduling optimization for subassembly line in ship production using simulated annealing, *Journal of the Korea Society for Simulation*, **19**, 73–82.

JEONG, Y. K., WOO, J. H., OH, D. K., AND SHIN, J. G. 2016 A shipyard simulation system using the process-centric simulation modeling methodology: Case study of the simulation model for the shipyard master plan validation, *Transactions of the Society of CAD/CAM Engineers*, **21**, 204–214.

KAARSEMAKER, J. AND NIENHUIS, U. 2006 Simulation of a maritime prefabrication process, *Proceedings*, Conference on Computer Applications and Information Technology in the Maritime Industries, May 8–10, Oegstgeest, the Netherlands.

KAGERMANN, H., WAHLSTER, W., AND HELBIG, J. 2013 Recommendations for implementing the strategic initiative Industrie 4.0: Securing the future of German manufacturing industry. Final Report of the Industrie 4.0 Working Group, Forschungsunion.

LAMB, T., CHUNG, H., SPICKNALL, M., SHIN, J. G., WOO, J. H., AND KOENIG, P. 2006 Simulation-based performance improvement for shipbuilding processes, *Journal of Ship Production*, **22**, 2, 49–65.

LEE, C. J., LEE, J. H., WOO, J. H., SHIN, J. G., AND RYU, C. 2007 A study on discrete event simulation of shipyard outdoor block movement, *Journal of the Society of Naval Architects of Korea*, **44**, 6, 647–656.

LEE, D. K., KIM, Y., HWANG, I. H., OH, D. K., AND SHIN, J. G. 2014a Study on a process-centric modeling methodology for virtual manufacturing of ships and offshore structures in shipyards, *International Journal of Advanced Manufacturing Technology*, **71**, 1, 621–633.

LEE, D. U., KIM, S. K., LEE, H. Y., PARK, S. K., LEE, D. H., AND WANG, G. N. 2012 A scheduling system based on DBMS for shipbuilding, *Transaction of the Society of CAD/CAM Engineers*, **17**, 26–34.

LEE, J., LEE, P., YOON, K., AND NAM, J. H. 2014b Quality verification of legacy data of manufacturing information system to improve results of shipyard manufacturing logistics simulation, *Journal of the Society of Naval Architects of Korea*, **51**, 6, 510–520.

LEE, K., SHIN, J. G., AND RYU, C. 2009 Development of simulation-based production execution system in a shipyard: A case study for a panel block assembly shop, *Production Planning and Control*, **20**, 8, 750–758.

LJUBENKOV, B., DUKIC, G., AND KUZMANIC, M. 2008 Simulation methods in shipbuilding process design, *Journal of Mechanical Engineering,* **54**, 131–139.

MCLEAN, C. AND SHAO, G. 2001 Simulation in shipyards: simulation of shipbuilding operations, *Proceedings,* The 33nd conference on winter simulation, December 9–12, Washington, DC.

MOON, J. H., RYU, W. S., AND CHA, J. H. 2016 Comparison of optimal path algorithms and implementation of block transporter planning system, *Journal of the Society of Naval Architects of Korea*, **53**, 2, 115–126.

NAM, S., JU, S. H., RYU, C., AND SHIN, J. G. 2016 The designing of production planning module for advanced planning system with respect to supply chain of the shipbuilding industry, *Transactions of the Society of CAD/CAM Engineers,* **21**, 353–362.

RUY, W. S., HWANG, H. J., AND PARK, C. K. 2015 An optimization of process planning around quays based on the yard customized GIS and the simulator, *Journal of the Society of Naval Architects of Korea*, **52**, 2, 97–103.

SONG, Y. J., LEE, D. K., CHOE, S. W., WOO, J. H., AND SHIN, J. G. 2009 A simulation-based capacity analysis of a block-assembly process in ship production planning, *Journal of the Society of Naval Architects of Korea*, **46**, 1, 78–86.

STEINHAUER, D. 2003 The virtual shipyard—Simulation in production and logistics at Flensburger, *Proceedings*, Conference on Computer Applications and Information Technology in the Maritime Industries, May 14–17, Hamburg, Germany.

STEINHAUER, D. AND MEYER-KONIG, S. 2006 Simulation aided production planning in block assembly, *Proceedings*, Conference on Computer Applications and Information Technology in the Maritime Industries, May 8–10, Oegstgeest, the Netherlands.

WOO, J. H., KIM, Y., JEONG, Y. K., AND SHIN, J. G. 2017 A research on simulation framework for the advancement of supplying management competency, *Journal of Ship Production and Design*, **33**, 1, 60–79.

WOO, J. H., SONG, Y. J., KANG, Y. W., AND SHIN, J. G. 2010 Development of the decision-making system for the ship block logistics based on the simulation, *Journal of Ship Production and Design*, **26**, 4, 290–300.