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Development of a simulation method for the subsea production system

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Abstract

The failure of a subsea production plant could induce fatal hazards and enormous loss to human lives, environments, and properties. Thus, for securing integrated design safety, core source technologies include subsea system integration that has high safety and reliability and a technique for the subsea flow assurance of subsea production plant and subsea pipeline network fluids. The evaluation of subsea flow assurance needs to be performed considering the performance of a subsea production plant, reservoir production characteristics, and the flow characteristics of multiphase fluids. A subsea production plant is installed in the deep sea, and thus is exposed to a high-pressure/low-temperature environment. Accordingly, hydrates could be formed inside a subsea production plant or within a subsea pipeline network. These hydrates could induce serious damages by blocking the flow of subsea fluids. In this study, a simulation technology, which can visualize the system configuration of subsea production processes and can simulate stable flow of fluids, was introduced. Most existing subsea simulations have performed the analysis of dynamic behaviors for the installation of subsea facilities or the flow analysis of multiphase flow within pipes. The above studies occupy extensive research areas of the subsea field. In this study, with the goal of simulating the configuration of an entire deep sea production system compared to existing studies, a DES-based simulation technology, which can logically simulate oil production processes in the deep sea, was analyzed, and an implementation example of a simplified case was introduced.

Keywords: Subsea production; Discrete event simulation; 3D visualization; Fluid flow simulation

1. Introduction

1.1 Background of Subsea production system

Oil and gas fields, which recently experience growing competition, have already reached a saturated state in inland areas, and thus the development area is being extended to coastal areas and the open sea that are distributed all over the globe. Accordingly, technologies and equipment for exploring and excavating the resources of deep sea areas that are buried underground under the sea have been gradually enhanced. Facilities that are used for the development of resources buried underground in coastal areas and the open sea are collectively prefixed with the term, subsea. The examples include subsea well, subsea field, subsea project, and subsea development. Figure 1 shows the configuration of the facilities for deep sea resource development, and Table 2 summarizes the explanations of major facilities. For deep sea oil field development, in 2003, ChevronTexaco Company succeeded in drilling down to a depth of 3052 m in Toledo in the Gulf of Mexico [1], which opened an era of 3000 m depth. A small number of advanced companies, which have high technical levels and know-how, are monopolistically maintaining a close relationship with oil major companies, and thus substantial difficulties are expected in market entry [2, 3].

Depending on the complexity of a system, subsea production systems can be classified into various types ranging from a system that consists of a single well that is connected to a fixed platform, FPSO, or an onshore platform through flowlines to a system in which a number of wells are connected to a manifold in a template or cluster form and transport oil to a fixed or floating platform or an onshore platform. When developing a reservoir that contains oil or gas, a subsea production system is used to continuously transport oil or gas to a floating platform or an onshore platform by drilling more than one well and installing appropriate deep sea facilities.

As the operation environment of this equipment corresponds to the deep sea or ultra-high deep sea, traditional equipment that has been previously used in offshore and onshore environments is not appropriate for this field development. Therefore, to collect oil and gas in the deep sea, equipment that is specialized for the deep sea needs to be developed; and for this equipment, the reliability of operation

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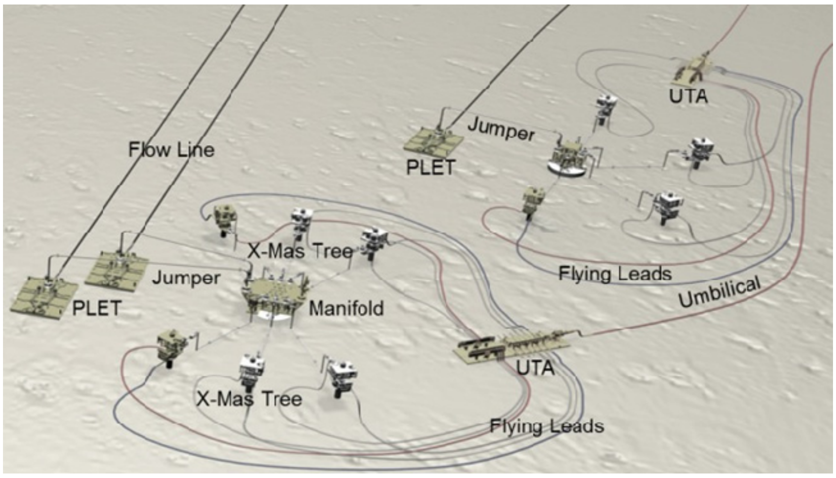


Figure 1. Typical configuration of a subsea production system.

without malfunction even in the deep sea environment is the most important. Only when this reliability is secured, economical excavation and collection of deep sea hydrocarbon resources are enabled.

The deep sea technology for natural resource production in the ocean is a specialized area, and is a field that requires high level of core technologies such as engineering and simulation. As most of the newly developed mine lots are gradually extended to the deep sea, relevant equipment and facilities require strict verification for the functions and requirements of various systems. In other words, special ships and equipment that are equipped with high-priced specialized equipment need to be operated, and thus a lot of cost and time are required to change existing ship/resource-related systems so that they can meet these demands. For the equipment operated in the deep sea, it is almost impossible to reproduce an operation environment as it stands, and thus a system integration test (SIT) for actual ship/actual equipment is almost impossible. Therefore, oil major companies and ocean/deep sea-related companies recently resolve this problem by finding out potential problems during installation/operation in advance through a virtual test using the newest engineering and information technologies. Using this newest simulation technology, it is possible to predict and verify the functions and dynamic behaviors of a system in advance in various conditions of the ocean and the deep sea. This approach is a model-based development methodology for an innovative high-tech plant and system solution; is an environment-friendly approach for the exploration and production of energy resources; and enables preceding evaluation and analysis of the dynamic behaviors of system components for resource production and distribution. Also, this simulation-based development methodology plays a role in providing an infra for the real-time virtual test of deep sea production, drilling, geological survey, and deep sea equipment installation/control.

For the simulation of the flow of subsea production, continuous behaviors of fluid and gas are implemented using a discrete event system (DES)-based commercial engine, and the simulation is performed by converting existing discrete events into discrete flow rate. For the stream of flow, a well becomes a fluid source, and oil or gas is created from this and is delivered to each tree. These fluids are gathered at a manifold through a flowline or a jumper. Then, it follows a scenario in which a selected resource is transported to offshore or onshore area through a production riser. For the linkage of the dynamic behavior and flow of subsea facilities, an architecture that can reflect the relation of dynamic behavior and flow behavior is implemented.

The results of this study could contribute to securing subsea production plant detailed design and manufacturing design packages in combination with the offshore facility design technology of existing domestic shipbuilding and marine engineering companies. Also, the results of this study could be used as the safety and performance prediction/evaluation module for supporting the integrated design of offshore plant and subsea production plant, rather than being used for existing simple operator education; provide data for the development of new processes and new products of subsea production plant; and contribute to securing smart field control-based technology, which is a new technology of recent ocean industry.

1.2 Previous research

In Korea, research relevant to subsea production facilities is currently in an early stage. Most existing subsea simulations have performed the analysis of dynamic behaviors for the installation of subsea facilities [4] or the flow analysis of multiphase flow within pipes [5]. The above studies occupy extensive research areas of the subsea field. In this study, a case of a comprehensive subsea-related research topic was introduced. In his thesis, Devegowa [2] examined fundamental and important issues related with subsea resource development. Especially, a study on energy loss that could occur during subsea production depending on the design and operation conditions of subsea facilities was performed. For this, to

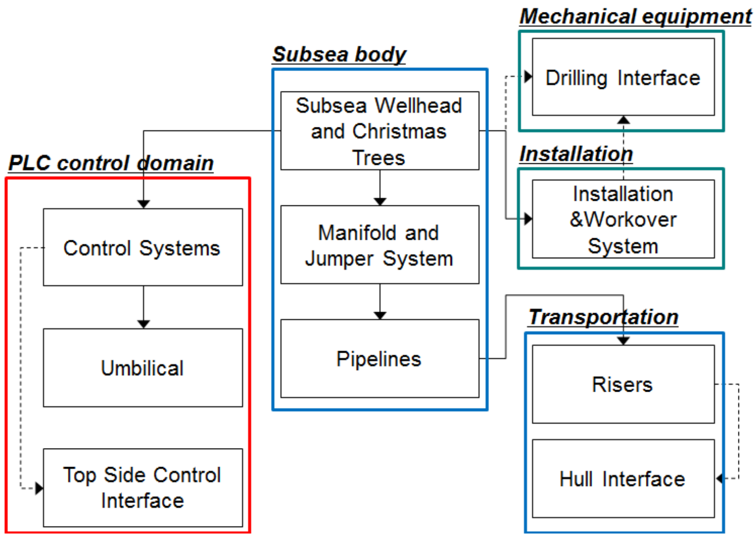


Figure 2. Category of subsea production system and relation.

examine the interaction between a well and subsea production facilities depending on various operation conditions and strategies, a study that uses a well engineering methodology based on a numerical multiphase flow simulator was performed. Choi et al. [6] described the characteristics of a subsea production and control system, major constituting equipment, and elements to be considered during design based on extensive research and design/installation experience for subsea systems; and presented an example of the result of optimal design performance. Through this, the characteristics of the general subsea production system field and of major constituting equipment and elements to be considered during design were suggested. Park et al. [7] laid a foundation for effectively educating relevant workers and students with the drilling process of offshore plant rig, by simulating the change and motion of equipment for the lower part of a riser among the drilling processes of offshore plant rig.

1.3 Coverage of research

The area of the facilities for marine resource development starts from an onshore well, which performs the collection of resources on the land; and in the direction that moves apart from the land, appropriate facilities are applied and operated depending on the depth of the sea. As the depth increases, higher-tech facilities and equipment are operated. Especially, onshore and near shore resources have already been depleted or the sizes of reserves are already known, and thus future investment is gradually moving to the deep sea, which is an unexplored area. Accordingly, the demands for the excavation equipment used for resource development in the deep sea (drillship, semi-submergible drilling rig, etc.) and for the equipment that can directly store, process, and separate resources (oil and gas) in deep sea offshore area are increasing. For the subsea related with this paper, previously, the gas or oil that had been collected by installing a well head after excavation were processed and stored in an offshore or onshore plant; but recently, a lot of tasks are done in the subsea, and the proportion of these tasks is gradually increasing. This is a kind of front-loading concept, and can be interpreted as an attempt to optimize the lifecycle, production process, in resource development.

The scope of the development in this study is basically centered on the simulation implementation for the stream of flow for subsea production processes. To achieve this, simulation techniques of various fields are required. Most existing simulations relevant to subsea production have performed the production of animation for visualization. In the case of the engineering simulation field, most existing studies have performed the engineering analysis of multiphase flow in an unsteady state, rather than dynamic behaviors; and many studies on this are currently in progress. The content of the research introduced in this paper is differentiated from those of existing studies in that it is a simulation that can visualize the dynamic behavior of the flow that occurs in a subsea system.

Figure 2 shows the logical relations of subsea facilities, which include technical classification. In the Subsea body and Transportation parts, the oil that has been extracted from the wellhead -Xtree that is connected to a well is gathered at a manifold, and is transported to an offshore or onshore plant through a pipeline and a riser. The PLC control domain shows the control flow of electrical devices and hydraulic systems for successful transportation of the oil. As shown in the flow, command signals are transmitted from offshore and subsea control centers to subsea facilities through umbilical. Lastly, the Mechanical equipment part shows a drilling system for subsea drilling and a functional module for the installation and maintenance of subsea facilities, respectively.

In terms of simulation using a computer, the processes for actual subsea tasks can be broadly divided into three kinds of element technologies. First, it is the kinematic simulation technology for the installation of drilling or equipment and the adjustment (i.e., dynamic behavior simulation technology). Second, it is the part for the transportation of flow that is controlled by valves and chokes. Third, it is the control part related with the operation of these equipment and facilities. If the three simulation technologies mentioned above are integrated as a superordinate concept, it can be regarded as a dynamic discrete event simulation. This is a theoretical concept, and is derived from the queue theory of industrial engineering. The part where technical differentiation needs to be continuously evolved in the future is a visualization method in terms of discrete events for expressing the behavior of double flow. This part is the area examined in this study.

2. Research methodology

2.1 DES methodology

The DES technique is a simulation technique, which performs calculation by implementing a model when an event occurs in a component within the model or there is a change in the environment that affects the model from outside the model. The flow of time progresses regardless of the occurrence of an event; and when an event occurs within a model, it is reflected in the calculation of the result value. In other words, DES does not perform any calculation in a model when there is no event occurrence, and thus an unnecessary load does not occur in a system; and whenever an event occurs, it is easy to check the flow of time. Therefore, it is an algorithm that is appropriate for a kind of plug-in module which strengthens the performance of an existing system when a production environment cannot be unified because production products and production flow change frequently such as a shipbuilding environment.

2.2 Flow simulation using DES

Fluid is a liquid or a gas, or exists as a mixture of these. The flow of fluid is basically a continuum. However, in this study, a method for converting this continuum into the stream of discontinuous discrete flow was introduced. The continuous flow of fluid can be modeled as discrete parts (or material) among the resources that are connected to one another in a system. In discrete part simulation, a basic dynamic entity that expresses flow is a part. In a general discrete system, each part has inherent characteristics where a part is created and stored in a simulation, is moved by a material handling system (MHS), and also can go through a series of processes (disassembly, assembly, process, etc.) based on the resource of a machine concept; while a discrete part that expresses fluid has a differentiation where it is the set of a series of units and each particle does not have inherent characteristics.

To model the continuous flow of a fluid, the attribute, flow rate, which occurs in different resources, should be assigned. The variation of flow rate is an attribute that can be observed when a fluid is created, destroyed, processed, and transported. The flow rate of a fluid between two different resources represents the flux of a fluid per unit time that moves through the entrance and exit that connect each resource. Basically, the variation of flow rate is caused by creation, destruction, migration, and external factors; and this is the most important input variable for fluid flow modeling. In other words, the input element that takes top priority for fluid modeling is the flow rate of a fluid among simulation entities (source, sink, reservoir, processor, etc.). Flow rate can be defined as the change in fluid volume per unit time. In this study, the definition of the flow rate of a fluid was assumed to be the change of discrete points regarding time series for a cylindrical three-dimensional structure that simulates the fluid, and the physical properties of the fluid that constitute this three-dimensional structure were assumed to be an incompressible homogeneous steady state for the change of flow rate. Also, the creation rate of the fluid, the production rate due to processing, and the destroy rate were implemented by the same principle as that of flow rate, and had the same physical property characteristics. Fluid flow (stream) modeling was designed so that it is consistent with the modeling of existing discrete parts. In the case of fluid modeling in discrete environment, the basic concept is similar to the modeling framework that includes the modeling characteristics for the flow of parts. For parts and fluids modeling, each entity and object can be mapped in one-to-one relations. Table 1 summarizes the homology of the entities for the modeling of discrete parts and fluids flow.

Table 1. Relations between discrete and continuous model.

Discrete parts	Fluids	Description
Part class	Fluids class	Product class along entire production system
Part instance	Fluids instance	Instance of product class
Source	Fluid source	Element where product is created
Sink	Fluid sink	Element where product is destroyed
Buffer	Tank	Intermediate location where product is staying for a given delaying time
Conveyor	Pipe	Transportation element through which product is transferred
Machine	Processor	Element which perform a certain task with given condition
Connec-tions	Fluid connections	Logical relation between each element
Cycle process	Fluid process	User defined process used by machine type element

The simulation model building for the production process of a subsea system is a stage that designs and implements a computer model which can simulate target processes. For the simulation modeling of a specific target, a series of procedures are required. A simulation modeling procedure is variable depending on the characteristics and complexity of a simulation modeling target and the purpose of simulation. If a

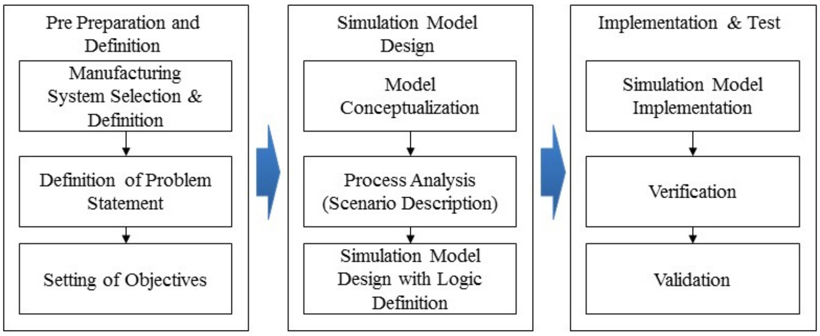


Figure 3. Modeling procedure for discrete event system.

target system for simulation modeling is simple, modeling is possible only with the procedure of analysis, modeling, and verification; while if a target system is complicated, modeling is impossible with this simple procedure, and a reliable model cannot be implemented. Therefore, to implement the simulation model for a complicated system, a systematic procedure is required.

Regarding the processes for designing and constructing a simulation model, there are cases that have been suggested in existing literature. These procedures commonly follow the procedure of 'analysis → design → implementation (modeling) → verification', and the implementation and verification are complementarily repeated as necessary. However, these procedures are limited in the application to a system where a simulation modeling target is associated with complicated products, processes, and facilities such as a subsea system. The first problem is that existing procedures could not link an appropriate methodology at a necessary time of a procedure. The second problem is that existing procedures did not suggest a detailed technical methodology in making the process flow for the modeling of a complicated manufacturing system and linking this to the implementation of a simulation model. In this study, to overcome these limitations and problems of existing simulation modeling procedures, a following modeling procedure was proposed by improving the problems of existing simulation modeling procedures. As shown in Figure 3, the simulation model building procedure proposed in this study is divided into three stages: proposed process (1) simulation modeling pre-preparation, (2) simulation model design, and (3) simulation model implementation; and each stage is again divided into detailed performance procedures.

In the simulation modeling pre-preparation stage, which is the first stage, the purpose of a simulation model is defined by selecting the target of simulation model building and analyzing the problems of a relevant manufacturing system. In the simulation modeling design stage, which is the second stage, a process scenario for simulation modeling is prepared based on the analysis of the products, processes, and facilities of a target manufacturing system using reliable analysis tools. Also, appropriate input/output methods for the definition of the simulation information, which is made in the data modeling stage, are determined, and these are reflected in the metacode. The simulation implementation and verification stage, which is the third stage, is divided into the model implementation stage in which an initial model is completed as the metacode of the previous stage is reflected in the implementation of actual simulation modeling, and the stage in which the improvement of the model is achieved by modification while going through the continuous verification stage after the completion of an initial model.

The simulation model building procedure proposed in this study is characterized by the fact that it was modified to be the most appropriate procedure for a shipbuilding process through the repeated simulation modeling of a shipbuilding process regarding the existing modeling methodology, and the technical details and detailed products that are required in each intermediate stage were defined.

3. Research content

3.1 Analysis of subsea production system facilities

Table 2 summarizes the analysis of major equipment related with a subsea production system. Among the equipment explained in the table, the equipment highlighted in red lines was directly reflected in the simulation model of this study.

3.2 Analysis of subsea production flow

The roles of subsea facilities in subsea resource development were examined. The subsea tree is a valve combination, which is made of valves. It is attached to the upper part of a well and separates each well, and thus plays a role in adjustment for controlling the flux of hydrocarbons in production and process facilities. The manifold gathers hydrocarbons from a number of subsea trees that are installed at wells, adjusts the flow, and has the function of sending them to offshore area through a riser. The flowline plays a role in connecting subsea trees and a manifold, and sending the oil (or hydro carbon), which has been produced from subsea trees, to a manifold. When the distance between a manifold and a subsea tree, which is installed at a well, is too close, a short and hard pipe called jumper is used. The umbilical is an electronic cable or an optical fiber bundle, which is connected to an offshore platform and a subsea tree or a manifold, and

Table 2. Analysis of a subsea production system.

Equipment	Feature	Target	Function	Design consideration
Compressor	Subsea processing equipment	• Prevent formation of sludge • Maintain the fluid flow within the hazard condition	• Maintain the given pressure during the transportation through the pipe line	• Proper required electric power consideration
Multiphase pump (Booster)	Subsea processing equipment	• Enhance the productivity by decreasing the back pressure of well • Cost reduction by integrating the production facilities (integration of fluid pump and gas compressor) • Increase the final product	• Integrated transportation of multiple production well • Transportation of multi-phase fluid simultaneously	• Sand erosion / seal failure • High temperatures • Presence of hydrates in fluid stream and long term performance under water
Separator	Subsea processing equipment	• Separation of oil, water and gas at sea bed, which decrease the production time and the cost (minimize the utilization of boosting system)	• Facilitating summation and sinking of fluid mixture by use of electric power or centrifugal force • Separation of oil, water and gas is processed at subsea	
Manifold	Subsea production equipment	• Tieing the several pipelines from christmas trees • Simplify the connection system such as the flowline and the riser system from the seabed to marine platform	• Subsea structure containing valves and pipework designed to commingle and direct produced fluids from multiple wells into one or more flowlines • Pressure control: well pressure control to prevent blow-out	• Existing infrastructure • Well density • Locations between well • Installation vessel • Future expansion plans
BOP	Subsea production equipment	• Manage the extreme erratic pressures and uncontrolled flow (formation kick) emanating from a well reservoir during drilling • Prevent tubing (e.g. drill pipe and well casing), tools and drilling fluid from being blown out of the wellbore when a blowout threatens	• Confine well fluid to the wellbore • Provide means to add fluid to the wellbore • Allow controlled volumes of fluid to be withdrawn from the wellbore • Shut in the well • Serve the casing or drill pipe	
Well head	Subsea production equipment	• Provide the suspension point and pressure seals for the casing strings that run from the bottom of the hole sections to the surface pressure control equipment.	• Casing suspension • Tubing suspension • Pressure sealing and isolation between casings at surface when many casing strings are used. • Pressure monitoring and pumping access to annuli between the different casing/tubing strings	• Pressure control - well pressure control to prevent blow-out • Commonality of components - minimum number of running tools
SUTA	Subsea production equipment	• Each control of the connection between umbilical and flying lead including umbilical installation	• Control wellheads those are connected by communication system, electric system, hydraulic system with same subsea control module through the one umbilical	

Table 2. Analysis of a subsea production system.

Equipment	Feature	Target	Function	Design consideration
SUTA	Subsea production equipment	• Each control of the connection between umbilical and flying lead including umbilical installation	• Control wellheads those are connected by communication system, electric system, hydraulic system with same subsea control module through the one umbilical	
Umbilicals	Subsea production equipment	• Deployed on the seabed to supply necessary control, energy (electric, hydraulic) and chemicals to subsea oil and gas wells, subsea manifolds and any subsea system requiring remote control, such as a remotely operated vehicle	• Steel tube and/or thermoplastic hose fluid conduits to provide hydraulic control and chemical injection service • Low voltage electrical power and communications provided via signal cables, fiber optic cables and power conductors • Medium voltage electrical power conductors Chemical injection lines for use in corrosion inhibition and prevention of wax and scale build-up	• Water depth • Required function (electric, hydraulic, water, etc.) • Environmental conditions and temperature
Flying lead	Subsea production equipment	• Providing chemical/hydraulic and electrical connections between umbilical termination assemblies, subsea distribution units, trees and manifolds, etc.		
X-Tree	Subsea production equipment	• Contain high-pressure fluid and prevent environmental contamination • Control the flow of hydrocarbons from its respective well via various control valves and choke, to receiving unit. This can be a fixed or floating vessel or produced via pipeline to shore	• Safely stop produced or injected fluid • Injection of chemicals to well of flowline Allow for control of downhole valves • Allow for electrical signals to downhole gauges • Bleed of excessive pressure from annulus • Regulate fluid flow through a choke • Allow for well intervention	• Temperature: high temperature and low temperature • Pressure: API governed design pressure (5 ksi, 10 ksi, 15 ksi) • Produced fluids: H_2S and CO_2 governed corrosion
PLET	Subsea transportation system	• Support easy installation of pipeline • Support the connection between pipeline and jumper	• Located at the end of a pipeline with a foundation large enough to resist movement or settlement, and supports and protects the flowline piping, hubs and valves. • Protect and support flow line piping, hubs, valves	
Jumper	Subsea transportation system	• Connection between wellhead/manifold and PLET/PLEM	• Control pressure of expansion and compression along with temperature change • Fix manifold, wellhead tree, platform spool with pipeline	• Strength analysis • Slugging • Riser base excitation • Installation procedures • Connector installation, sealing and capacity • Erosion and corrosion

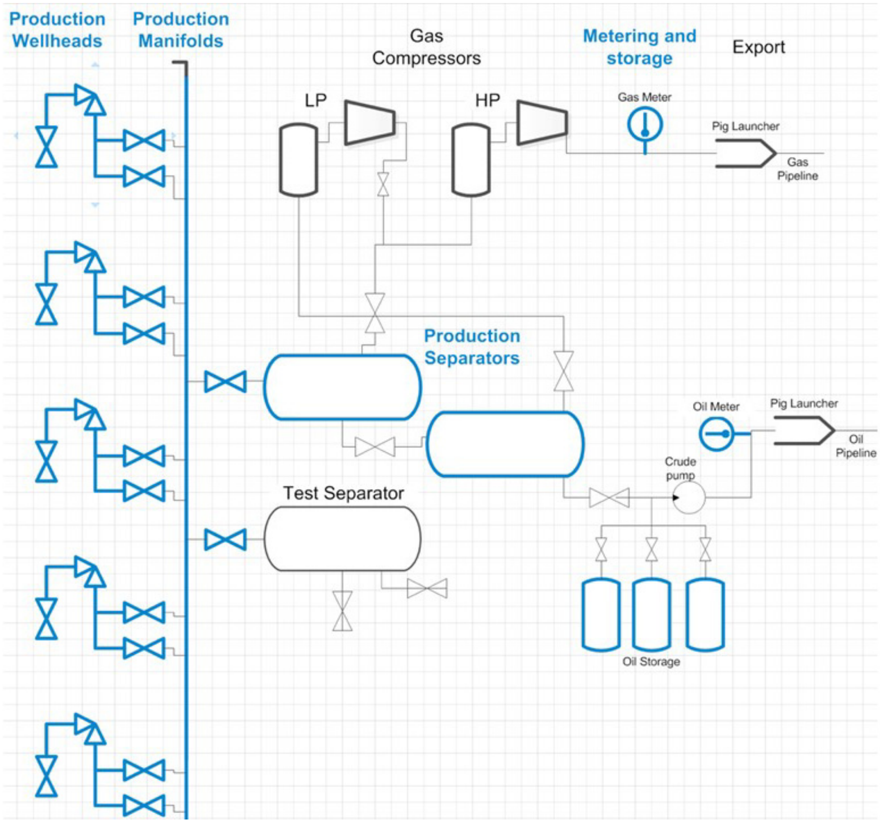


Figure 4. Oil and gas production flow diagram.

which plays a role in controlling electric power or hydraulic pressure. The processing control system refers to an aggregate of structures that simplify operation in the field and increase productivity. It plays a role of subsea products' brain, which requires high technical skills, and substantial parts have been technically standardized.

In this study, minimum block diagram symbols for understanding a subsea production system were listed, and using these, the schematic diagram of a basic system was expressed. For the flow control of a target system, a process diagram generally requires the definitions for details (type of valve, type of choke, types of pump and compressor, pressure condition, temperature condition, etc.). However, as the purpose of this study was the simulation model implementation of an initial development stage for subsea production, only basic elements were used. The target basic elements included valve, X-tree, manifold, jumper, separator, storage, and pipeline. Thus, minimum elements necessary for simulating subsea production were used. Figure 4 shows a diagram for subsea production using basic symbols. This is a schematic diagram for the flow of the subsea production process analyzed earlier, and is expressed using the symbols that are used for actual plant design or process design. In this study, the parts highlighted in blue in Figure 4 were implemented.

3.3 DES simulation of subsea production

Next step is to develop DES simulation model that can simulate a subsea production process based on the basic technology and the analyzed content introduced earlier. For the range of the target simulation model, among the entire system of subsea production, part of the representative processes shown in Figure 4, where the oil extracted from wells is gathered at manifolds through Christmas trees, and only oil and gas are discharged through PLET via separators, were selected as the range. Figure 5 shows the input-output of the simulation model.

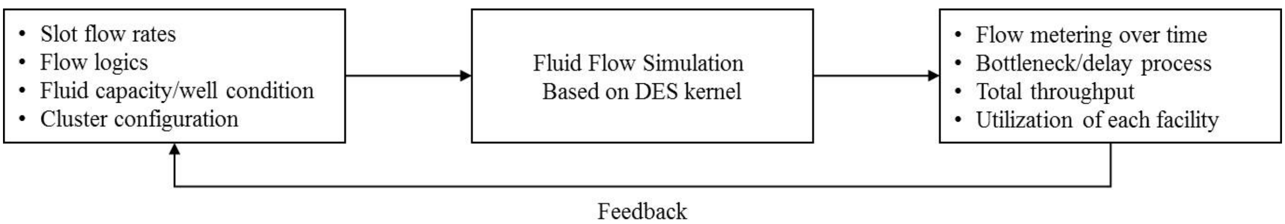


Figure 5. Input and output of subsea production model for simulation.

3.3.1 Simulation modeling

Simulation target

For the target subsea production system of this study, a virtual production system, which consists of four wellheads and four X-trees/one manifold/one separators for each wellhead, was designed. For the well, a process, in which the mixture of oil, water, and gas is gathered at a manifold through X-trees and is separated into each component through a separator, was assumed. Each component separated by a separator was made to be transported to an offshore platform through a pipeline via a jumper and PLET.

Simulation model design

The simulation model design is a stage in which the design of the simulation target described earlier is performed. The DES simulation SW used in this study utilizes a Pascal language-based compiling environment. The logic of the DES simulation model entity basically consists of process logic and route logic, and can use initiation logic if necessary. In this study, fluid process logic and fluid route logic for fluid simulation were applied. Figure 6 shows the fluid route logic, which is the core of fluid flow implementation.

Model development

Based on the logic for fluid simulation described earlier, simulation modeling was sequentially performed from the basic stage. First, for the fluid flow test in DES simulation environment, a test was performed by implementing a simple model, which consists of one fluid source, two tanks, and one processor (see Figure 7). The validation for the result of the test model was verified by comparing the amount of fluid created from the source during the simulation running time and the amount of fluid distributed in the model after the end of the simulation. Table 3 shows the simulation result of the processors and pipes, those results are validated through the comparing of the total fluid quantity.

The simulation model of the target subsea system was completed through the process shown in Figure 3. The process of correcting the input data and the model logic was repeated until valid results were obtained through the continuous running of the corresponding model and the examination of the result data. Figure 8 shows the model that has been completed through this process.

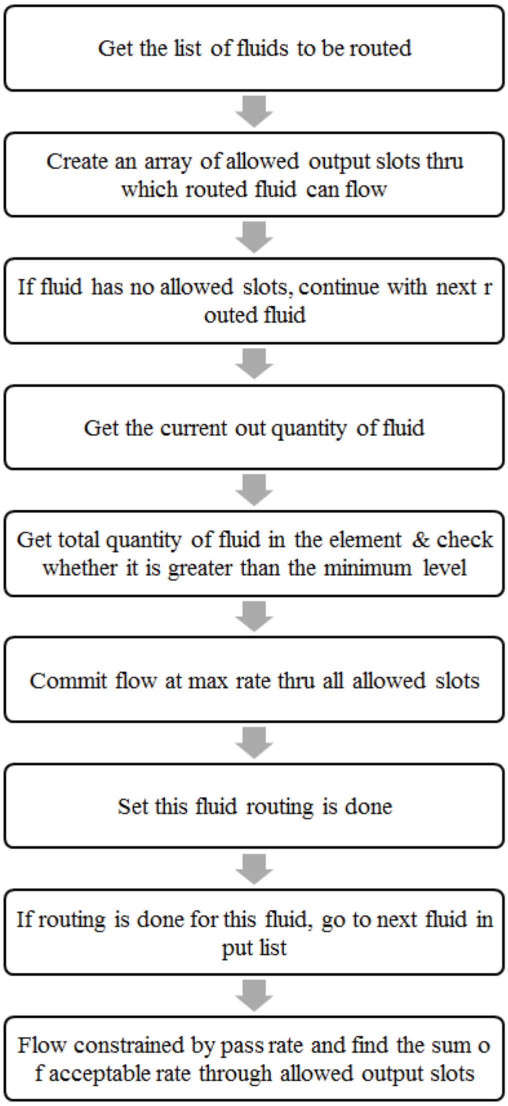


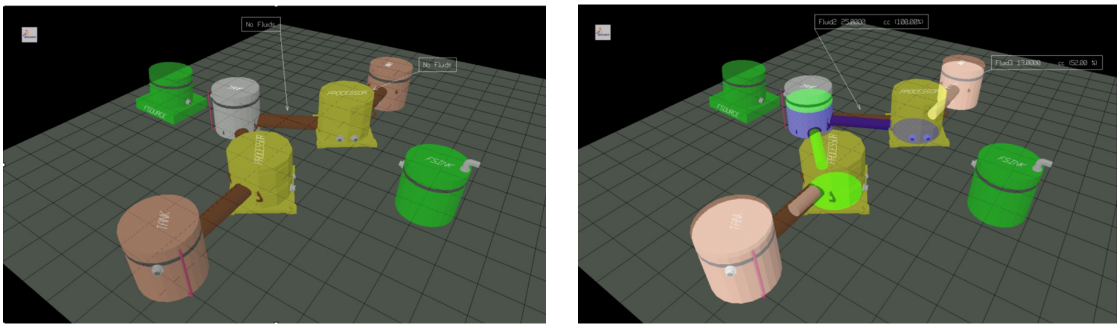
Figure 6. Route logic for fluid flow between model elements.

3.3.2 Input data

In the process of a subsea production system, the most important control variable is the slot flow rate of a valve, which is the passage that connects each facility. This variable determines the delivery of fluid from equipment to equipment, and thus, efficient flow of a system can be determined depending on the setting of this value. The next important condition is the setting of the behavior logic of each equipment and connecting pipe. For the flow of a fluid, unlike the flow of discrete parts in general manufacturing industry, the request process for task start and the process/transportation where actual tasks are performed could occur simultaneously. Thus, the results could vary depending on the definition of each logic that can be synchronized. Also, the storage capacity of a fluid that each facility can store is one of the important variables. When compared to general manufacturing processes, this is a concept similar to the size of part list for WIP, and affects the degree of buffer function for efficient flow. Tables 4 and 5 summarize the information on these input conditions. The change in this information affects the behavior and status of simulation, and based on this, decision making for appropriate process variables could be obtained.

3.3.3 Simulation results

The results that can be obtained from the simulation of the input data explained earlier include the flow rate of each facility for time series, utilization of each facility, total produc-



(a) (b)

Figure 7. Fluid flow test: (a) test model for the fluid simulation, (b) simulation running of the test model.

Table 3. Simulation result of test model: (a) result of processor 1 and 2, (b) result of connecting pipes.

(a)

Name	State times			Utilization (%)	Avg. process time	Avg. cycle time	Avg. Reqmt time	Avg. quantity	Avg. in low rate	Avg. out flow rate
	Idle	Working	Blocked							
Processor 1	7.644	2.344	0.012	23.444	0.002	0.001	0.002	1.444	0.234	0.117
Processor 2	4.991	4.984	0.025	49.839	0.001	0.001	0.001	1.490	0.498	0.249

(b)

Name	State times		Utilization (%)	Avg. quantity	Total in flow	Total out flow	Avg. in low rate	Avg. out flow rate
	Idle	Working						
Pipe1	9.890	0.110	1.099	11835	8465.999	8441.000	0.235	0.234
Pipe2	9.977	0.023	0.233	5.852	4220.000	4207.000	0.117	0.117
Pipe3	9.881	0.119	1.193	24.963	17968.000	17943.000	0.499	0.498
Pipe4	9.950	0.050	0.498	12.451	8971.000	8958.000	0.249	0.249

Table 4. Slot flow rate of each subsea production facility.

Element class	Fluid type	Slot flow rate
Fluid_Source_well01	Water	1000
Fluid_Source_well01	Oil	1200
Fluid_Source_well01	Gas	300
Fluid_Source_well02	Water	800
Fluid_Source_well02	Oil	2000
Fluid_Source_well02	Gas	1000
Fluid_Source_well03	Water	2000
Fluid_Source_well03	Oil	1000
Fluid_Source_well03	Gas	500
Fluid_Source_well04	Water	1200
Fluid_Source_well04	Oil	2000
Fluid_Source_well04	Gas	1000
Processor_Xtree01	Water	300
Processor_Xtree01	Oil	250
Processor_Xtree01	Gas	350
Processor_Xtree01	Water	280
Processor_Xtree02	Oil	320
Processor_Xtree03	Gas	400
Processor_Xtree01	Water	270
Processor_Xtree02	Oil	250
Processor_Xtree03	Gas	420
Processor_Xtree01	Water	240
Processor_Xtree02	Oil	320
Processor_Xtree03	Gas	380

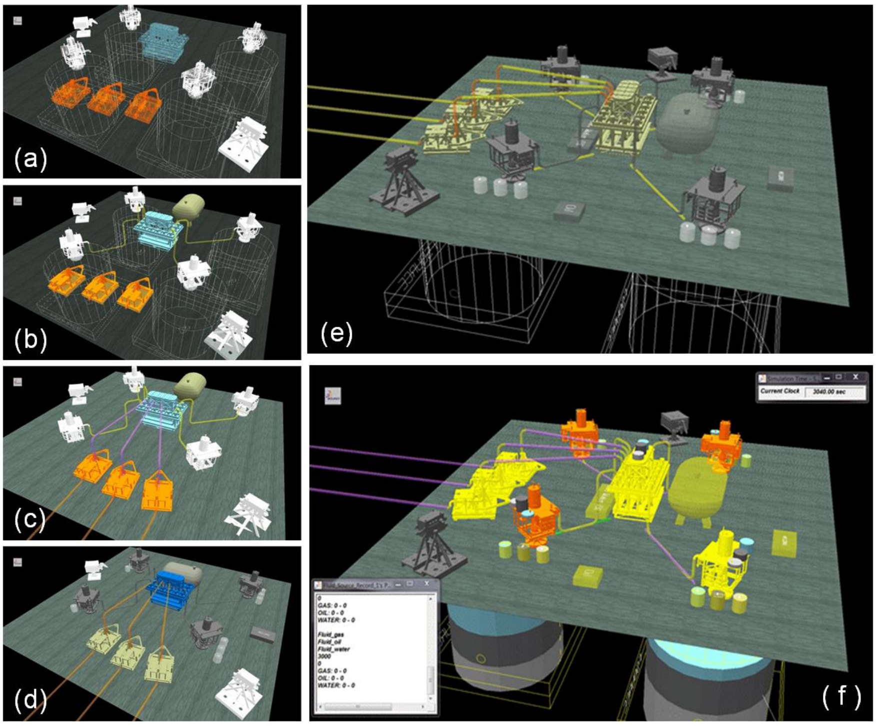


Figure 8. Developed subsea production simulation model: (a) major facility modeling, (b) jumper connection, (c) jumper and pipeline connection, (d) setting of fluid capacity, (e) completion of modeling, (f) model in running.

tion, and information on error facilities through the analysis of these results, as shown in Figure 5. However, as total production was not a target of this study, the flow rate and the utilization of major facilities were examined. Figure 9 shows the flow rate of the Christmas tree. This information shows the flow rates of gas, oil, and water, which change depending on the condition of each well and the capacity of the tree during the process in which oil is delivered from the well to the manifold through the tree. As shown in each graph, repeated variations with a roughly constant period were observed. These variations are affected by the condition of the jumper that involves input and output based on the tree as well as the condition of the tree facility. Therefore, these results are determined by the slot flow rates of the connecting pipes that connect the well-tree-manifold in the input of the earlier simulation. Figure 10 shows the flow rate of the manifold. As the flows from four Christmas trees were gathered at the manifold, the flow rate was determined by the variable conditions of the flow rate of the Xtree shown above and the slot flow rate between Xtree-manifold. Figure 11 shows the flow rate of the separator. In practice, a separator operates in combination with a manifold. However, in this study, they were separately considered because information on their combination was insufficient.

The results of the flow rates of the major facilities indicated that the flow rate, which was relatively regular at the front end of the flow, became irregular as it went through the facilities of downstream. The uncertainty depending on a specific probability distribution was accumulated as it progressed toward the downstream of the process, and thus, irregularity for the load of the process or the flow rate of the subsea increased.

Lastly, Tables 6 and 7 summarize the results of the internal calculation for each facility, tank, and jumper based on the simulation. The information on the utilization also showed a distribution of the utilization that reflects the accumulation of irregularity drawn earlier. It was found that the utilization decreased as it progressed toward the rear end of the process.

Table 5. Total available quantities of main facilities.

Element class	Capacity
Pipe_Xtree_Manifold_01	120000
Pipe_Xtree_Manifold_02	115000
Pipe_Xtree_Manifold_03	130000
Pipe_Xtree_Manifold_04	95000
Pipe_Manifold_Separator_PLET_01	80000
Pipe_Manifold_Separator_PLET_02	90000
Pipe_Manifold_Separator_PLET_03	100000

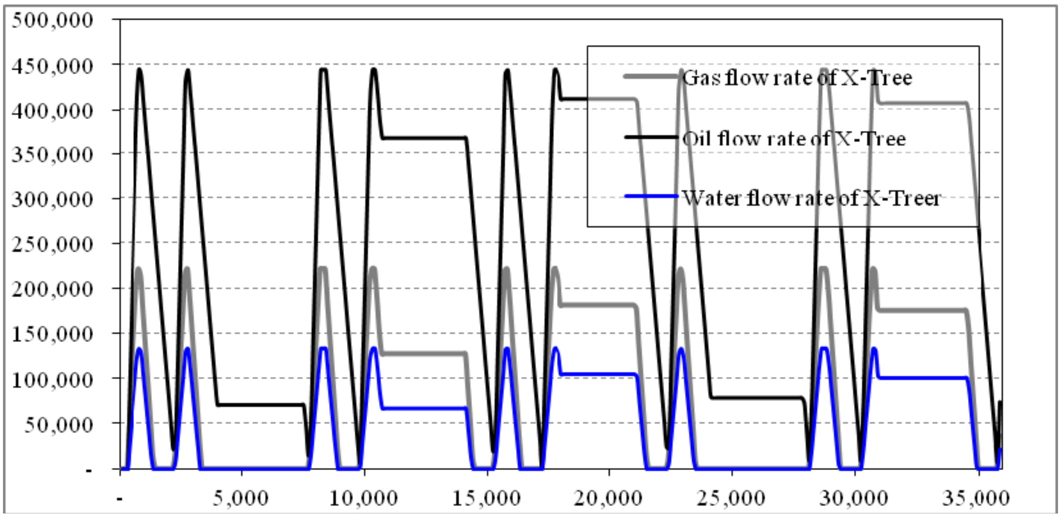


Figure 9. Flow rate results of a certain X-tree element.

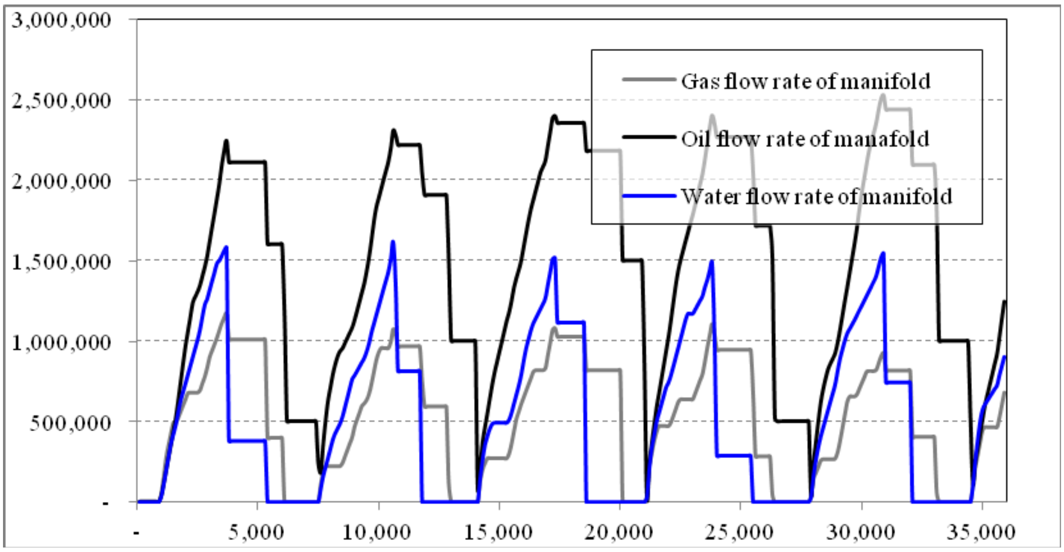


Figure 10. Flow rate results of a manifold.

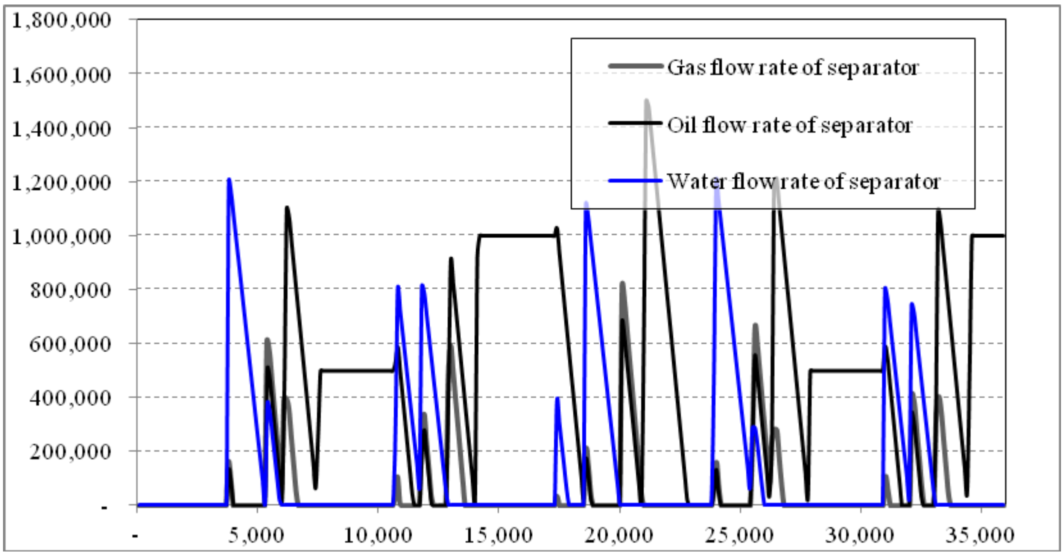


Figure 11. Flow rate results of a separator.

Table 6. Utilization of major facilities of a subsea production system.

Name	State times			Utilization (%)	Avg. Quantity	Total in flow	Total out flow	Avg. in flow rate	Avg. out flow rate
	Idle	Busy	Blocked						
Manifold	47.13	1.39	51.48	13.89	2458	28046	25000	0.779	0.694
Separator	47	3.67	49.33	36.66	604	25000	24000	0.694	0.667
Xtree1	12.53	2.81	84.66	28.11	461	8000	7398	0.222	0.206
Xtree2	12.43	4.17	83.4	41.72	378	7514	7200	0.209	0.2
Xtree3	12.06	8.2	79.74	81.97	290	7200	6955	0.2	0.193
Xtree4	13.8	4.79	81.42	47.86	731	7000	6562	0.194	0.182

Table 7. Utilization and flow rate of jumpers among major facilities.

Name	State times		Utilization (%)	Avg. Quantity	Total in flow	Total out flow	Avg. in flow rate	Avg. out flow rate
	Idle	Busy						
Pipe between Xtree1 and Manifold	8.339	1.661	16.61	68	6955	6946	0.193	0.193
Pipe between Xtree2 and Manifold	8.08	1.92	19.202	71	7398	7353	0.206	0.204
Pipe between Xtree3 and Manifold	8.096	1.904	19.044	68	7200	7200	0.2	0.2
Pipe between Xtree4 and Manifold	8.501	1.499	14.992	52	6562	65467	0.182	0.182
Pipe between Separator and PLET1	1.372	8.628	86.278	25	3045	3015	0.085	0.084
Pipe between Separator and PLET2	1.344	8.656	86.555	29	3045	3010	0.085	0.084
Pipe between Separator and PLET3	1.344	8.656	86.555	29	3045	3010	0.085	0.084

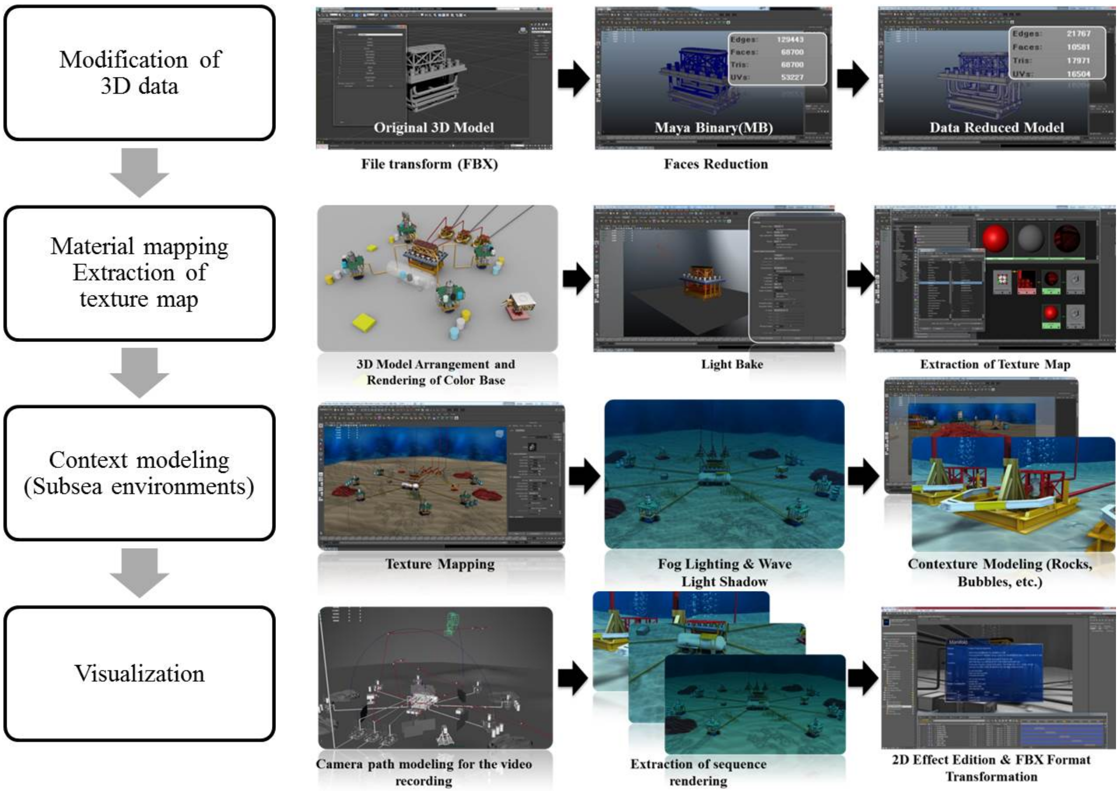


Figure 12. Modeling process for the 3D visualization contents for the education of the subsea production.

4. 3D visualization modeling for Subsea production system education

In this chapter, the education contents development of the subsea production system is introduced. The purpose of this development is to enhance the quality of the subsea lecture. The development of education for the subsea production system is based on the previous simulation modeling.

The first step is to derive the 3D models of production facilities from the DES simulation model, then the format of these models are transformed into the appropriate type of Maya Binary. Then, the data reduction is conducted for the smooth visualization. The second step is texture mapping with respect to the all the resource elements. This works increase the visibility of a subsea production system. The third step is to make environmental condition such as wave flows, bubbles, rocks and sands. Then last step is to make a 3D education contents according to the previously defined scenario in Figure 4. Figure 12 shows the overall process of 3D visualization modeling.

5. Results and future research plan

The research of this paper (subsea production system analysis and production process simulation) is top-level analysis from the view point of subsea engineering. That is to say, the implementation of the subsea production system is conducted with the end user's functional aspect, not with the detail engineering analysis such as muti-phase flow behavior or the phase variations of high-temperature, high-pressure fluid.

Based on the research of this paper, the simulation based platform development of a subsea production system is expected for the purpose of the system design of subsea production and the facility design such as manifold, separator, etc. This could provide the corresponding enterprise with the capability of agile system validation, which enables the reliable management of the customer's requirements.

The following research topics are planned for the enhancement of the effective simulation results:

(1) Simplified physics engine
(2) Fluid visualization function of 3D storage/retrieval tank with arbitrary shape
(3) Control system consideration such as SCADA or DCS, those are responsible for the comprehensive system behavior

Acknowledgments

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