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A Research on Simulation Framework for the Advancement of Supplying Management Competency

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Various efforts to overcome the current crisis of shipbuilding industry have been being made in every area, including development, administration, and customer management. For overcoming the crisis, this study proposes a methodology to reconsider the supply management competency, which consists of production, procurement, and logistics, by the virtualization of Plan Do See (PDS) cycle using simulation technology and introduces a case study to verify the proposed methodology. The keys to the methodology are a comprehensive simulation framework including systematic analysis for the index investigated through simulation and a simulation platform for constructing a smooth input/output environment by avoiding dependencies on existing solutions. The systemized simulation framework is expected to maximize the speed and precision of decision-making regarding the supply management of shipyard and therefore eliminate waste elements that generate a large deficit.

Keywords: modeling and simulation; simulation framework; discrete event system; key performance index

1. Introduction

1.1. Background: strategy for competency

THE COMPETITIVENESS field of a manufacturing industry can be divided into administrative management, supply management, development management, and customer management (Fig. 1). Administrative management, such as financial management, human resource management, and asset management, involves integrated management of every component of a company to its nonvalue-added areas from the perspective of cost. Development management is related to product and service model development, and its competitiveness can be increased by the integrated management of development information and collaboration environment construction. Customer management includes the entire company marking area, such as specifications for the product/service and the management of the technical roadmap.

Generally, the unified management of all the resources of a company has improved the administrative management by the use of Enterprise Resource Planning (ERP) systems, and development management has been applied to secure the continuity of the product information in its development stage and to ensure a smooth cooperation environment through product lifecycle management (PLM) systems. Customer management has been implemented with various systems for managing the roadmap of technologies and products, centered on the requirement, which is the contact point between the customers and product information. Recently, customer management has become more involved in the PLM area by expanding PLM to a field called marketing PLM.

Supply management, which is the subject of this study, includes process manufacturing and the transportation of products and services desired by customers, including procurement, manufacturing, and distribution. It has been strengthened by using supply chain management (SCM) for procurement and advanced planning and scheduling (APS) and manufacturing execution system (MES) for manufacturing. Such IT support systems show high level of maturity in the automobile and electronic industries.

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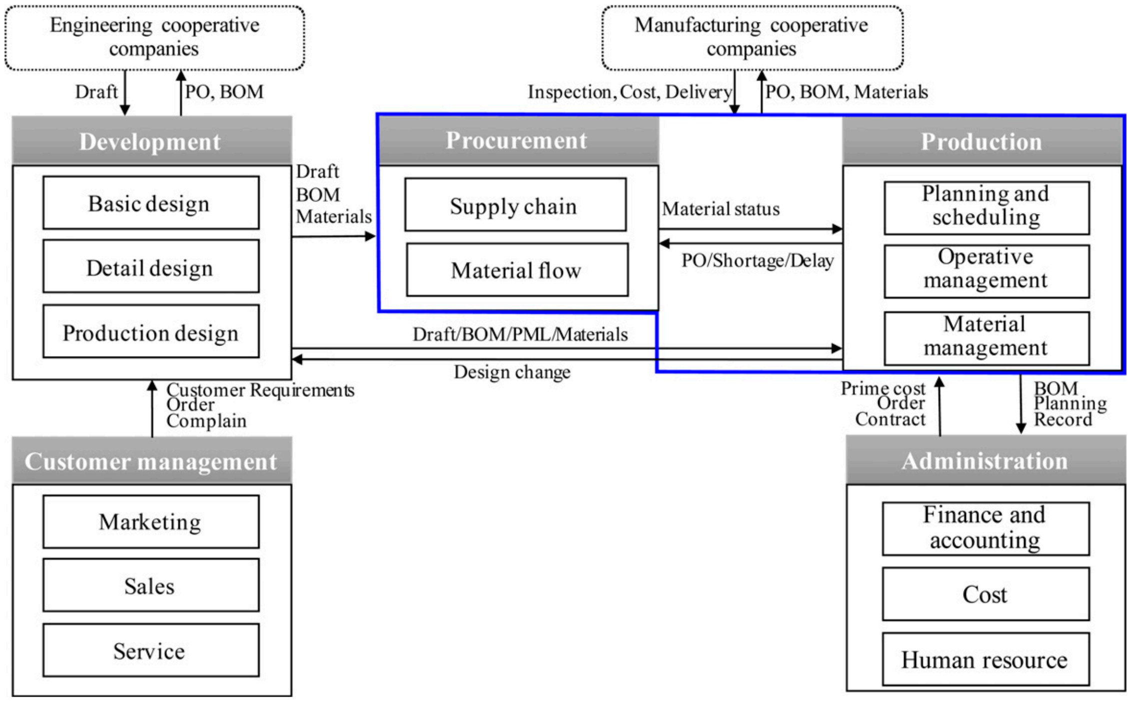


Fig. 1 Enterprise mega processes in manufacturing industry

However, in the case of the shipbuilding industry, the level of information and data standardization is low across the entire business compared with other manufacturing industries. Therefore, it is difficult to achieve the target management level, even with an excellent IT support system. In particular, the shipbuilding industry is in an unprecedented troubled state with the significantly changing market and the construction of structures for which there is little experience, such as marine plants.

Table 1 defines a detailed project that analyzes the issues and potential solutions for supply management by interviewing a few managers of large local shipyards. The production category of Table 1 considers the impact on the design and planning change and thus requires quantity-based production planning, payment for man-hours, and accurate working hour planning by predicting the production volume. Furthermore, the procurement category requires an SCM system for cooperative company support, integrated management for product lifecycle information including the supply chain, and the capability to predict procurement delays. The requirement for technology and methodology from these analyses necessitates various IT and industrial engineering application technologies, such as simulation, big data, standard time, and advanced planning and scheduling.

As a strategy for overcoming the present crisis of the shipbuilding industry of Korea, this paper introduces a simulation framework that is commonly included in most of the various categories among the technical requirements.

2. Historical review of computer simulation for shipbuilding

2.1. History of R&D of computer simulation in shipbuilding industry

The use of computers for manufacturing simulation started in the early 1970s but began in earnest in the late 1990s, when the simulation of the manufacturing-system behavior in virtual environments became possible owing to hardware developments and software improvements. The leading industries that applied computer simulation in manufacturing were those that introduced three-dimensional (3D) computer-aided design (CAD) and were highly automated, such as aircraft, automobiles, and electronics. On the other hand, the shipbuilding industry was left behind with regard to computer simulation because of its isolated IT

Nomenclature

APS: advanced planning and scheduling
BOM: bill of material
BSC: balanced score card
CAD: computer-aided design
CSF: critical success factor
DES: discrete event system
DM: digital manufacturing
KPI: key performance index
LOD: level of detail
MES: manufacturing execution system
MRP: material requirement planning
PLM: product lifecycle management
SCM: supply chain management
VDT: value driver tree
WIP: work in process

Table 1 Detail contents and resolution for production and procurement advancement

Category	Requirements	Description	Resolution domain	Recommendation
Production	Secure impact analysis system from design change	Construction of analysis of impact on production by design change	SCM + simulation	Agile prediction of quantitative production delay is required for the identification of the management point
	Planning and scheduling system with production volume base (not man-hour base)	Secure consistency of production volume management	APS	Fundamental approach is required for the revision of standard information system, because the business strategy of offshore plant construction is differentiated from that of general transportation vessel
		Master planning optimization through product mix simulation	Simulation	Single integrated process model of the entire production value chain including the development and the procurement is needed for the risk prediction. All the conditions affecting the production have to be included as a single unified model
		Advance reliability of planning and scheduling/schedule availability	Simulation	For this purpose, the flexible and agile simulation platform should be implemented
		Secure execution planning system aligning with master planning	APS	Constraint-based planning system is required for the synchronization of master planning and execution planning
	Improve working hours management system for offshore plant construction	Progress management based on production volume and construction of EVA (earned value analysis) system	EVA + simulation	In order to reduce the dispensable additional cost, subcontract payment has to be dealt based on working volume, not working hours. For this purpose, the working units have to be restructured in detail level and with cost related, through which the comprehensive expenditure can be normalized
		Construction of standard time unit considering offshore plant	Standard time	The machine learning could be a solution for the prediction of working time
		Improve production supporting system for suppliers	SCM + simulation	In terms of prediction, the supply chain has to be simulated with the variable of suppliers information and supply chain status, through which the preemptive action can be conducted with respect to the procurement delay
Procurement	Supplier supporting system linked with the production management	Production planning and scheduling based on design/procurement information	SCM + standard data	First, the reliable lead time of supply chain activities should be analyzed, then, if needed, analytic methodology should be adopted if the target data have big fluctuation and variation
		Revision of productivity index	KPI + big data	Big data technology could be a solution for the advancement of the productivity index because most management data of the shipyard have big size and abnormal characteristics. The causation by traditional stochastic analysis cannot be a solution, instead the big data technology such as machine learning is expected to identify correlation among management data
		Secure management system for suppliers' production capacity w.r.t. material/block/outfitting module	SCM + simulation	In terms of prediction, the supply chain has to be simulated with the variable of suppliers information and supply chain status, through which the preemptive action can be conducted with respect to the procurement delay
	SCM system with comprehensive coverage from design, procurement, and production phase	Development of pairwise management module on top of the APS and SCM system for the installation management of outfitting modules and spools	SCM + simulation	In order to stabilize the outfitting process of the offshore plant construction, the pairwise characteristic has to be realized in the planning of the outfitting process. Also, if needed, the variable lead time of each spool and equipment has to be considered
		Construction of monitoring system of each supply chain activity w.r.t. material/block/outfitting module	SCM + MES	Accurate monitoring of supply chain is crucial for the management of procurement and following production phase

environment due to global standards and a minimally automated manufacturing process.

Although many domestic manufacturing companies introduced IT-related best practices, including simulations from foreign companies, most references on simulation in the shipbuilding industry are related to Korean shipyards or its academia, as the Korean shipyards comprise the top global shipbuilding industry.

A few shipyards have researched virtual plants using computer simulation since the 1980s, but the very first case of a full-scale shipyard simulation study using the progressive concept of digital manufacturing (DM) was "Integrated Digital Shipbuilding Technology for Development of High Value-Added Ship" (Project no. 00,016,038) from 2001 to 2004, which was funded by Korea's Ministry of Trade, Industry and Energy (Han et al. 2008; Hwang et al. 2010; Lee et al. 2007, 2009). Under the supervision of Seoul National University and with Samsung Heavy Industry as its subject, the project established a digital model for every process of the shipyard using 3D kinematic simulation and discrete event system (DES) simulation software. The project also involved a study for constructing a system to link the production management business of the shipyard with the panel line, fabrication factory, and outdoor-yard production processes. The project established the world's first digital model subject to every shipyard process and proposed a direction for the advancement of future digital shipyards by deriving various use cases. However, it could not avoid dependencies on foreign simulation software, which left room for improvement regarding software localization.

The manufacturing simulation project of the shipbuilding industry as a national business with KRISO-supervision was "Simulation-based Production Technology for Ships and Offshore Plants" (Project no. 10,035,331) and was conducted from 2010 to 2015, with Hanjin Heavy Industries and Construction as its subject (Heo et al. 2013; Hwang 2013; Hwang & Gong 2011; Lee et al. 2014; Ruy et al. 2015). The biggest characteristic of the project was the localization of the kernel as a basis of the simulation for securing original technology related to the production simulation. Kernels for crane lifting simulation, process planning around quays based on the Geographic Information System (GIS), transporter logistic simulation, and shipyard production planning validation simulation were developed from the project, on the basis of which Hanjin Heavy Industries Co. developed an application program necessary for its field workplace. However, the facts that many dockyards could not participate in the project owing to recession and that Hanjin Heavy Industries Co., the only participating dockyard, had difficulty making efforts in R&D left a sense of disappointment.

A recent project in the field of dockyard production was called "Development of Simulation-based Production Management System for Middle-sized Shipbuilding Companies" (Project no. 10,050,495). This project established a DES simulation system to develop APS and verify its plan in a highly Software (SW)-dependent planning section of the Plan Do See (PDS) cycle of the product management in order to strengthen the supply management competency of middle-sized shipbuilding companies that have had difficulty surviving since 2010. The DES simulation part includes content for upgrading its functions and a system based on the kernels developed in the shipyard production planning validation simulation section of the aforementioned 10,035,331 project.

Other service projects conducted to satisfy the needs of dockyards include "Study on the Production Planning Verification Simulation of Block Assembly Process" (Lee et al. 2012), "Study on the Development of a Simulation Module for Dockyards' Integrated Distribution Control System Implementation" (Woo et al. 2010), "And Study for the Simulation-based Assembly Plant Design and Production Schedule With Limited Capability" (Song et al. 2009).

Flensburger 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 as a result of the project. 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). These researches have their own significance in focusing on the advancement of planning and prediction capability with the simulation application to the actual ship production planning apart from traditional simulation approach in ivory tower.

2.2. Technical trend based on Hype cycle of Gartner

Gartner, an IT market-research enterprise, annually announces the Hype cycle, which explains the current state and prospects of novel technologies. Gartner describes five stages of development for a new technology. In the first stage, which is called the Technology Trigger, the potential of the technology is revealed. In the second stage, called the Peak of Inflated Expectations, the technology receives attention from the media, and its success stories are reported. In the third stage, the Trough of Disillusionment, attention declines, as the technology becomes widely known and its nature and limits are revealed. Technologies that overcome this stagnation pass the stage called Slope of Enlightenment as their marketability is recognized, arriving successfully in the market and reaching a Plateau of Productivity.

Analyzing the field of production simulation from the viewpoint of the Hype cycle is as follows. The trend of virtualization and digitalization in manufacturing plants using computer simulation peaked in the late 1990s to early 2000s in terms of its expectations. During this period, many companies ordered projects through hasty decisions without understanding the weaknesses and losses of digital/virtual manufacturing. The providers (research institutes and associated SW companies) also lacked technology and experience, leading to incomplete results compared with the amount of investment. Thus, a rapid market decline occurred in mid to late 2000. Hardly any projects on production simulation were ordered by companies during this time. Consequently, more realistic approaches were implemented in the late 2000s that differed from the existing ones. The verification of practical results became more important than 3D visualization, and the importance of agile modeling was more noticed than a high-level of detail of the digital model. Moreover, research on lowering the difficulty level of access for engineers of production technology or production management department who are not simulation experts was conducted, as well as studies to increase the accessibility to the simulation system by merging it with web technology and overcoming the physical barrier. Most of all, efforts to avoid dependencies on foreign solutions, which acted as obstacles to R&D, made the domestic simulation software possible, guaranteeing the bright future of the DM industry of Korea.

As local manufacturers suffered from the deteriorating profit structure, front loading was emphasized as a survival factor for companies, and the rebirth of DM was presented as a method for this. More realistic approaches were made, centering around the electronics and automobile industries and based on the aforementioned improvement elements. The shipbuilding industry also changed the way it recognizes these elements as more of a must for "survival," rather than an option for "improvement," which was the case when the industry was booming with excess funds.

2.3. Current status of computer simulation

Computer simulation for manufacturing systems was packaged with a name called virtual manufacturing in the 1990s and was widespread under the title of DM since the early 2000s. Recently, it transformed into something called smart manufacturing, attracting new attention. These changes in the name were done to supplement the drawbacks of its previous generation by grafting the state-of-the-art technology (especially IT related) of the era. For example, the simulation of the recent smart manufacturing drew attention of the industry and academia by differentiating smart manufacturing from DM through the integration of the newest technologies, such as big data and the Internet of things (IoT), into the digital-plant construction, which was the goal of the previous generation.

For Industry 4.0,[1] which is currently the latest concept in manufacturing (1Q of 2016), CPS is being introduced as a practical methodology for manufacturing simulation. Corporate managers who pack their management philosophy with IT with a refined expression consider Industry 4.0 and CPS technologies that must be adopted. The academia allows them to speak with catchphrases to grant new R&D investment opportunities (without a dispassionate analysis process of their tangible, empirical part). However, analyzing the true nature of CPS from a more objective viewpoint reveals that it is only a Combination (physical assembly) and not a Fusion (chemical bonding), except for the development of a manufacturing simulation establishment base from technical progress.

2.4. Retrospect and lessons learned

As discussed in Sections 2.1 and 2.3, various efforts are currently being directed toward computer simulation, with a new title in order to strengthen companies' manufacturing competitiveness after the dynamic transition process. A considerable amount of government investment and corporate efforts have also been made domestically for this leading industry of shipbuilding. However, the studies on the prepared technological level, assuring realistic corporate capability, and definite goal setting are insufficient. The computer simulation market is also vulnerable to the sales gimmicks of IT salesperson who seek only profit.

In this section, the typical problems of manufacturing-simulation-related R&D and its projects are described, and potential solutions are proposed so that the elements for the proposed framework can be derived.

2.4.1. Uncertain target index. The biggest problem with existing studies and projects is the lack of a system that derives the target index to be identified. Every simulation explicitly suggests the target value to be confirmed through the simulation. The simulation target for structural analysis is to predict the weakness to distortion or destruction by interpreting the distribution of stress and strain. In flow analysis, the change of the control volume movement is predicted by interpreting the temperature, velocity, and pressure gradient of the working fluid. Here, indicators such as the stress and pressure are the necessary, explicit indices for interpretation. However, for computer simulation of a manufacturing system, there are numerous kinds of indicators for each purpose, compared with dynamic engineering simulation. Therefore, it is important to set a proper index for the use and the purpose of the simulation. Many previous studies did not consider setting a target index and focused on primitive indices such as utilization, throughput, and work in process. That is, the goal for the R&D was too focused on developing technical tools for simulation, making the systematic approach to set the target rather inadequate.

2.4.2. Dependency on commercial software. The next problem is the high dependency of the simulation tool to foreign solutions, which increases the burden of early investment costs and limits the maintenance and additional development. Because of the introduction of computer simulation to the domestic manufacturing business, services related to development could be performed by internalized local technology. However, the simulation solution had to depend 100% on Dassault Systemes (DS), which was the biggest 3D PLM company, Siemens (formerly DS, Tecnomatix), and minor companies such as Applied Materials and Lanner, who offer DES simulation solutions. A product called DM Works was recently developed by Easy Robotics (http://www.ezrobotics.com/) as a solution for an industrial robot simulation and is now widely used in the local automobile industry. However, a DES simulation tool that allows simulating the local movement of manufacturing system has not been localized and thus entirely depends on foreign solutions. The formerly introduced 10,035,331 project of the shipyard production planning validation simulation developed the first Korean DES kernel and led the 10,050,495 project to further develop it.

2.4.3. Absence of consistent and sustainable framework. The last problem is the absence of a series of unified guidelines, i.e., a framework, to build a simulation model. All previous studies and projects proposed a framework related to establishing each simulation model, but a comprehensive and specific study on the framework itself, which organically connects the information model, preprocessing, platform module configuration, simulation use case, with the context has never been conducted. Woo (2005) arranged the model-establishment procedure from an academic perspective according to experience in simulation model establishment for various shipbuilding processes of the 00,016,038 project. However, the study could not avoid the limits of foreign solutions, and a successive follow-up study could not be performed without sufficient investigation. Studies by Woo and Song (2014) and Song et al. (2011) established a system for production management indices and showed the configuration of relation with the simulation modeling process via case development. Recent ongoing studies, including the present one, have provided systems for production management index analysis by merging it

[1] Industry 4.0 or the fourth industrial revolution is a collective term embracing a number of contemporary automation, data exchange, and manufacturing technologies. It had been defined as "a collective term for technologies and concepts of value chain organization" which draws together Cyber-Physical Systems, the Internet of Things, and the Internet of Services.

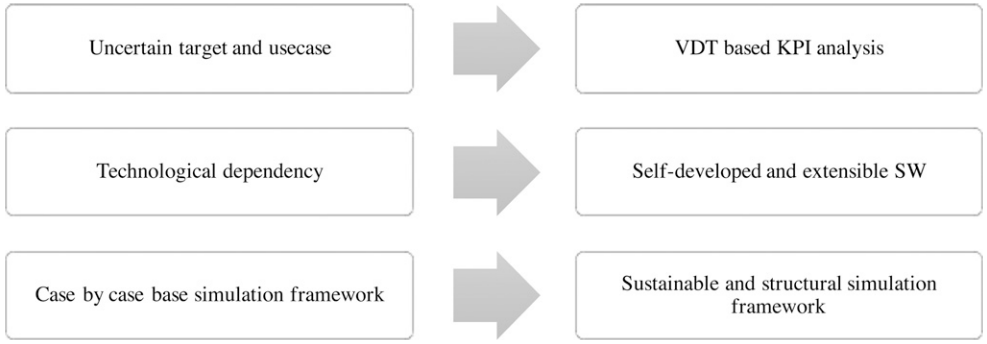


Fig. 2 Lessons learned from previous research and development, contribution of this paper

with business administration. The index-analysis system proposed in this study is also based on this previous study.

Therefore, the aforementioned problems should be resolved for the application of a sustainable simulation technology (Fig. 2). This paper systemizes the indicator derivation using value driver tree (VDT) among the tools of business administration on the basis of the scope of research from a precedent study (Song et al. 2011) and proposes the configuration and the specification for a simulation platform to lower the dependency on commercial solutions. In addition, it proposes a simulation framework including the mentioned index system and simulation platform. The possible applications derived from the results of the study can theoretically include every manufacturing industry, but this study preferentially limits empirical verification and cases to shipbuilding manufacturing.

3. Concept of simulation framework

This study proposes a simulation-based production management framework. In this section, the methodological concept for the proposed framework is defined, and Section 4 discusses the technical side of the framework. As the term "framework" is often confused with "architecture[2]" or "platform[3]," we define the framework proposed in this study as follows.

In this study, "framework" refers to a comprehensive series of business guidelines, methodology, and information model that are required to establish a simulation-based production management system. That is, the proposed framework includes elements for establishing a unit application system based on simulation as well as technical factors, relation among technical factors, and fundamental technology for its implementation.

The framework proposed in this study also includes methods such as VDT and performance measurement for setting the goal of the simulation system and measuring its performance by borrowing the concepts used in the business management field. An information model called 6-factor structures the external information related to the framework. Moreover, because the production activities of the manufacturing industries can be managed on the basis of events those are generated with discrete time base, the simulation core of the proposed framework is based on a DES formulation. The kernel, engine, and platform included in the framework are based on DES and can be structured as follows.

The DES simulation kernel is the module that performs tangible calculations on discrete events that occur according to the Queuing theory, which is a fixed component that is not affected by changes to other components. The DES simulation engine is a structure or single solution including the basic components for performing a simulation, and it includes the DES simulation kernel, an adaptor that receives the data for simulation, a modeler that produces the simulation model, an analyzer for simulation-result analysis, and a reporter that creates a report after the results are analyzed (Fig. 3).

"Platform" indicates the specific components used to establish a simulation-based manufacturing management system and a system that organically integrates them from an information viewpoint. The term is used in this study because the platform can easily develop and mount the necessary additional modules according to the goal of the system and flexibly structure the expanded system if necessary. This simulation platform is established according to the defined DES engine and includes a modular extension bus for organic integration with the other components. A detailed explanation on the specific components comprising the simulation platform is presented in Section 4.

Defining the framework and platform is necessary to establish a systematic simulation-based production management application system, i.e., to establish a targeted system by defining a 6-factor information model, a key performance index (KPI), and the platform functions (Fig. 4, right). According to the platform components, the final product established with the series of guidelines proposed by the framework is called the unit application system and can be implemented as an independently driven package.

4. Design of simulation framework

This section illustrates a detailed design of the component for the formerly defined simulation framework. In Fig. 13, the main factors for the simulation framework are the six factors in the information model (Fig. 5, left), the KPI analysis system based on VDT that derives the system function from the system target (Fig. 5, right), and the simulation platform as the execution environment.

4.1. 6-Factor as an information structure for simulation

Product, Process of Dassault Systemes, Resource Model (PPR Model) or Product, Process, Plant, and Resource Model (P3R

[2]A type of design structure that determines the main characteristics of a software.

[3]A type of execution environment defined by the development bases, such as the computer language, software, and hardware.

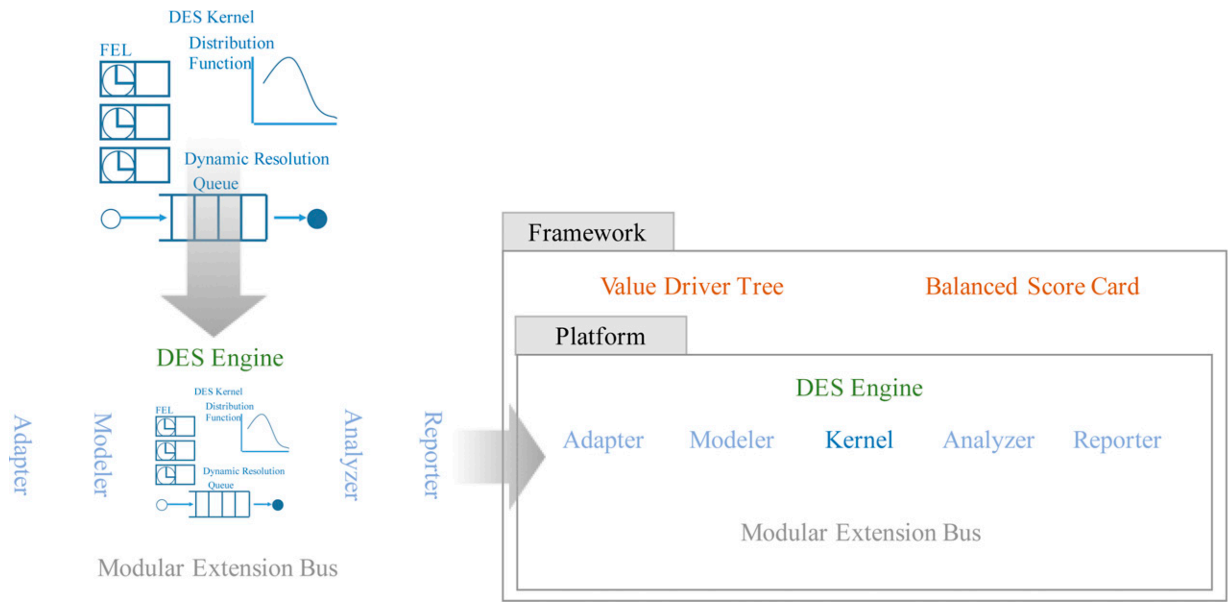


Fig. 3 Kernel, engine, platform, and framework

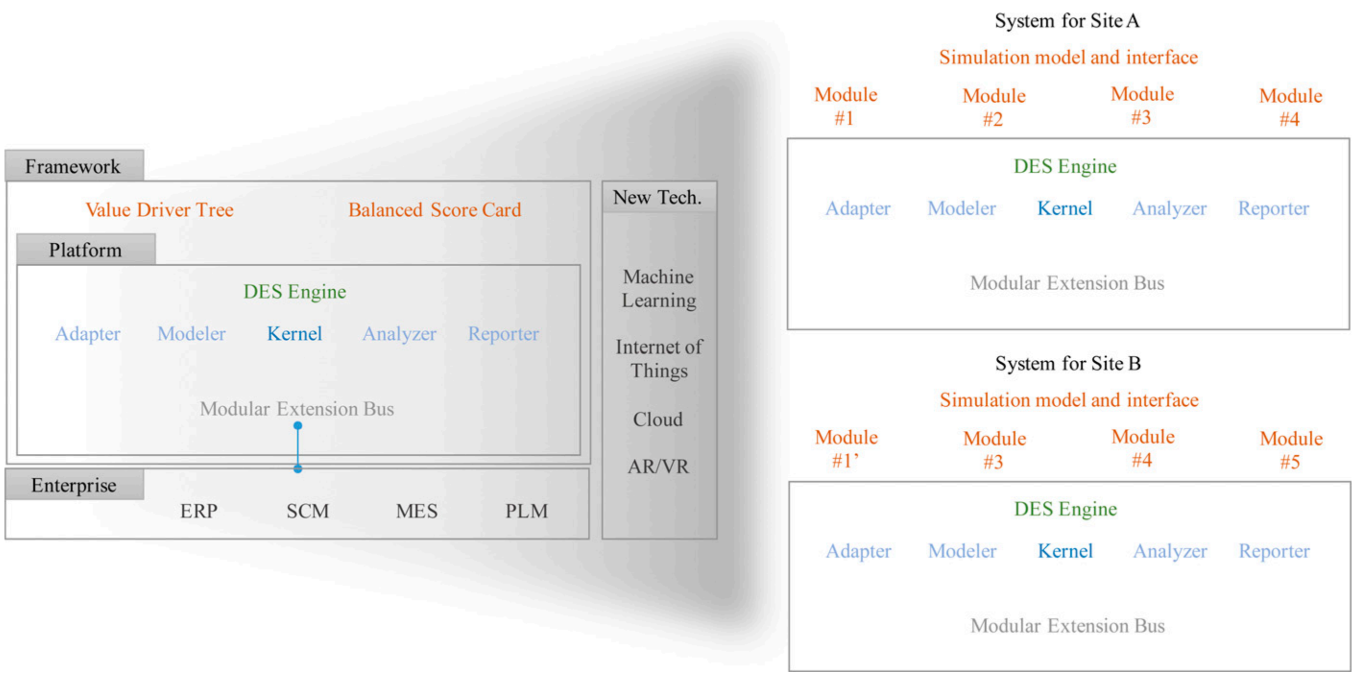


Fig. 4 Framework and system

Model) of Siemens PLM[4] are widely used as simulation information models (Lee 2013). Separating the PPR and P3R is useful in the general manufacturing industry for the establishment of a simulation information model. However, applying the PPR and 3PR models to the shipbuilding industry is problematic because it is an order-made production industry by nature.

In the shipbuilding industry, schedule planning is very important, and product, process, resource information is managed and centered around the schedule, which led to the proposal of a PPR-S (Product, Process, Resource, and Schedule) Model (Woo 2005) with the schedule added. The study continuously grew, and Lee (2013) proposed a PPR3S (Product, Process, Facility, Space, Labor, and Schedule) information model with a 6-factor component with the Resource part divided into facility, space, and human resources (Fig. 6).

[4]https://www.plm.automation.siemens.com/

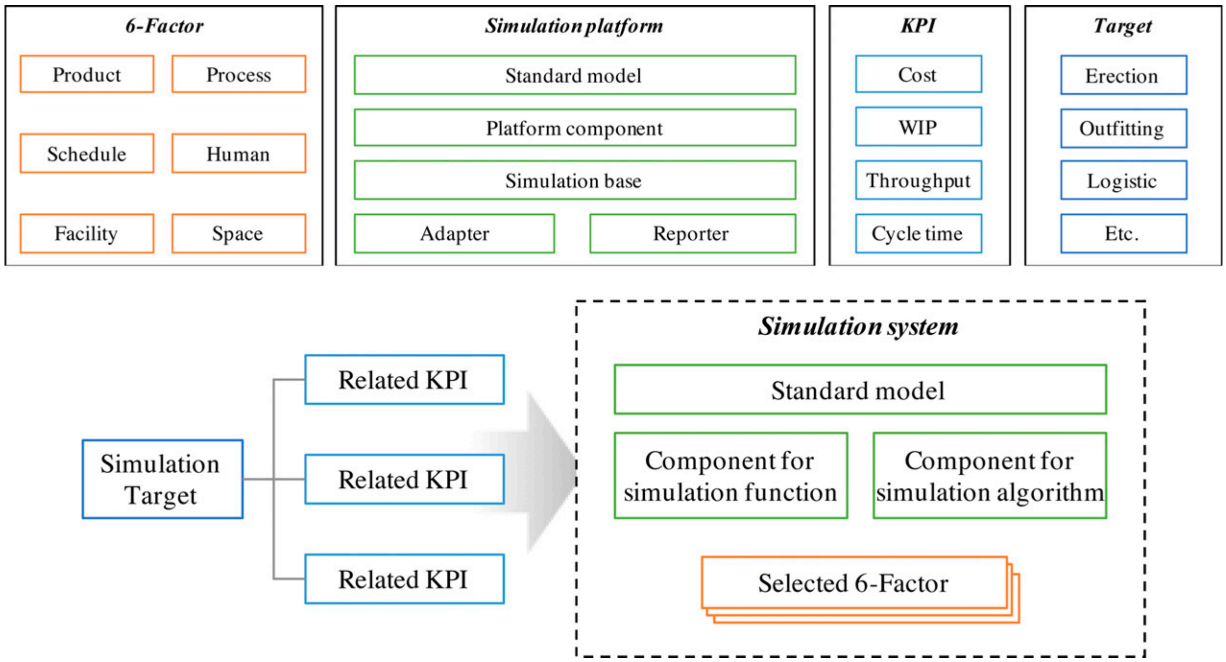


Fig. 5 Conceptual diagram of simulation framework

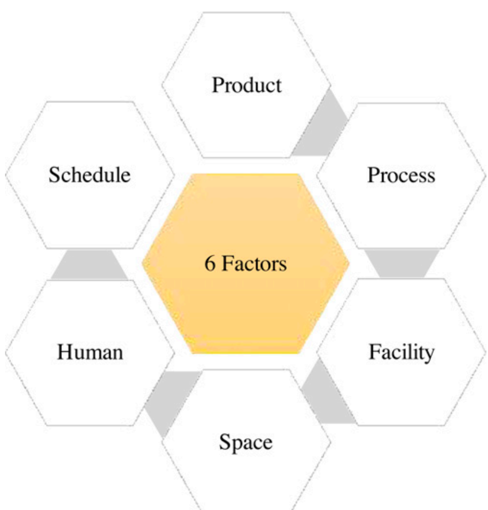


Fig. 6 Factor model for shipbuilding simulation

The product information can be largely divided into the hull structure part and the outfitting part. The hull structure part has a similar structure of the bill of material (BOM) information to the general manufacturing industry, which includes all product information from blocks to steel plates and stiffeners. Information on ship machinery is again subdivided into information related to the propulsion system, electrical system and interface, and subsidiary system.

Process information can be largely divided into indoor, outdoor, erection, and quay, which reflect the characteristics of the shipbuilding industry. Indoor processes are divided into plate stock, priming, cutting, forming, and assembly, in order of their implementation. Outdoor processes include the inspection process, preceding outfitting, and preceding painting process. After the loading process, the inner wall process includes outfitting, painting, and a sea trial. The process information must include process flow, relationship among the processes, process variables, and algorithm definitions.

Schedule information can be divided into a master plan for dock planning, a capacity plan for planning the work load of the main resources, a material requirement plan (MRP) for shipyard midterm planning, and an execution plan for daily work. The master plan includes the Key Event Plan, Dock Plan, and Quay Plan, and the Capacity Plan includes the plans for the workforce and facility. The MRP includes proceeding planning for all of the schedule before the loading and succeeding planning for the erection plan of loading at facilities such as a dock. The execution plan includes the volume, workforce, facility, and work stage.

Human resource information can be divided into the plant manager and administration group, engineering and maintenance group, and production group. Next is the subdivision group and the employee information of the relevant group.

Facility information is first divided into the production facility and transportation facility. The facilities needed for production are divided into the forming facility, welding facility, cutting facility, etc. The facilities needed for transportation are divided into the crane, conveyor, transporter, etc.

Area is one of the important resources for the shipbuilding industry. Managing and using the given area well greatly affects productivity. Area information includes all the areas subject to management, including the indoor/outdoor area information regarding the fixed and moving work stage, skid birth, or dry dock. Details for the subdivision of each component are illustrated in Fig. 7.

4.2. Improvement target and KPI

Song (2009) claimed that securing the KPI as a system construction environment is necessary for establishing a shipbuilding

Fig. 7 Categorization of six factors

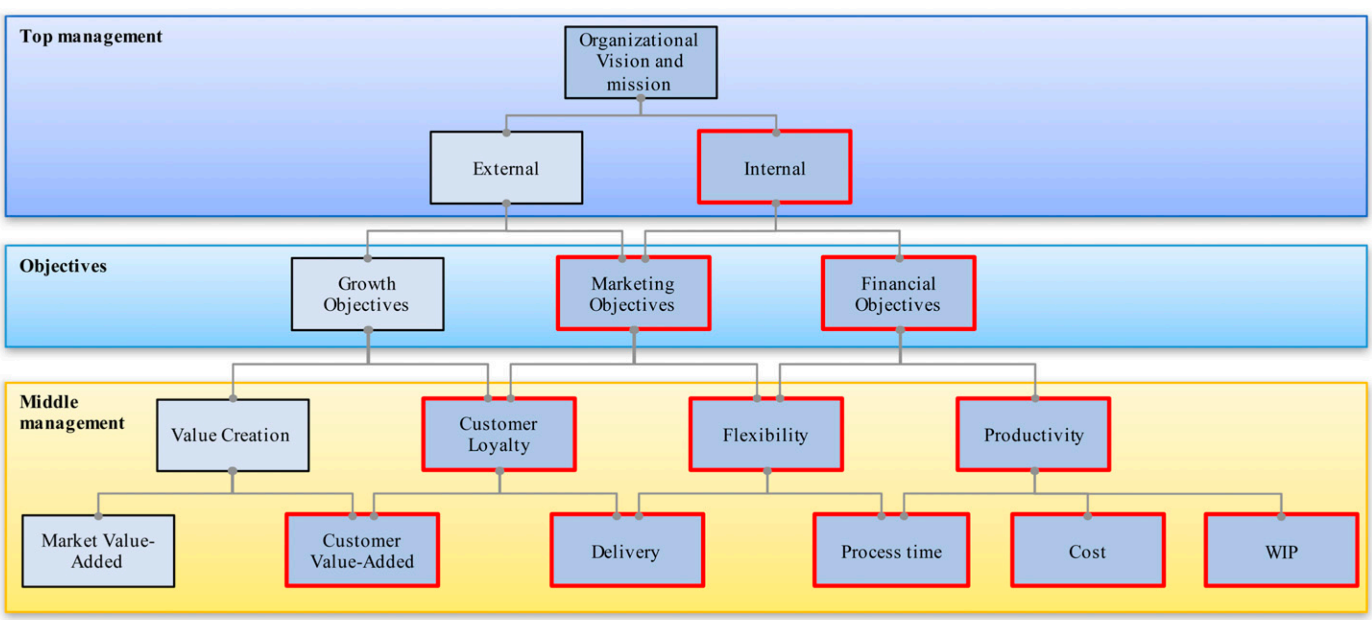
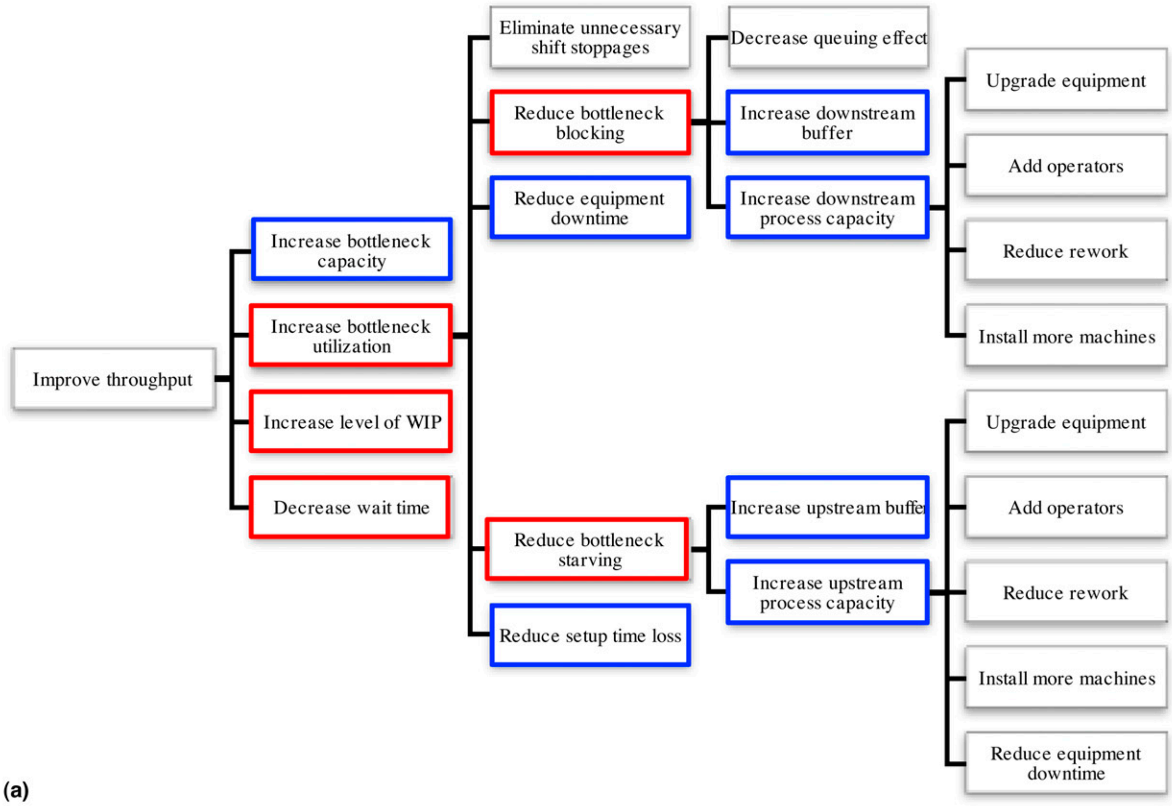
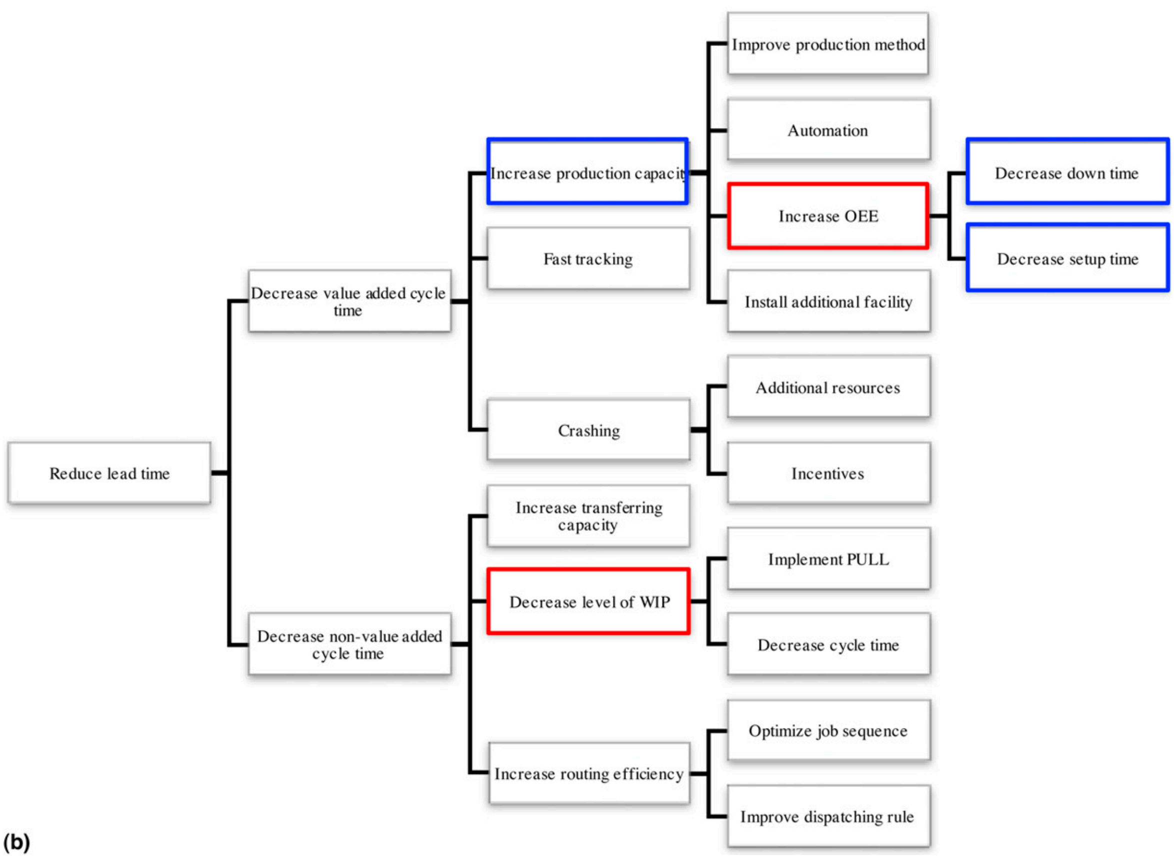


Fig. 8 Performance pyramid



(a)



(b)

Fig. 9 VDT deployment in terms of (a) throughput, (b) lead time, and (c) cost

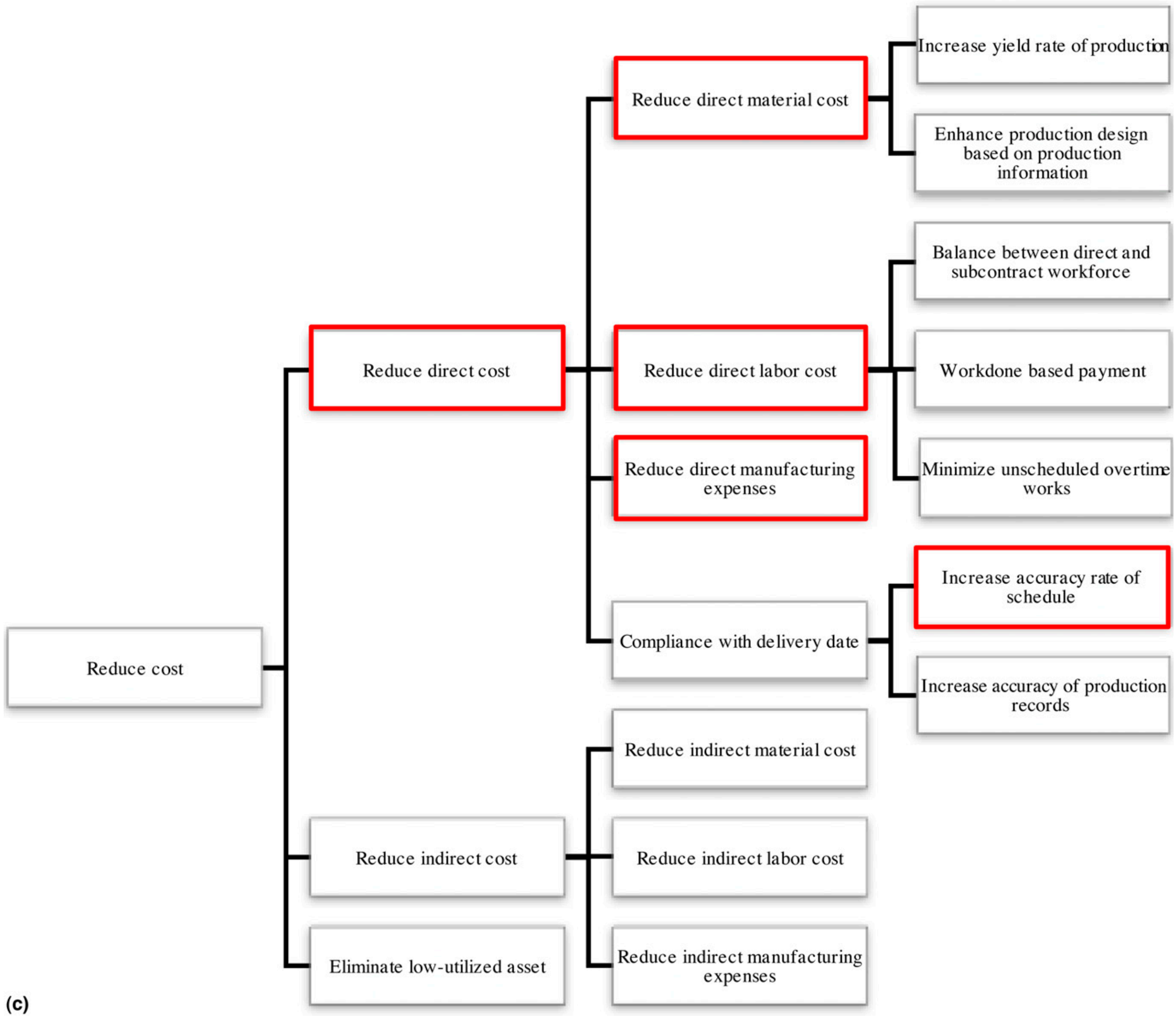


Fig. 9 Continued.

product-management system. As a system construction process based on general user requirements has difficulty considering an entire complicated system, if an additional necessary requirement for the target is derived in the middle of the system establishment, it needs an extensive complementary work. Song (2009) presented the logic whereby the implementation area of the system must be decided by deriving not only the early requirements but also the connected requirements derived from those by referring to its KPI. This logic is similar in the case of the simulation system. That is, a process deriving the function or results based on the KPI is required. Relevant studies such as Song et al. (2011) and Woo and Song (2014) have been performed.

To summarize the precedent studies, balanced score card offers a high-level perspective and strategy, and critical success factor (CSF) maps the success factor for each strategy. The mapped, nonmeasurable CSF is then linked to the refined CSF based on the performance pyramid. The internal process development for quantitative CSF deployment follows the performance pyramid shown in Fig. 8. Finally, the middle management level of the performance pyramid offers the KPI identification system suitable for the goal of the simulation by analyzing the main indices using VDT on the middle management level (Fig. 9).

4.3. Detailed description for the simulation platform components

The platform as an execution environment for the simulation framework is a frame that is loaded with the function using the aforementioned 6-factor information model and KPI identification. The simulation platform is composed of the standard model layer, platform component layer, simulation base layer, input data collection and generation layer, output data reporter layer, and finally real-time interface layer, as shown in Fig. 10.

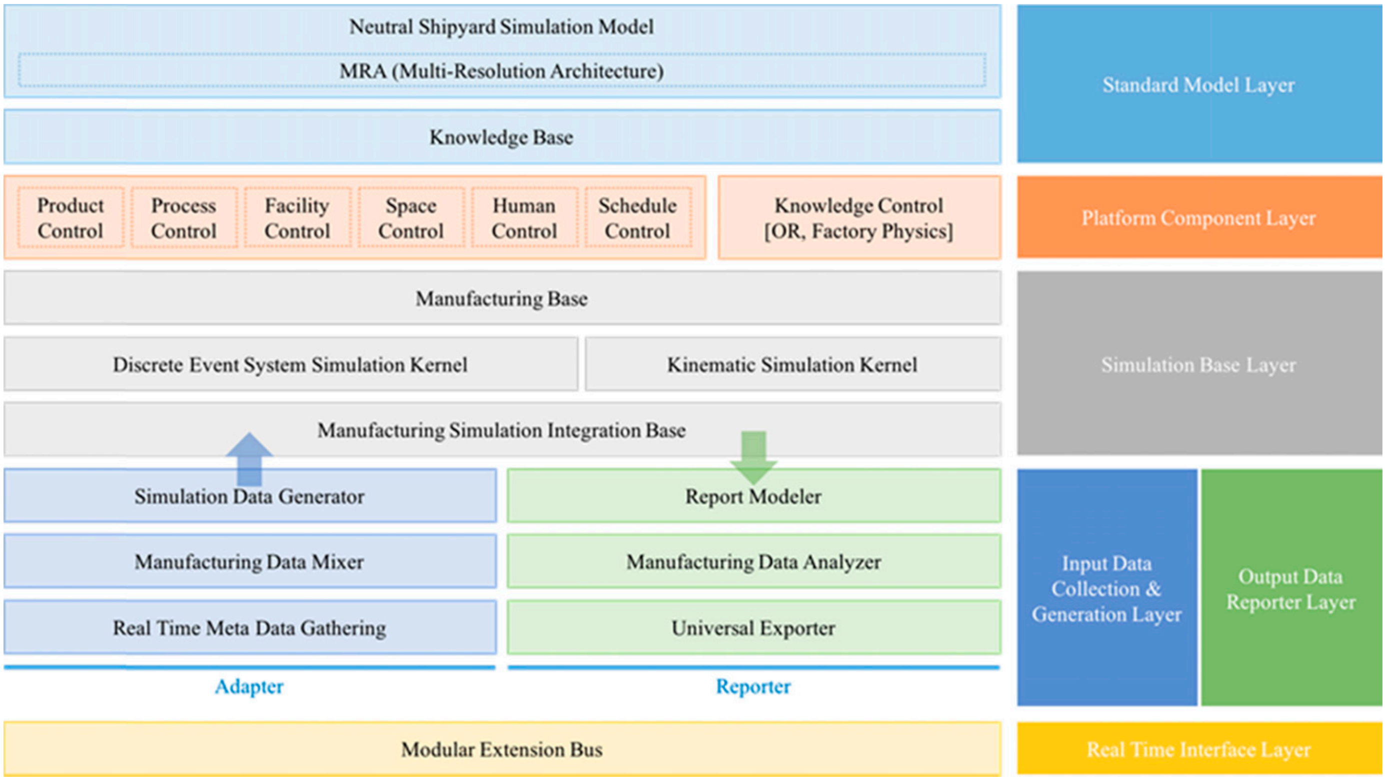


Fig. 10 Categorization of six factors for assembly process

The standard model layer is based on a neutral model that is compatible with a dissimilar simulation software or a dissimilar simulation platform. This simulation-neutral model must be modeled based on the process-centered modeling methodology and express a multilevel structure. Knowledge of the managers on site, tacit knowledge, or routing rules that cannot be expressed in a simulation-neutral model are managed using a different component that can manage a knowledge-based data. The standard model layer is the top-level layer shown in the proposed platform and can be directly accessed by users of the simulation system.

The platform component layer includes the component that controls the six elements (product/process/facility/human resources/area/schedule) that comprise the shipyard simulation model, as well as the component that controls the theoretical elements such as operation research or factory physics, which cannot be expressed in simulation model or information model. The platform component layer is located in the level connecting the simulation base and standard model layer.

The simulation base layer includes the kernels for performing simulation itself, as well as the integration component for the data input/output layer and its exchange. The simulation base layer is associated with the layer that collects and creates simulation data to perform the simulation and the layer that arranges the simulation performance results with a report form and printout. At the very bottom of the proposed platform is the real-time interface layer, which interfaces the generated onsite manufacturing data and the simulation data. The manufacturing site and the simulation system can be linked using this layer. The definition, input information, mechanism, and output information for each component are described in Table 2.

5. Validation of the simulation framework

The section shows that each element of the proposed framework corresponds to the various cases applied with the shipyard simulation system without omission. Examples of the subject simulation system include the block logistics simulation case for the large shipyard D, the indoors ship simulation case for the large shipyard S, and the shipyard master plan simulation case for the middle-sized shipyard S. The simulation framework correspondence relationship for each case is shown in Table 3.

6. Case study

Next, the proposed shipyard simulation framework was introduced. As previously mentioned, various studies have been conducted for applying simulation technology in order to resolve the various and complicated problems that occur during the shipbuilding process at shipyards. The production plan established by a shipyard can be divided into the dock plan, master plan, and execution plan according to the makespan of the planning and the purpose of the planning. However, not everything can be considered during the planning, such as facility constraint, spatial constraint, and human resource constraint. Thus, simulation technology is generally used to validate the production plan with regard

Table 2 Detailed description for the simulation platform components

Layer	Component	Definition	Similar technology	Input	Process or mechanism	Output
Standard model	Neutral shipyard simulation model	• Shipyard simulation model expressed by a standardized methodology independent of simulation platform components	• PLM services	• 6-Factor	• Neutral shipyard simulation model is configured by filtering and recombining the input properties	• Shipyard simulation model where a standardized methodology is applied
		• A model based on the MRA methodology that can express a hierarchical structure between processes	• SDX • NESIS	• Performance evaluation model	• Results can be saved as an XML file type or DB type, if necessary	
Platform component	Product control	• A component for expressing and managing the product information(steel, steel plate, part, and block information) used in the shipyard simulation model	• IGES	• 3D geometric information of each product	• Identifying shared information between products and information used in the external modules	• Integrated product information of shipyards
			• STEP	• Hierarchical structure information of each product	• Identifying information automatically extracted from the 3D geometric information	
			• JT	• Detailed properties of each product	• Structuration of product information	
			• XVL	• Routing information of each product	• Define how to connect 3D geometric information and product information structure	
	Process control	• A component for managing flows between processes by combining products and facility constraints based on the process-centric simulation modeling methodology	• Process oriented process planning (DELMIA Process Engineer)	• Characteristics and flows of the process • Relationships between processes • Product and facility constraints of each process • Variables, formulas, and operation algorithms of each process	• Connecting the flow between processes • Define product and facility constraints of each product • Enter characteristics and operation algorithms of each process	• A simulation model based on the process-centric simulation modeling method
	Facility control	• A component for managing factory and facility information, in which a function for calculating and expressing facility information based on the related rules and algorithms is provided		• Space information of each factory/facility • Relationships between factories/facilities	• Enter characteristics of each factory • Update space information to check the space occupied by facilities • Define characteristic of each facility • Define relationships between factories	• Integrated facility information of shipyards
	Space control	• A component for managing the space information, in which a function for calculating and expressing space information based on the related rules and algorithms is provided	• GIS • ESRI • Google Maps geocoding API • Spatial layout algorithm	• Space specification of each space • Space division rules	• Define space information including space specification • Define basic calculation algorithm to use space information	• Integrated space information of shipyards

(continued)

Table 2 Continued

Layer	Component	Definition	Similar technology	Input	Process or mechanism	Output
	Human control	• A component for managing and expressing the information of shipyard workers	• Human factor simulation • Crowd model	• Hierarchical information of human resource management of each shipbuilding process type • Manpower measure criteria of worker and worker's skill • Work order • Criteria for determining workers' healthiness	• Define systematic structure of human resources and management properties of each shipbuilding process type • Define hierarchical structure of human resource information • Define performance measurement element for a unit worker	• Integrated human resource information of shipyards
	Schedule control	• A component for managing information of hierarchical shipbuilding schedule	• APS	• Basic structure of shipyard schedule • Detailed information of shipyard schedule • Shipyard schedule information	• Identify hierarchical structure of schedule information • Define a hierarchical structure of WBS related with schedule	• Integrated schedule for simulation
	Knowledge control	• A component for managing rules, formulas, and knowledge of shipyards independently • This element can be changed continuously	• Knowledge management system • MathMI • MathCAD	• Production results of each department • Variables of each process based on the labor experience • Implicit knowledge of work site	• Represent an implicit knowledge using scripts, formulas, and binary codes • Connect DB and spreadsheet of the simulation system	• Standard information of knowledge management for shipyards
Simulation base	Manufacturing base	• A component for managing required properties and information for shipyard manufacturing simulation		• Production management knowledge of shipyards • Routing rules • Facility operation rules • Product distribution rules • Stock area operation rules	• Define characteristics of unit models that constitute simulation model • Implement an operation algorithm of unit models • Apply operation rule of simulation rule considering the MRA	• Execution model of shipyard production simulation
	DES simulation kernel	• A simulation kernel for executing a unit event and recording the results • This kernel is based on the DES simulation theory		• DES simulation model	• Arrange all events that have been scheduled to occur at a future time in chronological order (future event list) • Execute calculation of DES simulation	• Records of simulation results of each unit event
	Manufacturing simulation integration base	• Information gathered from other modules and simulation results is integrated and analyzed in this component • It also serves to distribute the information to other modules	• Business intelligence	• Input data information from external systems • Simulation execution results	• Update simulation reference data based on the accumulated simulation results • Integrate and deploy simulation information	• Metadata information of shipyard production simulation

(continued)

Table 2 Continued

Layer	Component	Definition	Similar technology	Input	Process or mechanism	Output
Input data collection and generation	Simulation data generator	• A component for generating input data to execute shipyard simulation by refining collected data in manufacturing workshops		• Execution and operation information of shipyard production system	• Divide shipyard production system information based on the 6-factor • Define simulation variables that can be used as input data for simulation model	• Shipyard simulation input data divided by 6-factor
	Manufacturing data mixer	• A component for generating meaningful data by refining data collected in real time	• Data mining • Big data • Statistical analysis	• Execution data of shipyard production system • Operation data of shipyard production system	• Delete duplicate data • Analysis collected data and refine the data	• Execution and operation information of shipyard production system
	Real-time metadata gathering	• A component for gathering and collecting various types of manufacturing raw data in real time	• MES • IoT	• Production results of shipyard work site worker • Operation information of shipyard work site facilities	• Organize simulation data	• Execution and operation raw data of a shipyard production system
Output data reporter	Report modeler	• A component for modeling report forms to export simulation results		• Report form requirements	• Elaborate a simulation report form as per reporting requirements	• Simulation report form
	Manufacturing data analyzer	• A component for analyzing simulation results and data to generate a simulation report in a fixed format	• Simulation SW report module	• Simulation execution results • Simulation report form	• Analyze simulation results based on the simulation report form • Define formulas to calculate required value in report form • Calculate required values according to the formulas	• Analysis report of simulation execution results
	Universal exporter	• A component to export analysis results in various formats	• XML-based report format	• Analysis report of simulation execution results • Requirements of simulation report file format	• Generate a simulation analysis report according to the required file format	• Analysis report file of simulation execution results

Abbreviations: MRA: Multi Resolution Architecture; SDX: Simulation Data eXchange; NESIS: NEutral SImulation Schema; IGES: Initial Graphics Exchange Specification; XML: eXtensible Markup Language; STEP: Standard for the Exchange of Product Model Data; XVL: eXtensible Virtual world description Language.

Table 3 Mapping matrix between simulation framework components and shipyard simulation cases

	6-Factor data						Standard model	
	Product	Process	Facility	Space	Human	Schedule	Neutral model	Knowledge base
	Platform component							Simulation base
Category	Product control	Process control	Facility control	Space control	Human control	Schedule control	Knowledge control	DES kernel
Block logistics (DSME)	• Block properties (size, weight)	• Block routing information	• Transporter • Jig • Work space • Road	• Yard	• N/A	• Start and finish dates for each process	• N/A	• N/A
	• Decision-making support for selecting transporters and work space by extracting the properties of a block	•	• Transporter operation logic • Jig operation logic • Minimum path calculation	• Yard operation logic • Space share calculation	• N/A	• Control of start and finish time of each process • Production record monitoring	• Heuristic algorithm on determination of yard	• Commercial kernel
Indoor shop (SHI)	• Properties of steel and parts • Steel → parts relation • Parts → block relation	• Steel stowage, cutting, part selection, subassembly	• Cutting equipment • Crane • Subassembly conveyor	• T/R Bay • Selection of parts and waiting area	• Subassembly personnel allotment	• Start and finish dates for each process	• N/A	• N/A
	• Part generation after steel cutting process • Start subassembly after checking available parts		• Cutting time considering cutting length for each production series • Conveyor tact operation • Crane moving logic	• N/A	• Personnel assignment according to required working time of subassembly	• Control of start and finish time of each process • Production record monitoring	• N/A	• Commercial kernel
Master schedule (SPP)	• Assembly BOM • Manufacturing BOM • Block and subparts information	• Post-cutting, pre-erection processes	• Crane • Transporter • Various equipment	• Whole yard	• N/A	• Start and finish dates of the master plan activities • WOD start and finish dates	• N/A	• N/A
	• Composition of block and subparts tree by analyzing the assembly BOM codes • Identification of input parts information for each process by analyzing the routing codes	• Definition of processes of each factory by taking interviews from field workers and on-site person in charge	• Definition of facility operation rules by taking interviews from field workers and on-site person in charge	• N/A	• N/A	• Control of start and finish dates of the master plan activities • Control of start and finish dates of the WOD activities	• Control of rules that assign workload when there exists alternate bays	• S1 in-house development

to various constraints. This study shows a case where the simulation framework is applied to validate a shipyard master plan.

The purpose of constructing simulation system must be decided in order to establish a simulation system using the shipyard simulation framework. The purpose of the simulation can also set the goal for not only improved shipyard productivity but also business process enhancement or cash flow enhancement. However, the purpose of constructing the simulation system must be specific, explicit, and expressed using quantitative KPI.

This study sets the purpose of the simulation system as maximizing the output. To maximize the output corresponds to time among the items in Fig. 8, and the VDT development focused on "increase bottleneck utilization" among the four corresponding factors, as shown in Fig. 9a. Therefore, the KPI of the established simulation system was decided to be the utilization of resources.

The next step is to configure the module that matches the purpose of the established simulation system among the simulation platform components. The verification analysis for the master plan to calculate the utilization of resources is based on DES simulation, and the components related to the input and the output of data for connecting external data must be selectively constructed. A DES simulation component developed for shipyards was used in this study, which includes the data exchange module that simplifies the connection with the enterprise system that manages the information of the shipyard production plan.

The variables necessary for performing the simulation must be selected after the simulation system components. The variables necessary for performing the simulation can be divided into product, process, workforce, space, facility, and schedule on the basis of the six factors, and these 6-factor variables can be configured in the block building schedule simulation targeted in this study, as shown in Fig. 10.

The next step is the configuration of the simulation system, which considers the specifications suggested by the simulation platform. Here, the shipyard production standard simulation model can be used. Figure 11 shows the results of the considered

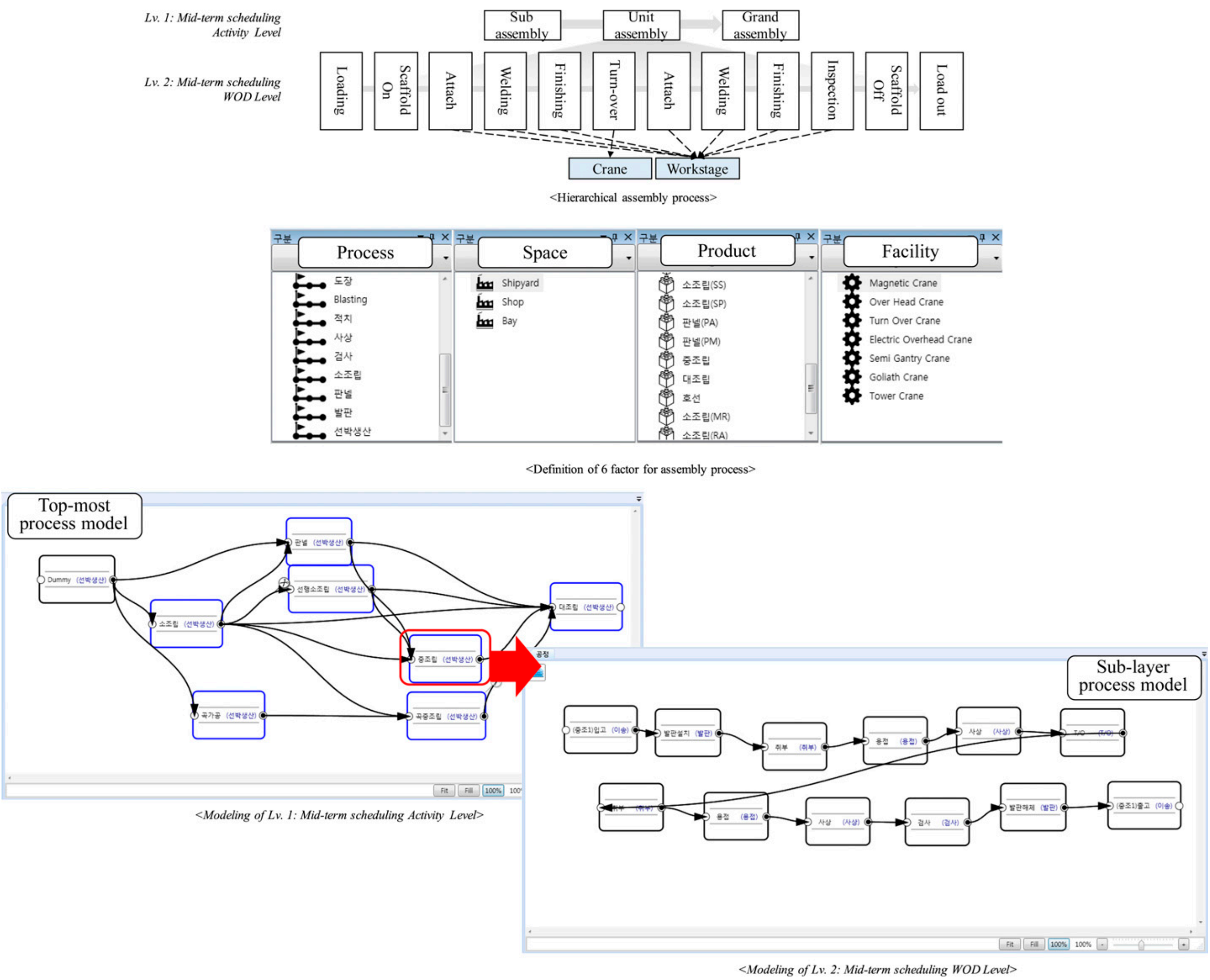


Fig. 11 Simulation model for shipyard master plan validation

simulation model configuration of the shipyard assembly workshop to verify the master plan. The proposed simulation platform uses the process-centric simulation modeling method. Therefore, it considers the connections among facilities, rather than the connections among the processes, as the existing commercial simulation software does, and the facility and the product are entered to each constraint of the process.

Final step is to run the simulation model and to analyze the results. As mentioned above, the target measuring index is utilization of each work stage. The resource constrained scheduling of each block is also conducted with the joint testing with the production manager of S shipyard. Figure 12 shows the utilization of each work stage with the variation of available crane conditions, where the utilization is calculated based on the simulation result and corresponding formulation. Figures 13 and 14 show the scheduling result of each block that is assembled through the entire unit assembly line, where two kinds of operational strategies (fast tracking) are compared in a quantitative way. Also, it is identified that

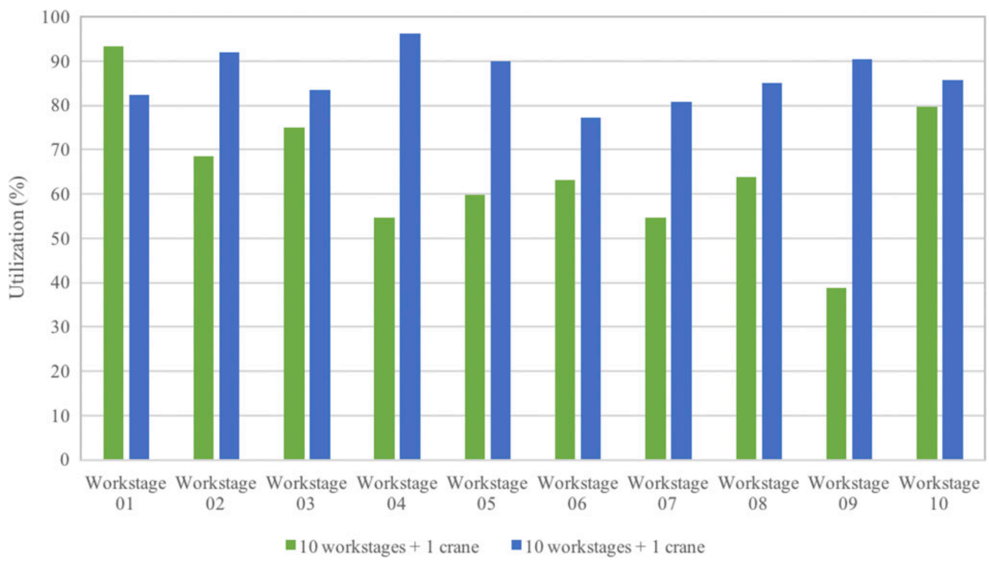


Fig. 12 Simulation result of work stage utilization

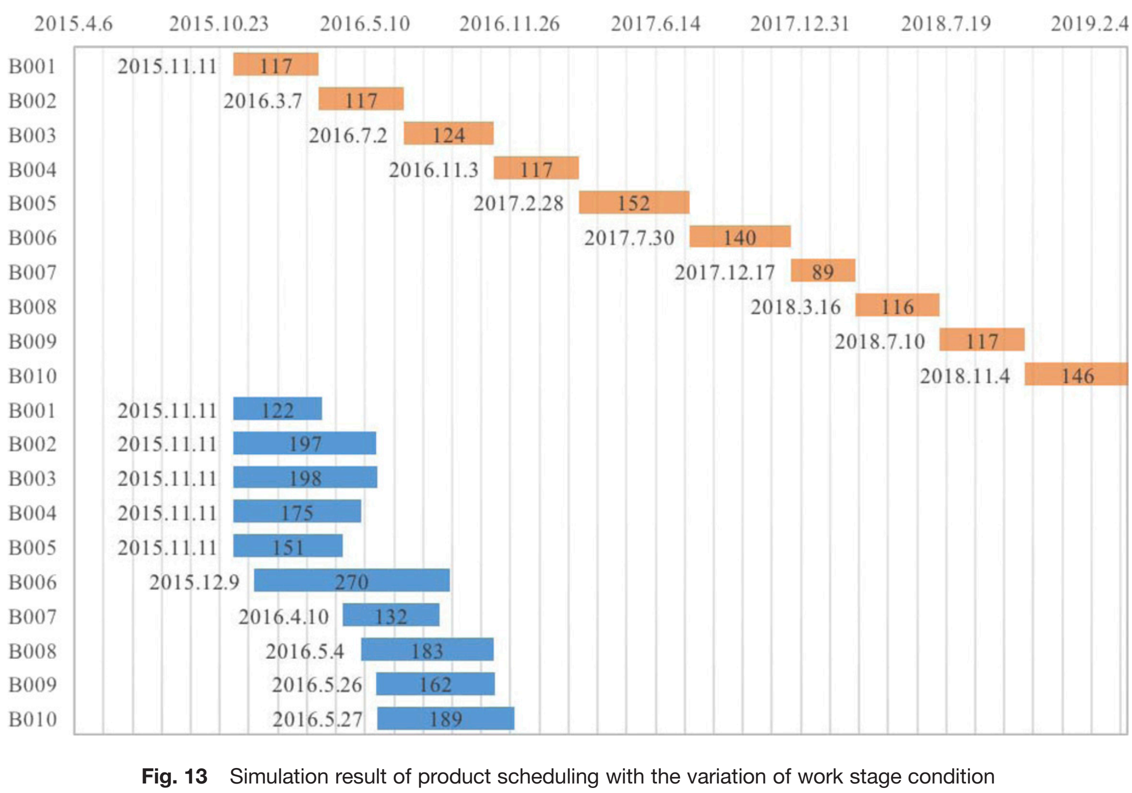


Fig. 13 Simulation result of product scheduling with the variation of work stage condition

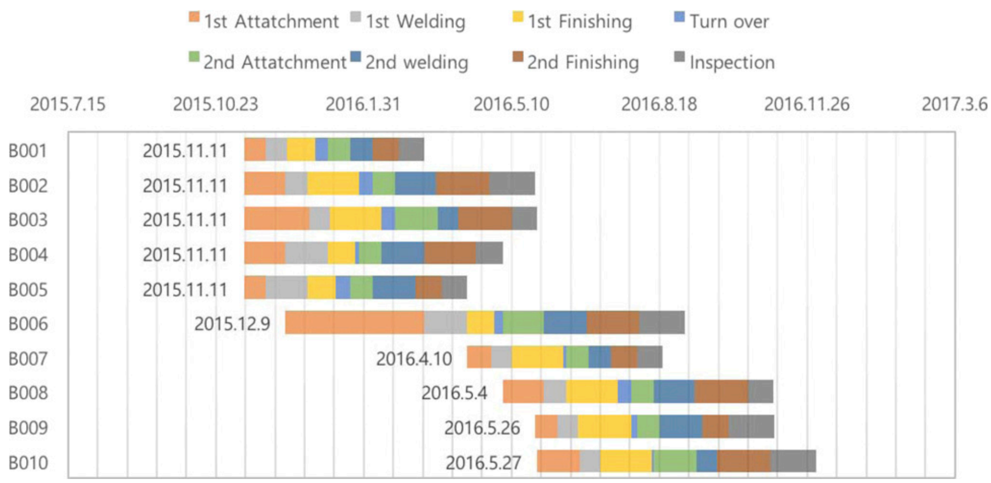


Fig. 14 Simulation result of detail product scheduling with the variation of work stage condition

the detail executable scheduling could be obtained as shown in Fig. 14, which is broken down from the result of Fig. 13.

7. Conclusion

Corporate competitiveness involves the areas of administrative management, customer management, development management, and supply management. This study introduces a simulation framework focusing on simulation-based production management technology as one of the ways to strengthen the supply competitiveness for the rapid, accurate prediction of the variability and the uncertainty of the supply system.

The simulation framework is composed of a KPI system based on VDT, a 6-factor information model, and a simulation platform that allows flexible development. The KPI system based on VDT targets the accurate KPI identification of the management subject, and the 6-factor information model reasonably classifies the company's information related to the identified KPI, thus targeting a smooth connection between the base system and the target system. The simulation platform, as the technical core, offers a component-based development environment that can smoothly add the targeted system function according to the kernel of the simulation center.

To verify the feasibility of the proposed simulation framework, a simulation model that maximizes the output, which is an important management subject for shipyards, was constructed, which yielded useful results. Using the proposed simulation framework, a comprehensive study will be performed in the future with regard to the construction of not only a fragmentary production management system but also a sustainable virtual management platform using Industry 4.0 or CPS. These are the recent issues for the advancement of the manufacturing industry.

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