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ARTICLE

Development of an evaluation framework of production planning for the shipbuilding industry

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ABSTRACT
Shipbuilding competitiveness can be improved by implementing a production planning system that reflects production environments and can achieve a high degree of completion. Unfortunately, even South Korean shipbuilders, which are the world's most competitive, lack relevant research on the objectives, and a comprehensive evaluation method for the systemisation of the production planning process and the results of production planning. This study proposes a comprehensive ship production planning process by analysing production planning tasks executed in major South Korean shipyards. In addition, it proposes an evaluation framework and an evaluation system to assess production planning based on an integrated production planning process. The evaluation framework consists of the planning stage and the stage of operation in a company, thereby enabling evaluation of production planning from multiple perspectives. In addition, while establishing the evaluation system for the results of production planning in large-scale shipyards, the study presents the core items necessary to introduce and build a real evaluation system through the framework.

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KEYWORDS
Planning; scheduling; shipbuilding; evaluation framework

Introduction

Background

Since 2015, South Korea (hereafter, Korea) has maintained its first place in the world's shipbuilding order book by capturing 41% of all orders.[1] Korea is the base for the world's top 5 shipbuilders, while 7 out of the top 10 shipbuilders are Korean companies. However, with the continuation of the recent recession in the shipbuilding industry, the operations of those shipbuilders have suffered more serious losses and their order records have decreased drastically, resulting in large-scale restructuring and downsizing. Among the many causes of the crisis in the Korean shipbuilding industry, the key ones are severe competition with Chinese shipbuilders, the long-term economic recession and the failure of business reorganisation around offshore plants. As the competition in the shipbuilding market becomes harsher and the offshore plant industry appears to be growing, major Korean shipbuilders have attempted to win as many orders as possible while reorganising their businesses around offshore plants. However, Korean shipbuilders have not been fully prepared to construct offshore plants. This hasty business reorganisation has generated unexpected, astronomical losses. The shipbuilders are seeking a diagnosis for their difficulties and a fundamental improvement in competitiveness.

In the shipbuilding industry, competitiveness consists broadly of product development and production. In comparison with Chinese or Japanese competitors, Korean shipbuilders excel in product development. On the other hand, with respect to production, a competitive shipbuilder is equipped with capability and efficiency in facilities and workforce, and the capability to manage the production process systematically. However, Chinese shipbuilders appear to be competitive fast followers in terms of the capability and efficiency of facilities and workforce, while Japanese shipbuilders seem to be more competitive in terms of production management capability.

In order to realise systematic production management, such factors as production process, inventory, human resources, quality, operation process, operation activity, material and production schedule need to be managed in an integrated way, and a supporting system is required. In particular, among the main activities of production management, production planning is a core process that determines a product need date (PND), manages inventory and provides necessary information for human resource planning, including outsourcing. The goal of production planning is to improve the accuracy of production management and to raise productivity by optimising the management of available resources. In this regard, production planning is essential for securing production competitiveness.

Despite the importance of production planning, no systematic and integrated concept of production planning for shipyards has been fully developed. Moreover, since production planning is evaluated separately at each decision-making level, from the chief executive officer to the production manager on site, or at each functional department, from production to sales, it is difficult to draw a comprehensive conclusion. Thus, this research aims not only to establish a systematic and integrated process of production planning but also to propose

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an evaluation framework of production planning to build a system that can evaluate production planning comprehensively enough to cover every decision-making level and functional organisation.

Literature review

Between the 1980s and early 1990s, the basic concept of production management and production planning for shipbuilding was established, and research that addressed production planning focused on the connection with product design and process planning. Yoon and Kim (1993) analysed requirements for the initial development of a process planning and scheduling support system and established the concept for its development.

Later in the 1990s, research concerning production process planning was actively undertaken. Its main focus was an individual process, like erection, PE (pre-erection), assembly and fabrication. At that time, various methods, such as the genetic algorithm and heuristic approach, were utilised for research on production planning and production load balancing (Choi et al. 1996; Cho and Kim 1997; Lee and Hong 1994; Lee and Kim 1995; Koh 1996; Woo, Ryu, and Hahn 2003).

On the other hand, two research projects have been conducted, setting a foundation for the production planning system currently used by many Korean shipbuilders. The first project is Computerized Ship Design and Production System (Lee 1993), conducted by the Korea Research Institute of Ships and Ocean Engineering. This project developed a ship production scheduling system using ship models, including a piping arrangement model. The process planning system developed by this research covers cutting, fabrication, assembly and welding on the basis of the shape information of parts, assembly stage and bill of material information. In addition, a technique was developed to extend this system to production planning by considering available resources.

For the second research project, Daewoo Shipbuilding and Marine Engineering developed an integrated expert system reflecting the characteristics of production planning for shipbuilding (Lee, Lee, and Choi 1996). Called Daewoo Shipbuilding Scheduling (DAS), this project developed scheduling systems, including DAS-ERECT for determining an erection schedule, DAS-PANEL for setting up a flat block assembly schedule and DAS-CURVE for establishing a curved-block arrangement schedule.

Later, each shipbuilder, such as Samsung Heavy Industries, Hyundai Heavy Industries, and Dawoo Shipbuilding and Maritime Engineering, carried out research on such areas as production planning and job process innovation through information strategy planning, business process reengineering and process innovation. Along with this trend of integrated innovation, other researchers have addressed production planning methods and algorithms by considering the characteristics of the ship production planning process (Im 1994; Liu, Chua, and Yeoh 2011; Persona, Regattieri, and Romano 2004; Tu 1997), developed a system for efficiently executing a production planning process (Kim and Lee 2007; Lee, Kim, and Kim 2008), and considered a scheduling method using optimisation and simulation (Krause et al. 2004; Varghese and Yoon 2006). In particular, research has been conducted on planning and management of production processes using Markov decision processes (Dong et al. 2016) or simulation models (Back et al. 2017) for naval vessels and offshore plants that have complex outfitting processes. Recently, a shipbuilding planning system using the concept of constant work-in-process has been proposed considering the characteristics of the shipbuilding process (Yue, Rui, and Yan 2017), while research related to the supply chain management technique has been conducted considering the characteristics of the shipbuilding industry (Mello et al. 2017).

Cho et al. (1998) conducted a study on the hull block assembly plant planning system. To determine the assembling order of multiple blocks, they proposed a scheduling methodology that allocates resources using a heuristic algorithm and loads are levelled through bottleneck process identification. Hwang et al. (2014) developed a diagram-based representation method for modelling block distribution work in the master planning stage to execute the block distribution plan automatically, based on the expert's knowledge. Kang, Seo, and Chung (2017) determined the assembly sequence that minimises welding deformation, considering the geometry of the block. Chryssolouris et al. (1999) proposed a methodology for short-term production planning in shipyards and proposed hierarchical models of factory, job shop, work centre and resources. In addition, task allocation logic based on dispatching rule is applied to the lowest level resources of the hierarchical structure. Job flow time, job tardiness, number of tardy jobs and capacity utilisation are applied as evaluation indices for planning. Chryssolouris, Mourtzis, and Makris (2003) extended the existing study (Chryssolouris et al. 1999) to validate the proposed method by applying the production management system of the repair shipyard, including the material management and procurement process to the actual shipyard.

Research and development so far have concentrated on designing functions for production planning and implementing such functions in a computer system so that they can be applied to production management tasks in a shipyard. However, the validity of plan information formed by a computer system is assessed mostly based on the experience of those in charge of production planning. In other words, since there has been widespread belief that the evaluation of production planning in the shipbuilding industry should depend on the experiential knowledge of staff in charge, there has been little academic research attempting to systematise the evaluation of production planning or to improve the efficiency of the planning process through the evaluation.

In addition, several studies, led by academics such as Cho et al. (1998), Chryssolouris et al. (1999), Chryssolouris, Mourtzis, and Makris (2003), Hwang et al. (2014) and Kang, Seo, and Chung (2017), are academically meaningful and helpful practical studies in shipbuilding production planning but cannot systematically evaluate established plans.

Research objectives

The evaluation system of production planning is an enterprise-level management system that needs to be built based on the related organisation and job processes of the company. For

Table 1. Detailed classification and details of production plan of shipbuilding industry.

Classification		Plan area	Details
Semantic	Explicit		
Strategic plan	Product-mix plan	Planning	• Determination of product mix and dock turnover rate • Determination of product information and principal key events
Capacity plan	Long-term production plan		• Capacity management of human resource and main resources • Management of plan information for strategic plan and ship (allocation of quantity/working time, determination of progress rate)
Master plan	Mid-term production plan		• Determination of mid-term activity plan for strategic plan and product mix
Operational plan	Short-term production plan		• Determination of detailed short-term activity plan for mid-term plan
Execution schedule		Scheduling	• Allocation of workforce to execution job, analysis of production level, issue of work order, aggregation and analysis of results
Production plan		Supporting	• Extraction of shapes of components or products from design information • Determination of production method at site according to functions of components or product
Standard information management			• Standard working time management • Standard unit time management, etc.

this reason, a systematic methodology and framework are required for evaluating production planning.

This study proposes a framework for establishing an evaluation system of production planning in a shipyard. Our evaluation framework of ship production planning is developed based on the Zachman framework, which is usually implemented at the stage of architecture concept design of the enterprise architecture framework (Zachman 1987). The Zachman framework is a logical structure or architecture proposed to integrate the components of an enterprise information system. This framework suggests ways to analyse an enterprise according to its perspectives and focuses. A unit cell can be defined by a combination of a perspective and a focus, and necessary components can be identified using the unit cell. This enables the classification of the evaluation measure into a production planning stage and a production planning perspective to present key information necessary for the evaluation of production planning and a detailed method to pick out such information.

An evaluation system is constructed by applying the proposed evaluation framework to a real shipyard case. In practice, the real process of constructing an evaluation system for production planning is demonstrated and the detailed outcomes produced in each process are identified. Finally, the evaluation system is verified by applying our evaluation framework to the planning work of a real shipyard.

Analysis of shipbuilding production planning system

This section analyses the planning systems of major Korean shipbuilders to yield an integrated production planning process for the shipbuilding industry. The integrated production planning process not only standardises common terminology and definitions, which have been applied differently by each shipbuilder, but also proposes a guideline for a framework and detailed indicators from a planning perspective to set up the evaluation framework and system proposed in this study.

As the term ‘production planning’ is defined and classified differently by each shipbuilder and its usage has not been clearly identified yet, this study aims to define and classify the planning stage and to demarcate the scope of production planning. The plan stage is divided into planning and scheduling. In this study, planning refers to a management aspect in which a long-term plan reflecting a strategic policy is set up. In other words, this study determines ‘when’ and ‘what’ will be produced. On the other hand, scheduling refers to setting up a short-term work plan that reflects capacity-related constraints, such as facility, work stage and workforce, and thus, can be implemented at a real shipyard. ‘Short-term production planning’ is another name for ‘scheduling’. Specifically, the process of scheduling allocates resources (where, who) needed for implementing the plan (what, when) that has been determined in the planning stage.

The plan-related terminology that is generally used in a shipyard includes functional areas, like strategic plan, capacity plan, master plan, operational plan, execution schedule, production plan and standard information management.

According to the abovementioned definitions, strategic, capacity, master and operational plans belong to the planning area that determines when and what will be produced; on the other hand, the execution schedule corresponds to the scheduling area, since it involves actual work carried out by reflecting constraints concerning the facility, work stage, workforce and equipment. Production plan and standard information management are not directly related to scheduling but provide basic or standard information necessary for determining plans. Accordingly, these functional stages have been classified as a supporting area. Table 1 presents the terminology of production planning for the shipbuilding industry and its definitions.

Evaluation framework of production planning

Necessity for an evaluation framework of production planning

Each shipyard prepares plans by using a functional stepwise method like the integrated shipbuilding production planning process described in Section 'Analysis of shipbuilding production planning system'. A planning result is examined in various ways before being implemented in a real shipbuilding site. In case any problem is found, an appropriate measure needs to be provided and various plausible alternatives proposed. In addition, a planner tries to improve the degree of planning through various activities, like reflecting the results of real production and rescheduling. A planning result can be analysed differently according to various perspectives. The importance of an issue is not constant, but the priority of a necessary plan varies according to the enterprise-level situation. Thus, a planning result should be analysed from various perspectives, and information available in the plan needs to be maximised to present an alternative to real problems of shipbuilding sites rather than fragmented analysis. For this reason, a systematic evaluation method that enables multilateral and effective analysis is necessary.

The conventional method of evaluating a planning result is qualitative analysis that depends on the evaluator's subjective judgement. Even if quantitative analysis were performed, it would focus mainly on whether the planning result was adequate for the corresponding planning objective. The planning objective usually reflects only the perspectives of a particular planning stage. In other words, an assembly master plan is evaluated by an evaluator of the assembly master plan, who examines how the plan satisfies the objective of the assembly master plan. Table 2 shows the planning objectives and the corresponding planning results of each stage that are generally adopted in shipyards.

The most serious problem with the current evaluation method is that there is no systematic methodology for evaluating production planning. Most evaluation research depends on particular groups of evaluators or the personal know-how or experience of the evaluators. Accordingly, if there is no necessary experience or high level of understanding about related planning information, the evaluation itself is often impossible. Moreover, even if the evaluation work is conducted, a single perspective of the individual planning stage is applied. Comprehensive evaluation that considers the entire planning process is difficult or hardly possible.

Evaluation framework in a shipyard

The evaluation framework of production planning proposed in this study has the following three characteristics. First, it has a systematic evaluation measure for each planning stage and planning perspective. Second, it systematically manages key information for evaluation of production planning. Finally, it enables an evaluation system to be implemented quickly and managed effectively. This study proposes a method of arranging evaluation criteria for each planning stage and reflecting various views of decision-making members in a shipyard. In addition, it presents essential items for comprehensive and systematic evaluation; that is, objectives, methods, connectivity, evaluators and periods, and to suggest a detailed method of arranging the core content of each evaluation item. Our evaluation framework is an application of the Zachman framework (O'Rourke, Fishman, and Selkow 2003; Sowa and Zachman 1992; Zachman 2003), which is usually implemented at the architecture concept design stage of enterprise architecture.

The key point of an evaluation framework for shipbuilding production planning is to define essential information for arranging evaluation criteria for each planning stage and perspective, and for evaluating production planning through the abstraction of information. This can be expressed by a three-dimensional schema that is formed by adding the axis of the planning stage to the two-dimensional schema of the Zachman framework (Table 3) In this framework, the axis of the planning stage of the three-dimensional schema has four stages of strategy planning, capacity planning, master planning and operational planning, while the axis of the evaluation perspective includes the six perspectives of marketing, design, production, procurement, finance and personnel. Moreover, the framework is constructed to define key information of evaluation, including method (how), connectivity (where), agent (who), time (when) and objective (why), for the evaluation measure (what) identified by each planning stage and each evaluation perspective (Figure 1). To understand the relationship with the Zachman framework further, the *Y* axis of the original Zachman framework (Table 3) is referenced as the perspective axis in the author's framework (Figure 1). In addition, the *X* axis of Zachman's is referenced as key information axis in the author's framework.

The proposed evaluation framework of production planning has the three axes of planning stage, evaluation perspective

Table 2. Examples of planning results for planning objectives in each stage of production planning of a shipyard.

Stage	Planning objective	Planning result
Strategic plan	• On-time delivery • Optimal construction of product mix • Maximum dock turnover rate • Maximum utilisation of quay and dock	• Optimal product mix is configured to utilise maximum dock and quay and to reflect objectives of management strategy • Major node schedules are determined so that a complete ship is delivered on time and the dock turnover rate (annual batch number) can be maximised at the same time
Capacity plan	• Maximum utilisation of human resources from mid- and long-term perspectives • Maximum enterprise-level operation rate (utilisation) of main resources • Accurate prediction of production	• Set up capacity plan that can maximise the enterprise-level operation rate of main resources and the utilisation of available human resources • A measure is prepared to achieve a production goal, including outsourcing plan
Master plan	• Improvement of productivity by load balancing	• Validity of strategic plan and capacity plan is examined • The plan balances the loads of each process
Operational plan	• Accurate establishment of specific schedule • Optimal distribution of materials among working groups and workstages • Improvement of productivity by load balancing	• The degree of master plan is verified • Balanced distribution of materials for each working group and workstage • Preparation of specific plan that balances the loads of each process

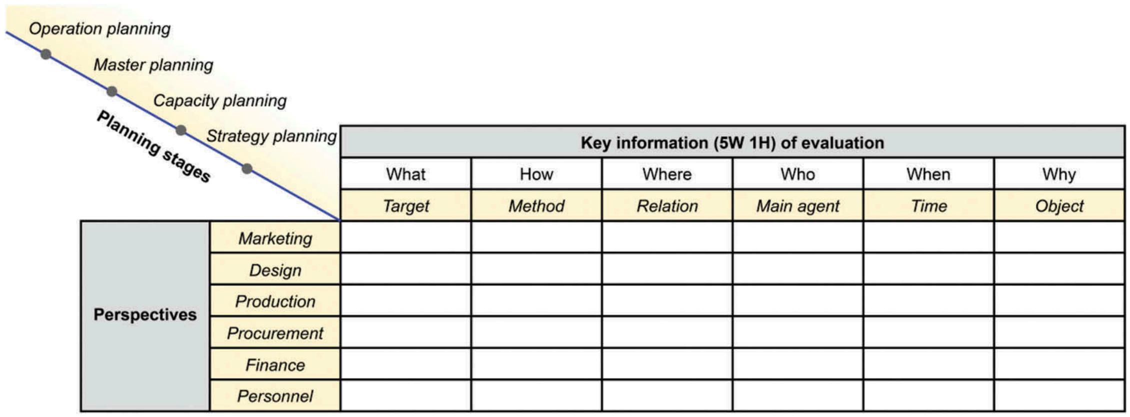

Figure 1. Evaluation framework of production planning for shipbuilding industry.

and key information of evaluation. As the method of describing the key information of evaluation is not defined differently according to the planning stage and evaluation perspective, the definition of the three-dimensional cell is ultimately simplified to the definition of the key information of evaluation. In other words, the axes of the planning stage and evaluation perspective in the framework are used to classify the evaluation measure of the key information of evaluation. When the remaining five abstracted components of key information (evaluation method, evaluation connectivity, evaluation agent, evaluation time and evaluation objective) are defined for the classified evaluation measure, the cell definition of the three-dimensional classification schema is completed (Figure 2).

An evaluation framework is an execution tool that constructs and introduces an evaluation system quickly and easily by defining minimum items and construction method. Accordingly, it is essential to define necessary information for the fast and convenient construction of an evaluation system using a framework. A cell of an evaluation framework can be composed of stages that define evaluation measure, method, connectivity, agent, time and objective. This corresponds to the process of deploying key information about specific evaluation items under the so-called ‘five Ws and one H’, as shown in Figure 1.

Among the ‘five Ws and one H’ of key information about a specific evaluation item, the stage of ‘what’, in which an evaluation measure is determined, classifies the measures that can be derived according to the perspective of the corresponding planning stage. At this time, an appropriate range of content is to be defined so that the evaluation measures are not classified too minutely. Table 4 shows the method of classifying evaluation measures for an evaluation item.

Next, the stage of ‘how’, in which an evaluation method is derived, prepares a formula, criteria, and list of evaluation measures, and applies the evaluation measure for the planning process and results to be evaluated. In other words, for the evaluation measures defined at the stage of classifying evaluation measures, a list of evaluation results and a specific formula and criteria for each list are prepared. Table 5 presents the process of preparing an evaluation list and criteria for a particular measure.

The stage of evaluation connectivity, which corresponds to ‘where’ of the key information, connects an evaluation measure and another relevant evaluation measure belonging to another area. This stage constructs a matrix formed by combining the perspective of planning execution and the planning stage, and displays evaluation measures highly related to the target evaluation item, as shown in Table 6. The table indicates that, when the measure MP-MFG-001-001 is examined, CP-MFG-001-002 and MP-PRC-001-001 need to be considered together.

The stage of evaluation agent describes in detail the information related to evaluation items. The information should include department and staff in charge, the person who undertakes the evaluation and the date of evaluation. The objective of the evaluation should be described clearly. Table 7 shows the process of this stage, which is the ‘who’. The stage of defining evaluation time describes the impact of each evaluation measure on an enterprise-level situation (Table 8). Finally, the stage of ‘why’ describes the objective of the evaluation in detail.

Construction of an evaluation system of production planning

In this section, based on the evaluation framework set up in previous chapter (‘Evaluation framework of production planning’), the study proposes a method to build an evaluation system of planning results in a large-scale shipyard and presents key items necessary for implementing the system.

When an evaluation system is constructed, the following tasks need to be performed. (1) The outline of the system, which describes the background and objective of preparing the system, is written. (2) Basic information of evaluation, such as planning stage, evaluation perspective and organisational system, is defined. (3) Evaluation measures of an evaluation framework are classified according to planning stage and evaluation perspective. (4) An objective of production planning that corresponds to the evaluation objective is described and a corresponding list of evaluation measures is derived. The derived list of evaluation measures needs to be mapped to the objective of production planning, and a weight factor is assigned. Finally, when the key information for each evaluation measure is described according to the cell definition of the evaluation framework, the evaluation system can be completed (Figure 3).

Table 3. Zachman framework.

	Data	Function	Network	Organisation	Schedule	Strategy
	Entities (what)	Activities (how)	Locations (where)	People (who)	Time (when)	Motivation (why)
Planner	Lit of things important to the business	List of processes the business performs	List of locations in which the business operates	List of organisations important to the business	List of events significant to the business	List of business goals/ strategies
Owner	Semantic model	The business process model	The business logistics system	Work flow model	Master schedule	Business plan
Designer	Logical model	Application architecture	The distributed system architecture	Human interface architecture	Processing structure	Business rules
Builder	Physical data model	System design	Technical architecture	Presentation architecture	Control structure	Rule design
Subcontractor	Data definitions	Programs	Network architecture	Security architecture	Timing definition	Rule specification

Outline of evaluation system

When the outline of an evaluation system is established, the background and objective of the system are described. The objective should be defined clearly, and the method of constructing the system needs to be determined in detail. Generally, the outline is prepared based on the following three items (as the outline is written in essay style to consider the financial status and yard situation of the shipbuilder, no example is provided):

- Specification of planning objective,
- Comprehensive analysis of planning result,
- Enhancement of planning efficiency.

Definition of basic information of evaluation system

The basic information of an evaluation system consists of the planning stage, evaluation perspective and organisational system. As each shipyard that is willing to apply an evaluation system might set up a production plan at a different stage and might have different evaluation perspectives, it is necessary to clearly define the planning stage and evaluation perspectives before constructing the evaluation system. Assuming that a planning process conforms to the integrated production planning process proposed in Section 'Analysis of shipbuilding production planning system', the planning stage can be divided into the four substages of strategic plan, capacity plan, master plan and operational plan, as shown in Table 2. Moreover, the evaluation perspectives can be expressed by extending the basic perspectives (*Y*-axis of Figure 2) defined in the evaluation framework presented in the previous chapter (Evaluation framework of production planning), as shown in Table 9. The basic perspectives are marketing, design, production, procurement, finance and personnel. These planning stages and evaluation perspectives are allocated as key elements of evaluation items and measures constituting an evaluation system.

Classification and list of evaluation measures

The classification stage of evaluation measures classifies the list for each planning stage and evaluation perspective in accordance with the classification method defined by the evaluation framework of shipbuilding production planning. At this stage, identification numbers are given to structuralise the classification. Table 10 presents specific evaluation measures for master plans. These measures are related to items concerning 'load balancing' and 'schedule adherence', which seem to be the core items among generally available evaluation items for a large-scale shipyard.

Establishment of planning goal and mapping of evaluation measure

The stage of setting goals and mapping evaluation measures determines planning goals, maps evaluation items and measures onto the goals, and attributes weight factors. This stage is the most essential part in the construction of an evaluation system. A production planning goal can define either a broad range, such as maximisation of enterprise-level profits and enhancement of

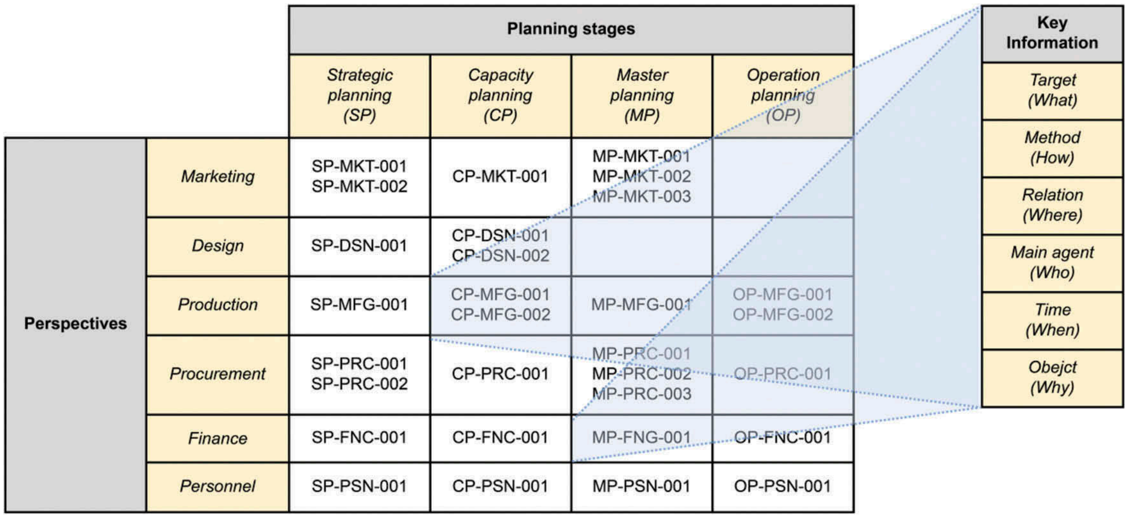

Figure 2. Cell definition of evaluation framework.

Table 4. Contents of evaluation items and measures (key information about 'what').

ID	Planning stage	Perspective	Evaluation item	No.	Evaluation measure
Identification number of evaluation item (e.g. SP-MKT-001), which comes from the cell definition of Figure 2)	Planning stage related to the evaluation item (horizontal axis of Figure 2)	Business area of evaluation perspective (vertical axis of Figure 2)	Evaluation item regarding relevant planning stage and evaluation perspective	001 002 003	• Evaluation measures are listed, which provides measures for the relevant evaluation item • Multiple measures could be listed for one evaluation item

Table 5. Contents of evaluation method and criteria (key information about 'how').

Evaluation measure	Item list of evaluation measure	Weight factor (%)	Upper limit	Lower limit	Criteria and formula
• This field relates to the evaluation measure of Table 4 • Evaluation entry list and criteria/formula are described here	• How the relevant evaluation measure could be quantified is described here • Multiple entries can be created	Weights of each item are written here according to importance	Upper limit of designated evaluation method	Lower limit of designated evaluation method	Evaluation criteria for each item are written here.

Table 6. Connectivity matrix of evaluation measures (key information about 'where').

MP-MFG-001-001	Building plan	Capacity plan	Master plan	Operational plan
Marketing				
Design		CP-MFG-001-002		
Production				
Procurement			MP-PRC-001-001	
Finance				
Personnel				

Table 7. Table of people and departments in charge of evaluation (key information about 'who').

Evaluation measure	Department	Business headquarters	Objective
This field relates to the evaluation measure of Table 4	• Department (e.g. sales, production and design) responsible for relevant measure is written here • Normally, multiple departments are designated	Headquarters (e.g. commercial ship and offshore plant) overseeing departments is written here	The goal of each department on the evaluation measure is written here

productivity, or a particular local situation, like minimisation of confusion in an assembly workshop. After a list of planning goals is prepared, a mapping table needs to be constructed by selecting evaluation measures from the list (Table 10). When evaluation measures are completely mapped onto each planning goal, each evaluation measure is given a weight factor. If there is no evaluation measure corresponding to an item, a new measure can be added and utilised. Table 11 shows the mapping results of evaluation measures for the planning goal 'stabilisation of assembly production load'.

Table 8. Table of persistence and importance of each evaluation measure (key information about 'when').

Evaluation measure	Required measurable situation	Persistence	Importance
This field relates to the evaluation measure of Table 4	• This part describes the measurable yard situation that needs to be monitored to produce a list of results for that evaluation measure • Multiple situations could be designated	• An observation cycle is written here • Observation cycles can be persistent or specific	An importance score based on the impact on the performance measure is written here

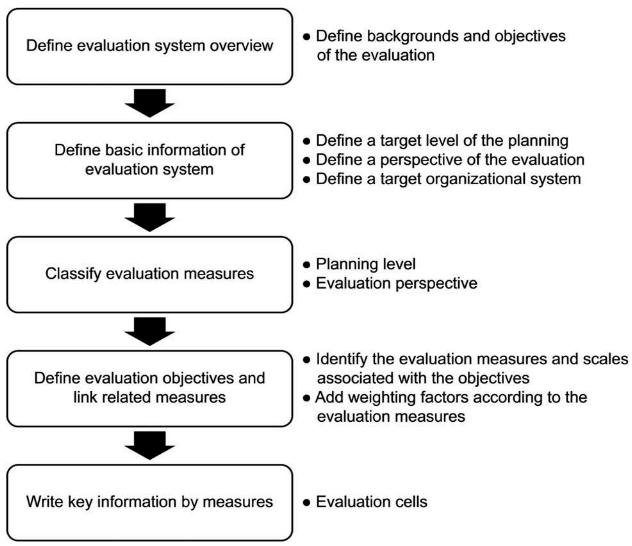

Figure 3. Development procedure of evaluation system.

Table 9. Exemplar definitions of evaluation perspectives.

Perspective	Contents	Core issues
Marketing	Evaluation perspective on sales, marketing and management strategy	• Winning a contract • Customer relations • Enterprise-level objective • Sales
Design	Evaluation perspective on design and process management	• Product shape • Product performance • Customer specifications • Drawing release plan
Production	Evaluation perspective on production management	• Production resource • Production schedule • Production capability
Procurement	Evaluation perspective on purchase, procurement and distribution	• Distribution • Delivery date • Work-in-process
Finance	Evaluation perspective on enterprise-level money flow	• Production cost • Profit • Money flow
Personnel	Evaluation perspective on human resource management	• Human resource management • Outsourcing management

Determination of key information for each evaluation measure

When the list of evaluation measures, the list of planning goals and the mapping of evaluation measures are completed, as shown in Table 11, key information introduced in the previous chapter ('Evaluation framework of production planning') is determined for each evaluation measure, thereby completing the evaluation system. The key information is determined by constructing an evaluation framework cell based on the 'five Ws and one H' defined previously (Figure 2). This study contains examples of key information corresponding to 'how' (Table 12) and 'where' (Tables 13 and 14) for 'assembly production load balancing of master plan' (MP-MFG-001-002) of Table 11.

The example presented in Table 12 shows an evaluation method and a range of evaluation indicators for the evaluation measure 'assembly production load balancing of master plan' in accordance with the guideline presented in Table 5. This measure adopts the standard deviation of weekly assembly person hours and the standard deviation of weekly assembly production volume as the evaluation methods, and assumes the same relevance by setting a 50% weight factor for each method. In addition, each method has upper and lower limits, and any value outside the range is excluded as an abnormal value (or caution is expressed). The results of each method are three classes: high, middle and low. The evaluation methods for each evaluation measure are expressed by Equations 1 and 2.

$$\sqrt{\frac{1}{N}\sum\left(X_i-\bar{X}\right)^2} \tag{1}$$

$i = 1, 2, \ldots, N \quad , N = \text{Number of weeks}$

X_i: Person hours at week i, $\bar{X}$: Average of weekly person hours

Standard deviation of weekly assembly person hours

$$\sqrt{\frac{1}{N}\sum\left(Y_i-\bar{Y}\right)^2} \tag{2}$$

Table 10. Examples of evaluation item and measure list for master plan stage.

ID	Planning stage	Perspective	Evaluation item	No.	Evaluation measure
MP-MFG-001	Master plan	Production	Production load balancing	001	Fabrication production load balancing
				002	Assembly production load balancing
				003	PE production load balancing
				004	Erection production load balancing
				005	Block painting production load balancing
MP-MFG-002	Master plan	Production	Minimise schedule delay	001	Minimise fabrication schedule delay
				002	Minimise assembly schedule delay
				003	Minimise PE schedule delay
				004	Minimise erection schedule delay
MP-PRC-002	Master plan	Procurement	Minimise work-in process	001	Minimise work-in process of block painting
				002	Minimise work-in process of block painting
MP-PSN-001	Master plan	Personnel	Minimise available worker variability	001	Fabrication worker load balancing
				002	Assembly worker load balancing
				003	PE worker load balancing
				004	Erection worker load balancing

Table 11. Planning goals and mapping results of related evaluation items.

NO	Planning goal	Related evaluation item	Related evaluation measure	Weight factor (%)
005	Assembly production load stabilisation	Production load balancing for each job of capacity plan (SP-MFG-001)	Assembly production load balancing of capacity plan (SP-MFG-001-002)	20
		Minimisation of human resource variation in capacity plan (SP-PSN-001)	Human resource load balancing for assembly in capacity plan (SP-PSN-001-002)	10
		Production load balancing of master plan (MP-MFG-001)	Assembly production load balancing of master plan (MP-MFG-001-002)	25
		Minimisation of human resource variation in master plan (MP-PSN-001)	Human resource load balancing for assembly in master plan (MP-PSN-001-002)	10
		Production load balancing of operational plan (OP-MFG-001)	Assembly production load balancing of operational plan (OP-MFG-001-002)	25
		Minimisation of human resource variation in operational plan (OP-PSN-001)	Human resource load balancing for assembly in operational plan (OP-PSN-001-002)	10
006	Assembly production schedule and on-time delivery	On time delivery of contractual ship (SP-MKT-002)	On-time delivery of contractual ship (SP-MKT-002-001)	10
		Minimise delay in master plan (MP-MFG-002)	Minimise assembly delay in master plan (MP-MFG-002-002)	60
		Minimise work-in process in operational plan (OP-PRC-002)	Minimise stock before hull painting in operational plan (OP-PRC-002-001)	30

Table 12. Key information for an assembly production load balancing of master plan: criteria.

Evaluation measure	Item list of evaluation measure	Weight factor (%)	Upper limit	Lower limit	Criteria	
Assembly production load balancing of master plan (MP-MFG-001-002)	Standard deviation of weekly assembly person hour (Equation 1)	50	3000 MH	N/A	High	0–100 MH
					Middle	100–200 MH
					Low	200–300 MH
	Standard deviation of weekly assembly production volume (Equation 2)	50	300 ton	N/A	High	0–10 ton
					Middle	10–20 ton
					Low	20–30 ton

Table 13. Key information for an evaluation measure: matrix of evaluation connectivity.

MP-MFG-001-002	Capacity plan	Master plan	Operational plan
Production	Assembly production load balancing (CP-MFG-001-002)	Fabrication production load balancing (MP-MFG-001-001)	Assembly production load balancing (OP-MFG-001-002)
Personnel		Assembly worker load balancing (MP-PSN-001-002)	

$i = 1, 2, \ldots, N, \quad N =$ Number of weeks

Y_i: Production volume at week i, $\quad \bar{Y}$: Average of weekly production volume

Standard deviation of weekly assembly production volume

Based on the connectivity matrix of evaluation measures (Table 6) proposed in the previous chapter ('Evaluation framework of production planning'), Table 13 shows evaluation measures related to the evaluation measure 'assembly production load balancing of master plan' on the matrix of the

Table 14. Key information for assembly production loads: Analysis of evaluation connectivity.

ID	Related measure	Relation	Description of connectivity	Ground
CP-MFG-001-002	Assembly production load balancing	Leading	As the assembly schedule adjusted by the assembly work balancing of the capacity plan affects the assembly-related activities of the master plan; it also has an effect on the fabrication production load balancing	In the stage of the capacity plan, based on the balanced assembly schedule, a specific activity schedule of the master plan is determined
MP-MFG-001-001	Fabrication production load balancing	Lagging	As the assembly schedule adjusted by assembly load balancing affects the fabrication schedule, it also has an effect on production load balancing	The schedule of fabrication work is based on the schedule of assembly
MP-PSN-001-002	Assembly worker load balancing	Lagging	When the person hours of assembly work become balanced, the input of human resources in work is balanced	The human resource plan is based on the assembly production load
OP-MFG-001-002	Assembly production load balancing	Lagging	Production volume load balancing of assembly-related activity in the master plan adjusts the schedule, which again affects the production load balancing of the operational plan	The detailed activity schedule of the operational plan is based on the activity schedule determined in the stage of the master plan

planning stage and evaluation perspective. From Table 13, it is clear that the measure has a relationship with the measures of assembly load balancing of capacity plan, fabrication and assembly workers of master plan, and assembly load balancing of master plan. Accordingly, those related measures need to be considered along with 'assembly production load balancing of master plan'. Moreover, Table 14 shows some examples of the connectivity logic of items to be described.

Finally, Tables 15 and 16 show the results of assembly load balancing of master plan, which concern the main agent and time of the evaluation measures, using the guideline shown in Tables 7 and 8.

Application of the proposed evaluation framework and example evaluation

The methodology of the proposed evaluation framework and its items can be implemented directly by any shipbuilder that has constructed a production planning system. A planning evaluation system was developed to practically apply the evaluation of production planning presented in the previous chapter ('Construction of an evaluation system of production planning').

Development of evaluation application

The component-based development (CBD) method is adopted to develop the application. The CBD method is fundamentally based on object oriented technology. It is a reuse-based approach to defining, implementing and composing loosely coupled independent components into systems.

First, the use cases of the target system were investigated based on the requirements (to save space, they are not presented in this article). The use cases of the target system are shown in Table 17 and Figure 4.

After the use-case analysis, the overall application design and implementation were conducted based on the development framework of component-based development, which undergoes use-case storyboard making, user interface design, application prototyping, user interface modelling, data modelling, business component modelling and deployment modelling. Figure 5 depicts the business component model of the evaluation application, showing the overall structure of components and their relationships.

The external system in Figure 5 represents the planning and scheduling system of the shipyard. The left side of Figure 5 is the target system, structured as three-layer architecture. In the data layer, the planning service agent component, manages the

Table 15. Key information of assembly production load balancing of master plan: main agent.

Evaluation measure	Department	Business headquarters	Objective
Assembly production load balancing	Ship sales team	Ship business headquarter	• In case of winning a shipbuilding contract, judge the assembly production load situation
	Standard plan team	Production support headquarter	• Predict assembly production volume in master plan and identify problems
	Marine sales team	Marine business headquarters	• In case of winning an offshore plant contract, judge the assembly production load situation

Table 16. Key information of assembly production load balancing of master plan: evaluation time.

Evaluation measure	Required measurable situation	Persistence	Importance
Assembly production load balancing	Lack of storage space for blocks in an assembly workshop	Periodic evaluation	Middle
	Lack of assembly facility and transportation device	Periodic evaluation	Middle
	Confusion and congestion of assembly materials	Periodic evaluation	Low
	Unbalanced work load among assembly workshops	Constant evaluation	High
	Excessive outsourcing volume of assembly	Periodic evaluation	Middle
	Excessive stock of assembly blocks	Periodic evaluation	High

Table 17. Use-case analysis for the development of evaluation application.

ID	Use case	Requirement	Description	Priority
U001	Selection of evaluation target	R002 R003 R004 R005 R006	• Planning target list is available and viewable • Appropriate evaluation measure list is viewable and selectable when target planning level is selected • Evaluation measures that must be included in the target evaluation case are viewable and selectable with priority assignment	High
U002	Inquiry of evaluation result	R007 R008 R009	• Evaluation result is viewable, and the calculation progress bar should be shown before completion • The calculation result must be viewable and consider target evaluation measures and their weight factors • The detailed attributes, such as weight factor, calculation method and upper and lower limits, must be viewable when a specific evaluation measure is selected	High
U003	Inquiry of related evaluation measure	R010	• Related evaluation measures must be viewable and comparable when a specific evaluation result is selected	High
U004	Inquiry of evaluation framework	R011	• Evaluation framework of relevant evaluation measures can be viewed	High
U005	Selection of planning case	R012	• The planning cases generated at each planning stage are viewable and selectable for the evaluation target selection	Moderate

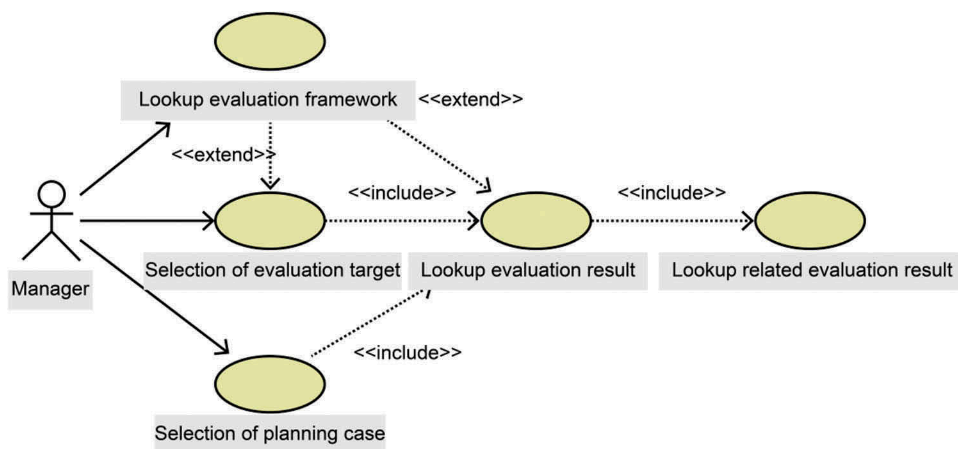

Figure 4. Use-case diagram for evaluation system development.

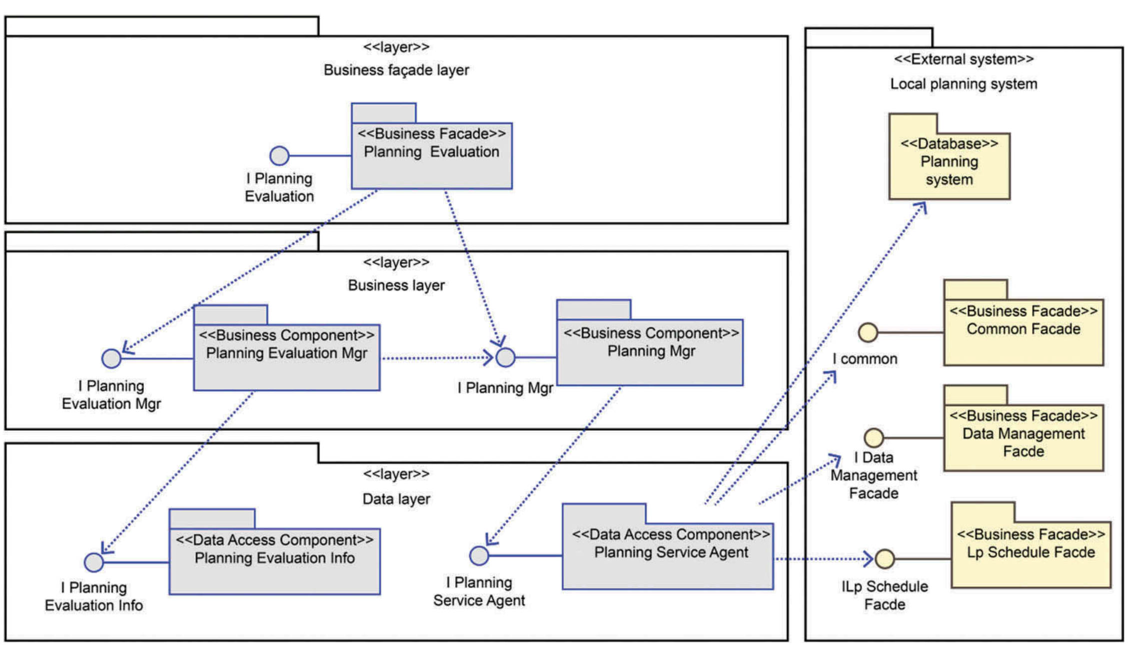

Figure 5. Business component model.

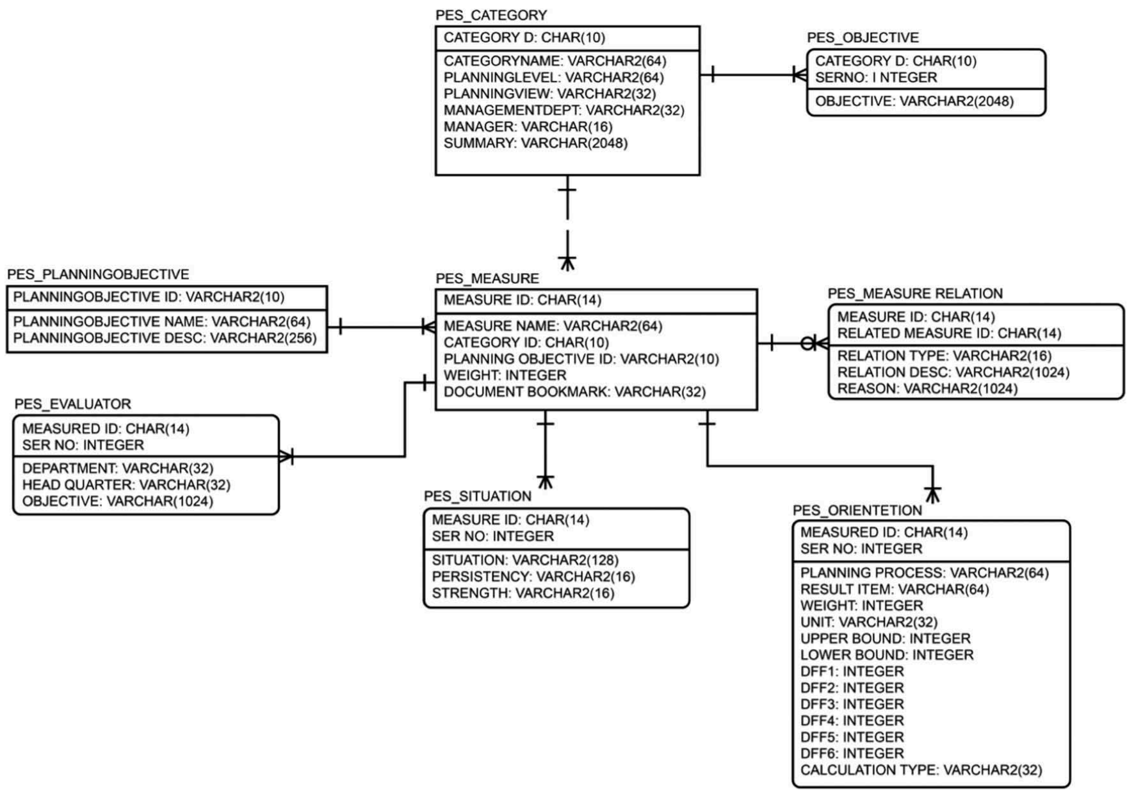

Figure 6. Database model.

planning data and interface with the local planning system. The planning evaluation info component in the data layer manages all data in the evaluation framework, such as perspectives and key information. The planning manager and planning evaluation manager component of the business layer include all the functions and attributes for data processing of the data layer. Finally, the planning evaluation component of the façade layer includes all the interface functions that enable the user interface operations.

Figure 6 shows the skeleton of the database model. Figure 7 shows the developed evaluation application.

Example of evaluation of work load balance

The validity of the evaluation system is verified through scenarios in which the evaluation results are improved when the evaluation is performed after the plan is established, the evaluation results analysed and the problems solved. After the production plan is established, the problem is quantitatively identified through an evaluation measure calculation, a solution is developed and the plan is revised. The results of the re-planning can be re-evaluated to confirm the improved results and revise the plan.

In this study, the target planning (or evaluation) period of 2005 was selected because shipyards have security concerns about the current data. The target vessel and relevant block information are shown in Table 18.

The initial planning, which includes the assembly process to be evaluated, is aimed at generating activities related to pre-outfitting, pre-painting, grand assembly, unit assembly, subassembly, forming and cutting based on the pre-erection schedule determined at the dock planning stage. Figure 8 shows the results of the initial assembly plan. The red bar in Figure 8 shows the work load of the assembly process.

An evaluation of the load balancing is performed for assembly over the 4 weeks from the 25th week (13 June 2005) to the 28th week (8 July 2005). The work load is shown in Table 19. The evaluation was performed on the evaluation measure 'assembly production load balancing of master plan (MP-MFG-001-002)' among the goals of load stabilisation, previously constructed as an evaluation system in the previous chapter ('Construction of an evaluation system of production planning') (Table 11).

To conduct the evaluation, a master planning case is first selected. The evaluation proceeds by selecting the evaluation measure 'assembly production load balancing of master plan' for evaluation purposes. The evaluation results are summarised by the results of 'standard deviation of weekly assembly person hour' and 'standard deviation of weekly assembly production volume' of the MP-MFG-001-002 evaluation measure, as shown in Figure 9. According to the score quantification criterion defined in this case, the combined score of the two detailed evaluation results is 40 points ($0.5 \times 40 + 0.5 \times 40$).

From the evaluation, it can be concluded that the work load between the 25th and 26th weeks in 2005 was excessive, and a new plan was developed so that the amount of assembly for the 25th to 26th weeks would not affect the load situation for the 27th to 28th weeks. In the PE planning process, the adjusted the hull schedule of six PE blocks is adjusted among the total of 37 PE blocks, which are assembled (small and large) in the 25th to 26th weeks in the initial plan. The activities, including assembly and all

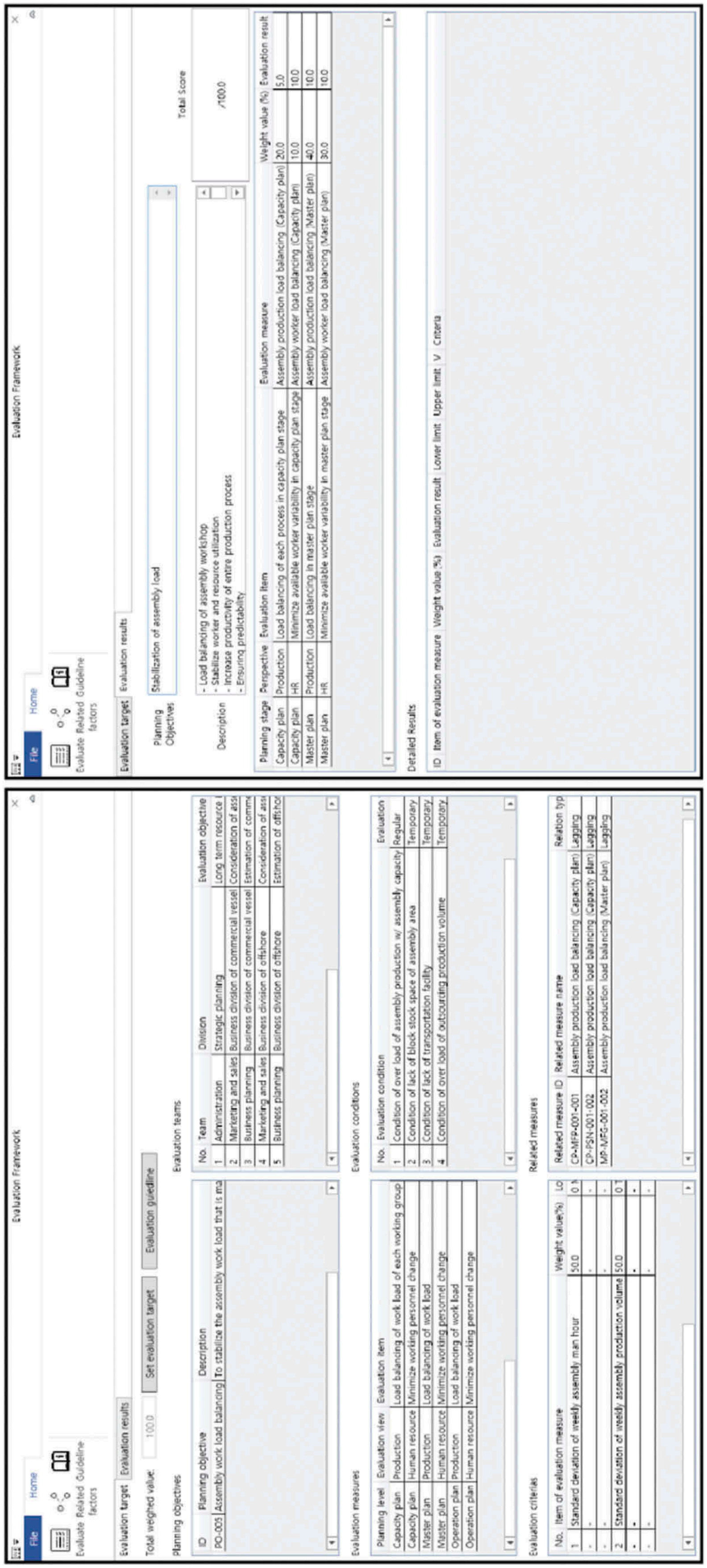

Figure 7. Application of evaluation framework.

Table 18. Planning target vessel and management level (related activity).

Item	Information
Vessel type	BC (Bulk Carrier)
Vessel size	75K
Number of erection blocks	60
Number of PE blocks	37
Number of grand blocks	189
Related planning activity	Unit and grand assembly

Table 19. Planning results of target period before improvement.

Item	200525	200526	200527	200528
Total work load (hour)	6300	5820	5000	5310
Total material weight (ton)	12,600	11,640	10,000	10,620
Total welding joint length (m)	18,900	17,460	15,000	15,930
Total block weight (ton)	1831	1677	1271	1125

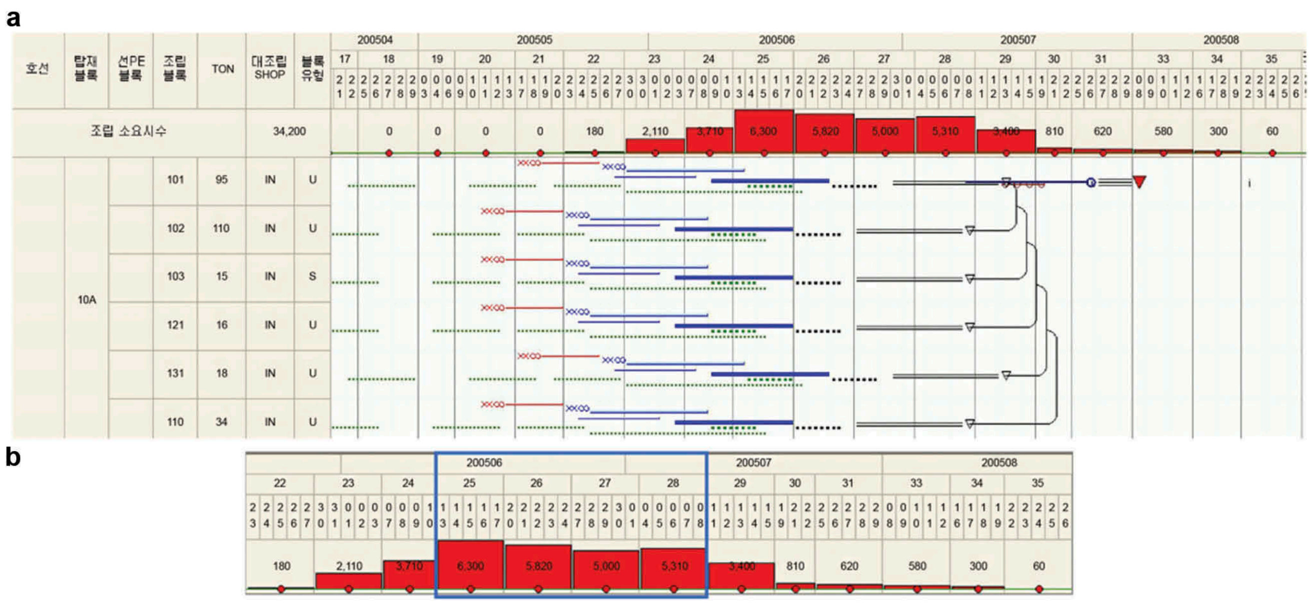

Figure 8. Planning results before improvement (top: overall planning environment; bottom: work load of evaluation target period).

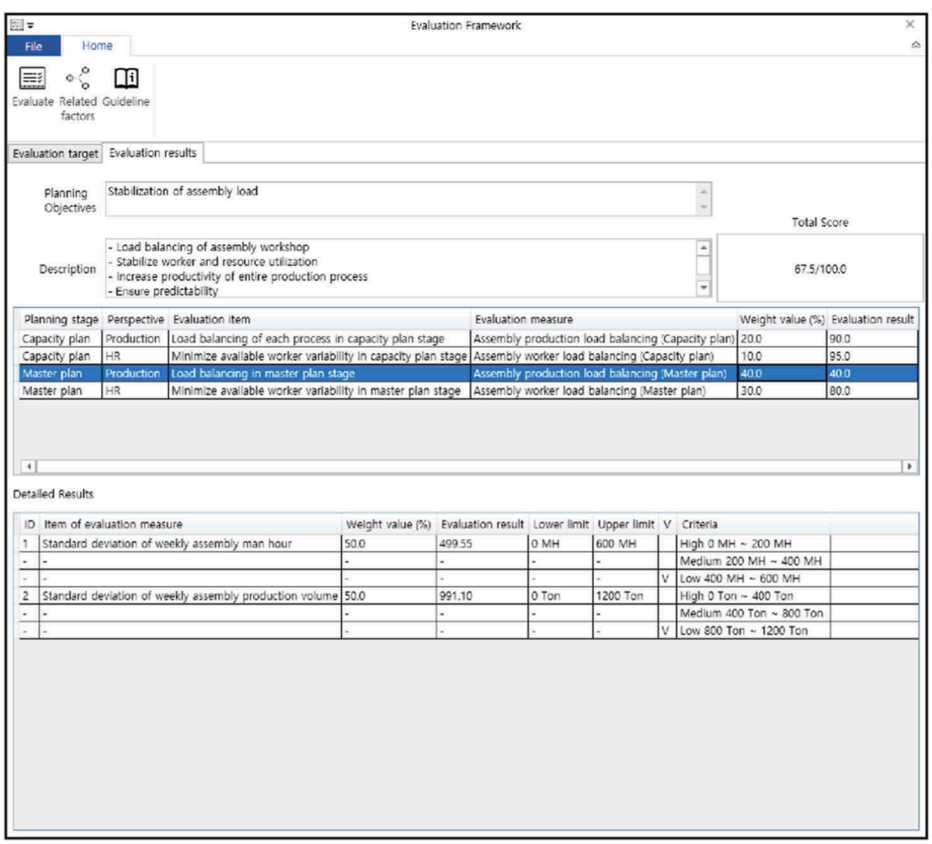

Figure 9. Evaluation result of assembly load balancing at master plan stage.

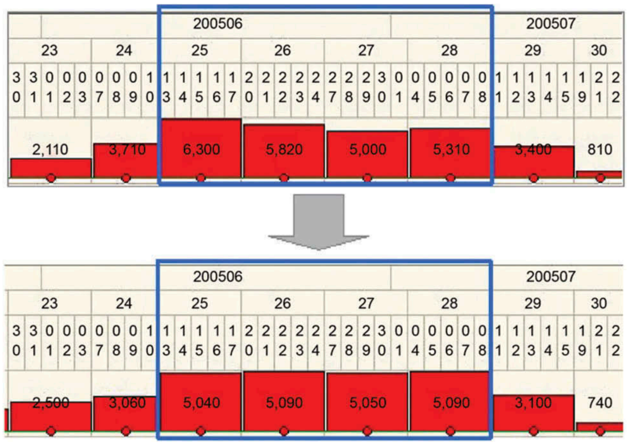

Figure 10. Planning results of assembly work load after improvement.

Table 20. Planning results of target period after improvement.

Item	200525	200526	200527	200528
Total work load (hour)	5040	5090	5050	5090
Total material weight (ton)	10,080	10,180	10,100	10,180
Total welding joint length (m)	15,130	15,270	15,150	15,270
Total block weight (ton)	1285	1486	1288	1090

the activities arising from the relationship with PE, are adjusted within the allowance of PND of the block erection stage at the dry dock. Figure 10 and Table 20 show the results of re-planning through repetition of this adjustment process.

The results from the evaluation system after improvement are shown in Figure 11. Here, the score for the evaluation scale is 100 points (0.5 × 100 + 0.5 × 100). In this way, it can be observed that the evaluation score increased from 40 points to 100 points owing to an improvement effect from the re-planning. Owing to the improvement in schedule, the total score also increases from 67.5 (Figure 10) to 91.5 (Figure 11). Therefore, the application confirmed that if improvement is made in the right direction through re-planning with appropriate evaluation, quantitative evaluation is properly reflected.

Note that there is a decrease in overall volume after improvement over the period shown in Figure 10 than before the improvement. This is because the production volume from week 24 to week 28 is distributed even in the period not shown in Figure 10, due to distribution of the overload during re-planning, according to the constraint conditions.

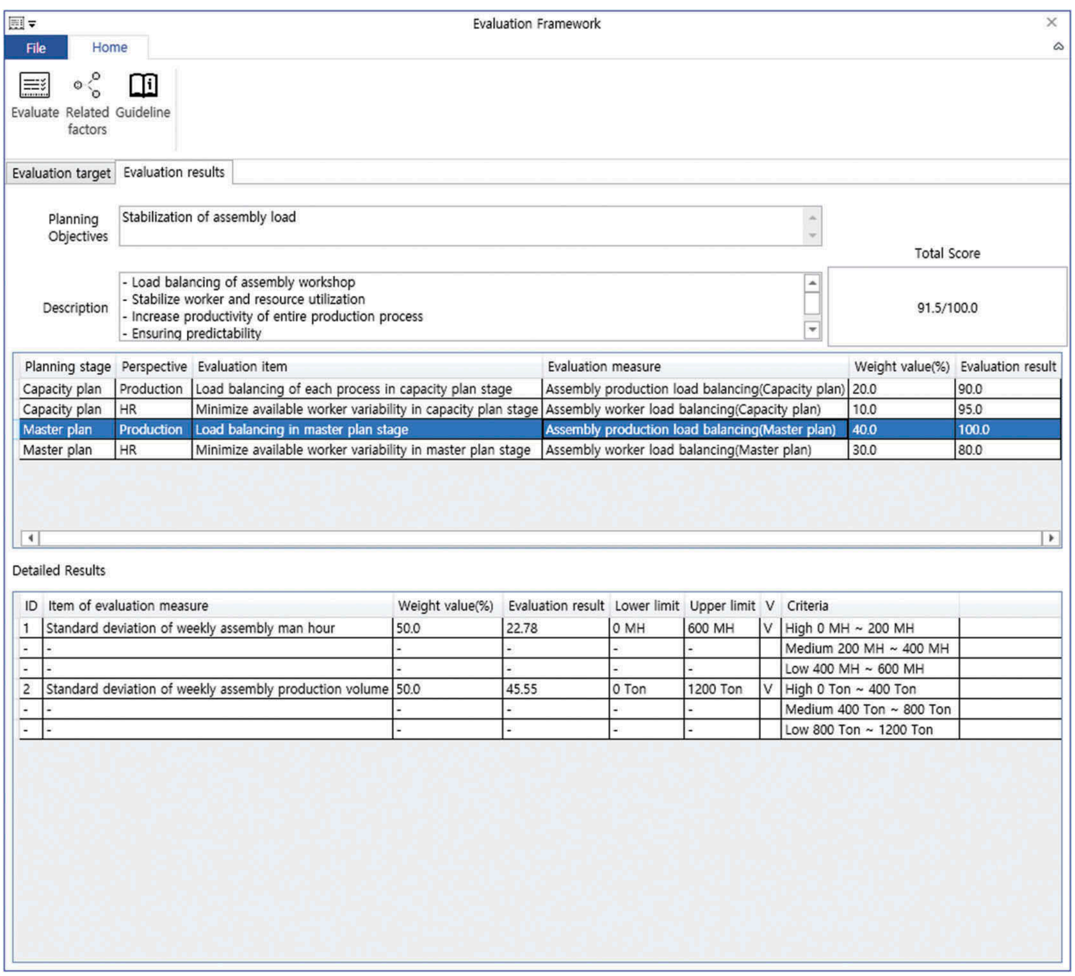

Figure 11. Evaluation results of assembly load balancing at the master plan stage.

Conclusions

This study systematically presents the integrated production planning process of a large-scale shipyard, and proposed a framework for constructing an evaluation system for such production planning from the perspectives of each level, and then constructed the system. In addition, it shows a practical case of constructing a real evaluation system for a virtual shipyard by using the proposed integrated process and framework. The integrated production planning process proposed in this study was based on the analysis of the production planning process of large Korean shipbuilders. This integrated process shows systematic integration according to planning stages and functions. It connects and clarifies the flow of working processes and the connectivity of processes in each planning level. Moreover, information of data input and output, external environmental factors and execution tools are arranged specifically according to each planning stage and function.

The evaluation framework of shipbuilding planning systematically defines evaluation items according to each evaluation perspective and planning stage, and presents a method of specifically describing the key information (goal, agent, time, method and connectivity) of each evaluation item, thereby setting a foundation for consistent, systematic and efficient evaluation of production planning. The evaluation framework will help introduce an evaluation system for production planning, which has been a difficult task, and then manage the system consistently and continuously.

In addition, the study constructs a practical evaluation system in a virtual shipyard using the proposed framework to verify the practical applicability of the framework and construction method, and to provide readers with useful information for the real construction of a system. The example case demonstrated that an objective and quantitative evaluation of production planning is possible through the series of processes of selecting planning goals, mapping related evaluation measures onto the goals and distributing weight factors.

The Industry 4.0 idea, which emerged in Germany, is affecting the shipbuilding industry. Therefore, the Korean shipbuilding industry is also preparing for the intelligentisation and automation of shipbuilding production management. This study attempts to apply an evaluation method of shipyard management system to newly developed technology, especially simulation based production management system.

Note

1. Clarkson research, July 2015, Order backlog.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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