Production Process Modeling and Simulation in Subassembly Lines at a Shipyard

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Abstract

To simulate material flow in a subassembly line at a shipyard, the product, process and resources are modeled for the subassembly process. The subassembly line at a large shipyard was selected. It consists of several sub-processes such as base joining, piece alignment, tack welding, and robot welding processes. The analysis and modeling were carried out by using the UML(Unified Modeling Language), an object-oriented modeling method as well as IDEF, a functional modeling tool. Initially, the characteristics of the shop resources were analyzed using the shipyard data, and the layout of the subassembly line was designed with the resources. A production process was then modeled using the resources and the layout. The production process modeling of the subassembly lines was performed using the discrete event simulation method. Using the constructed resource and process model, the productivity and efficiency of the line were investigated. The number of workers and the variations in the resource performance such as that of a new welding robot were examined to simulate the changes in productivity. The bottleneck process floated according to the performance of the new resources. The proposed model was viewed three-dimensionally in a virtual environment so that interferences among objects and space allocations for the resources could be easily investigated.

Key Words: Virtual Manufacturing Simulation, Modeling, Shipbuilding

1. Introduction

1.1 Motivation and objective

Manufacturing industries have been trying to reduce product production time and cost in many ways. They have changed manufacturing systems, installed new production lines and robots, and adopted new planning and scheduling systems to shorten the time-to-market and to achieve higher productivity. For today's design-driven and customer-centric companies, products are mass-customized, personalized, constructed from modules, and designed and built around the world. Simulation-based manufacturing, digital manufacturing, or virtual manufacturing simulation (VMS), whatever the means, is an approach to achieve such a goal.

Shipbuilding industries have begun to construct a digital model of their shipyard to control and revise all elements in their shipbuilding processes. VMS with the digital model is adequately used to predict how much a manufacturing system will improve and what behaviors it will show when its environment is changed. This paper will analyze the shipbuilding process, develop a digital model, and simulate the shipbuilding process with the developed model to enhance the productivity.

1.2 Literature review

Shin (2002) suggested that a new systems approach for process improvement. The approach includes the systems analysis by the use of the Unified Modeling Language (UML), systems diagnosis by the Theory of Constraints (TOC), and systems verification by discrete event simulation (DES).

Sohn (2000) described a methodology for

performance measurement, which estimates the efficiency of a manufacturing system with respect to productivity, cost, and quality. This methodology monitors the work in process with simulation-based design and estimated costs. They analyzed the performance of the system quantitatively with statistical quality control. However, they did not use a three-dimensional (3D) CAD model was not used and did not verify their conclusions.

Sasaki and Sonda (2002) studied 3D digital mockup systems for work strategy planning. Their process planning for hull blocks was visualized and simulated with the Assembly Tree Editor. Interference in the assembly stage were checked, and the production stage workability was evaluated with a human model.

Fridenfalk and Bolmsjö (2002) researched the design and validation of a sensor guided control system for robot welding in shipbuilding. Robot simulation was examined to develop control algorithms for seam tracking during welding based on through-arc sensing. Experiments using a welding robot were validated.

Sargent (2001) discussed approaches and to verify and validate their simulation models. They described their validation approaches. Two different paradigms related verification and validation of the model development process. Also, they discussed the use of graphical data statistical references for operational validity and recommended a procedure for model validation.

1.3 Overview of paper

VMS was carried out to verify productivity improvement of shipbuilding when the welding torch is replaced with a high-speed rotation torch in the subassembly line. The production lines in the subassembly at a shipyard will be simulated through discrete event simulation to evaluate the performance of the production lines with respect to the number of products produced and the reduction in cycle time after adoption of a new system. For this simulation, the legacy system must be analyzed and simulated. And, recently, techniques for manufacturing system analysis and modeling have been introduced. UML (Shin, 2002) and Integration DEFinition (IDEF) (Sohn, 2000) have been used for system analysis and design of AS-IS and TO-BE models.

Object-oriented methodology, found in software engineering, is used to develop systems (Rumbaugh et al., 1991). UML is a standard modeling language for software a language for visualizing, specifying, constructing, and documenting the artifacts of a software-intensive system. Basically, the UML enables the developers to visualize their work products in standardized blueprints or diagrams (Booch et al., 1999).

In addition, the product, process, and resource (PPR) concept, integrating product development, production processes, and resources, is the basis of system analysis and modeling.

Using the constructed resource and process model, the productivity and efficiency of the shop were investigated with DES.

1.4 Analysis, Modeling and Process Planning

Large amount of data need to be collected to analyze and model the system. These data may include data from documents and interviews with workers at the site. All of the information is the basis for modeling the system by product, process, and resource.

And system behavior is simulated with real processing times, speeds, human resources, schedules, failure rates, repair times and sequences.

Finally, the model can be visualized in real time to detect potential problem areas, and analysis results can be used to optimize the system.

1.5 Virtual Manufacturing Simulation

In this paper, discrete event simulation using DELMIA QUEST was carried out to verify the productivity analysis. The material flow of the subassembly line was assumed to be a discrete, dynamic and stochastic system. Several simulation software packages were evaluated, such as ARENA, WITNESS and QUEST. All of the software packages could carry out discrete event simulation. Among them, QUEST was selected because of its powerful visualization features and its ability to exchange a 3D geometric model with CATIA and IGRIP (Fast, 2000).

The objective of material flow modeling is fundamentally different from that of robot modeling. The objective of robot modeling is to validate the behavior of the resources with its related process and product and to extract the cycle time from the model. On the other hand, the objective of material flow modeling is to predict the overall physical and logical system behavior influenced by internal and external changes, and to suggest systematic and reliable alternatives (Shin et al., 2002).

DES aimed to obtain the process cycle time but it had in obtaining this time from the design data. A robot simulation model based on a real shipyard can obtain the precise cycle time of the process without any time measurement.

The cycle time from the robot simulation is validated by the experiment with Time study, which is an analysis of a specific job, to find the most efficient method in terms of time and effort.

2. Application

The layout of the subassembly line has a sequence of sub-processes. The sub-processes have the tact time. SKID pattern are supplied as an input for the subassembly line. The SKID pattern shows the arrangement of to-be-assembled pieces on the base plate (See Fig. 1). The SKID pattern includes real and converted welding lengths. The converted welding length is a length of welding used to calculate the welding time and cost per unit welding length for different welding conditions, such as welding positions, methods, and so on.

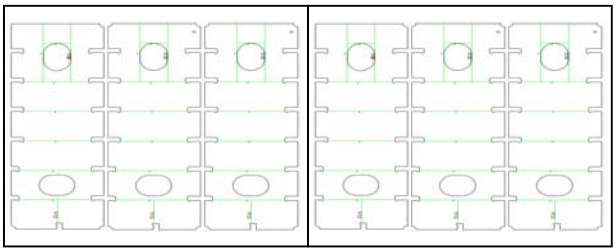

Fig. 1 SKID Pattern

To simulate the assembly line, two systems, AS-IS and TO-BE, are defined. An AS-IS system consists of a gantry with two hanging-type welding robots. And a TO-BE system employs a new welding robot whose welding speed is about double of that of the AS-IS system. A virtual manufacturing simulation was carried out to verify the productivity analysis of the subassembly line with new robot application.

2.1 Product

Products of the subassembly line are called sub-blocks. Sub-blocks are made of flat pieces. The block information can be obtained form BOM (Bill of Materials). Those blocks in the subassembly line include floors and girders of a ship structure. Using the BOM of a subassembly, a manufacturing BOM can be easily described. Manufacturing BOM represents the assembly procedure of sub-blocks.

2.2 Process

The subassembly line process consists of six sub-processes: tack welding (SAW in abbreviation), arrangement (ARR), fit-up (FIT), robot welding (WELD1), manual welding (WELD2), finish (FIN), and back heating.

IDEF and UML models were constructed for the sub-processes. A sequence diagram of robot welding provides us interactive exchange of information among worker, roller conveyor, and gantry crane.

2.3 Resource

Resources in the subassembly line were modeled, including work floor, cranes, workers, and so on. The behavior of welding robot was analyzed for the precise modeling. Maximum speeds and travel limits of its joints were investigated while the robot was in welding.

3. Virtual Manufacturing Simulation

3.1 Problem to be resolved

Using developed product, process, and resource models, material flow simulation is carried out. First, the robot was simulated as close as possible to the operation of a real robot for a more reasonable cycle time. With the provided cycle time, DES was investigated to verify the productivity. Two observations were studied to execute a more realistic simulation.

First, we used the unit cycle time of mechanical resources from the robot simulation and that of human's working from shipyard data. The cycle time from robot simulation was key for the present study. To measure the unit cycle time for the robot, accurate robot simulation was carried out. The robot simulation enabled us to estimate and predict the cycle time in the sub-processes.

Second, to validate the robot simulation, the cycle time of the real robot operation was compared with that of the virtual robot simulation. Then, the new cycle time of the new robot was calculated from the simulation. The new cycle time was adjusted according to the difference that was obtained between the real and the virtual.

3.2 Validation by Experiment

To validate the constructed robot simulation, we used a stopwatch to measure the cycle time of the robot operation. As shown in Table 1, Time Study is the most popular technique among other techniques. The worker operation time was not measured. Over 100 welding robot operations were examined. Seventy-two experimental data were used for robot simulation.

Table 1 Time Measuring Technique

Operation Measuring Technique	Utilization(%)
Time Study	46
Standard Data System	23
Estimation Based on Experience	14
Work Sampling	3

3.3 Robot Simulation

Fig. 2 illustrates the robot simulation model and was used to validate the cycle time

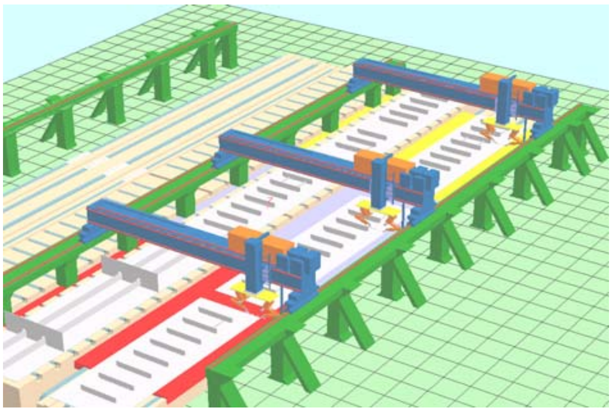

Fig. 2 Robot Simulation Model

Product data was generated for the robot simulation since no 3D CAD data was available at the shipyard. The format (See Table 2) had not only 3D points of x, y, z, but also angles of yaw, pitch, and roll. There were the number and name of the flat bar in the first column. Reference coordinates for the format are indicated in Fig. 3. The format represents the integration of design and production information since the product data was used for calculating the cycle time in the production process.

Table 2 Input Data Format

14	X Axis	Y Axis	Z Axis	Yaw	Pitch	Roll
p1399_b18d_f90_x1	855	653	16	0	135	0
	855	1897	16	0	135	0
	869	653	16	180	45	0
	869	1897	16	180	45	0
p1399_b18d_f90_x2	1678	675	16	0	135	90
	899	675	16	0	135	90
	1678	687	16	0	135	-90
	899	687	16	0	135	-90
p1399_b18d_f90_x1_1	1710	653	16	0	135	0
	1710	1897	16	0	135	0
	1724	653	16	180	45	0
	1724	1897	16	180	45	0

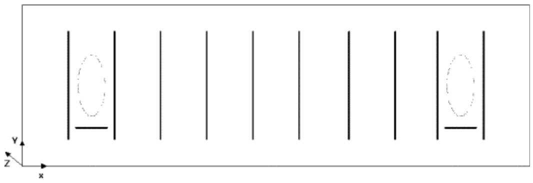

Fig. 3 Reference Coordinate

3.4 Results

From the simulation and experiment, as seen in Table , the deviation between the real and virtual machines is 2.9%. In Table 3, 'Remainder' is the worker preparation time for robot welding, and the value remains constant. It can be concluded that the simulation was quite accurate.

Table 3 The Difference between Experiment and Robot Simulation(time:min)

	Experiment	Robot Simulation	Difference
Robot Welding Cycle Time	77.6	75.3	2.3
Remainder	33.9	33.9	0.0
Total Cycle Time	111.6	109.2	2.3

Calculations of the new cycle time were made for the robot simulation between the AS-IS and TO-BE systems. The results are shown in Table 4.

Table 4 Comparison of AS-IS and TO-BE(time:min)

	AS-IS(36cpm)	TO-BE(80cpm)	Save(%)
	Robot Simulation	Robot Simulation	
Robot Welding C/T	75.3	49.6	34.1
Remainder	33.9	33.9	0.0
Total Cycle Time	109.2	83.5	23.5

Due to the high-end feature of the new robot, the TO-BE system delivered 34.1% savings in robot operation. With the 'Remainder' time, we could save the cycle time by 23.5% in the robot welding sub-process. Since there was 2.9% deviation between the real and virtual machines, the new cycle time of robot welding in a real process would be 85.4 minutes, as shown in Table 5

Table 5 Prediction of new cycle time in Real World

	AS-IS(36cpm)	TO-BE(80cpm)
Virtual World(min)	109.2	83.5
Real World(min)	111.6	85.4

3.5 Discrete Event Simulation

Before installing the new robot, the shipyard should simulate the subassembly line with the new robot to find the number of throughputs that would be produced in the line and the effect of the improved process on the other sub-processes. Discrete event simulation (Banks et al., 2000) was needed to simulate the subassembly line with DELMIA QUEST.

- Assumption
  Simulation Time: 60 hr
  Input Quantity: A week amount of SKID
  Ignore machine failure, set-up time
  Consider A, B line as one line
  Proceed if post-process finished, Wait if not

- Process Variables

  Number of worker at each process
  Resource performance

- Scenario

  AS-IS: old welding robot (2/1/3/2/4/2)
  TO-BE: new welding robot (2/1/3/2/4/2)
  CASE 1: Experiment based on data in WELD1 without two workers in WELD2 (2/1/3/2/**2**/2)
  CASE 2: Experiment based on data in WELD1 with an extra worker in ARR (2/**2**/3/2/**2**/2)
  CASE 3: Experiment based on data in WELD1 with an extra worker in FIT (2/**2**/**4**/2/**2**/2)

Here, (2/1/3/2/4/2) stands for the number of workers in each sub-process in SAW, ARR, FIT, WELD1, WELD2, and FIN. CASE 1 was the condition in which two workers are reduced in ARR due to the high performance of the new robot. Note that two workers had no tasks. CASE 2 was a condition in which one worker was deployed at the ARR sub-process. The other worker was deployed at FIT sub-process in CASE 3.

Fig. 4, 5 and 6 show the simulation results. In the Fig. 4, we show the CASE 3 which is well balanced situation. In the Fig. 5, we increase the throughputs which are the number of skids after 60 hours work. In the Fig. 6, we reduce the lead times which are the working time for 38 skids.

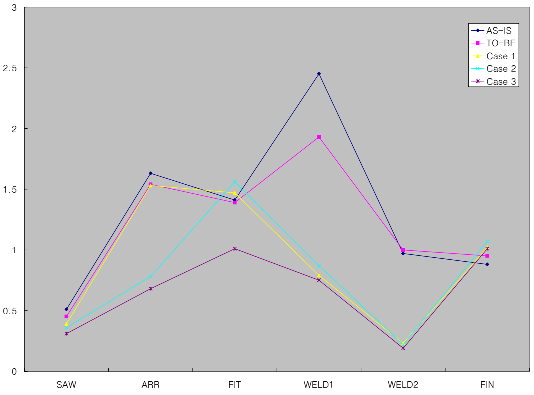

Fig. 4 Comparison of Loads

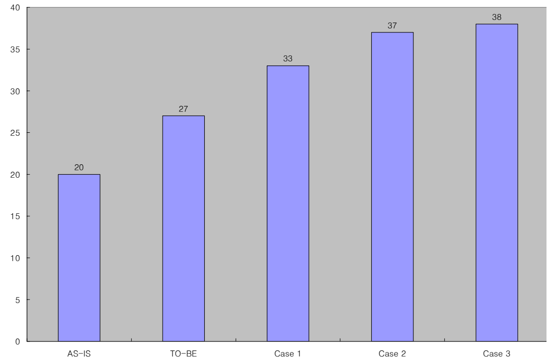

Fig. 5 Comparison of Throughputs
(the number of skids after 60 hours)

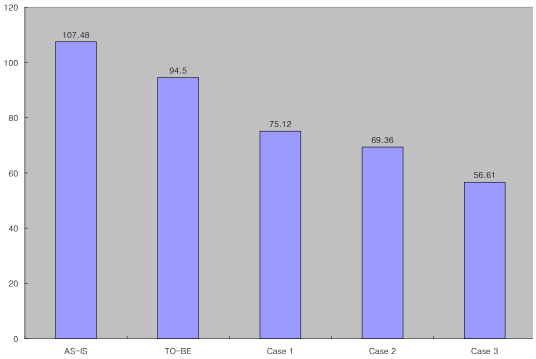

Fig. 6 Comparison of Lead Times
(working time for 38 skids, time:hour)

4. Conclusion

This paper presents a simulation of a subassembly line at a shipyard to simulate material flow in line. The product, process, and resources were modeled for the simulation.

The analysis and modeling procedure were carried out using the UML and IDEF. A production process was modeled using the resources and the layout. The production process modeling was performed using the discrete event simulation method.

Practical simulations were carried out with shipyard data. The cycle times in the experiments were compared to that in robot simulation; both agreed very well. After deploying a new robot in the subassembly line, productivity increased to maximum of 26%. We considered new allocation of workers. The bottleneck process floated according to new resources. The proposed model was viewed three-dimensionally in a virtual environment to easily investigate the interferences between objects and space allocations for the resources.

5. Acknowledgment

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References

1. Shin, D. H., “Forming Shop Analysis, with UML and Simulation,” M.S. thesis, Dept. of Naval Architecture and Ocean Engineering, Seoul National University, 2002

2. Sargent, R. G., “Some Approaches and Paradigms for Verifying and Validating Simulation Models,” Proceedings of the 2001 Winter Simulation Conference.

3. Shin, J. G., Woo, J. H., Shin, D. H., Lee, J. H., “An Object-Oriented Production Process Modeling and Simulation of Shipyard Fabrication Shop in a Virtual Environment,” Proceedings of 2002 Ship Production Symposium, Boston, Oct.

4. Sasaki, Y. and Sonda M., “A Study on 3-D Digital Mockup Systems for Work Strategy Planning, ” ICCAS, 2002, Sep 9-12, Malmö, Sweden, pp 413~427

5. Fridenfalk, M. and Bolmsjö, G., “Design and Validation of a Sensor Guided Control System for Robot Welding in Shipbuilding,” ICCAS, 2002, Sep 9-12, Malmö, Sweden, pp 457~472

6. Banks, J., Carson, J. S., Nellson, Ⅱ B. L., and Nicol, D. M., “Discrete Event System Simulation, 3rd Edition,” Prentice Hall, Inc, 1998

7. Booch, G., Rumbaugh, J. and Jacobson, I., “The unified modeling language user guide”, Addison-Wesley, 1999

8. Fast K. R., “Development of a Shipbuilding Simulation Process Modeling Database,” NSRP 0562 N4-98-3, 2000

9. Rumbaugh, J., Blaha, M., Premerlani, W., Frederick, E., and William, L. “Object-Oriented Modeling and Design,” Prentice-Hall International, Inc, 1991.

10. Sohn, S. J., “Multi-dimension Process Control of Productivity, Cost and Quality for Automated Manufacturing systems in Shipbuilding,” M.S. Thesis, Dept. of Naval Architecture and Ocean Engineering, Seoul National University, 2000.