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3D 시뮬레이션을 활용한 렌즈모듈 자동화조립시스템 개발

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Developing Automatic Lens Module Assembly System Using 3D Simulation

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ABSTRACT

Virtual manufacturing (VM) is a powerful technology for developing a new product, new equipment and new manufacturing system, and three-dimensional (3D) simulation is a core technology in VM. 3D simulation involves both mechanical simulation and discrete event simulation. This paper introduces a case study of implementing 3D simulation for developing an automatic assembly line in a Korean optical factory. This factory produces a lens module that is the part of a phone-camera. 3D simulation technology is applied from the early stage of development. In the conceptual design and the initial design phases for individual equipment, 3D mechanical simulation using CATIA® and IGRIP® is conducted. 3D discrete event simulation with QUEST® is applied to the detailed design of the equipment and of the whole system. The focus of the simulation is to verify the technical and economical feasibility of the new automatic system. As a result, the takt time is reduced to the quarter of the manual system, and the number of workers in a line is reduced tremendously.

Key words : 3D simulation, Lens module, Assembly line, Automatic, Design

요 약

가상생산기술은 신제품의 개발, 새로운 장비 개발 및 새로운 제조시스템 개발에 유용한 도구이며, 특히 3D 시뮬레이션 기술은 가상생산의 핵심기술이다. 3D 시뮬레이션 기술은 기계적 시뮬레이션 기술과 이산사건 시뮬레이션 기술로 구분할 수 있다. 본 논문에서는 휴대폰 카메라에 장착되는 렌즈모듈 조립을 생산하는 국내 회사의 사례를 소개한다. 이 회사에서는 렌즈모듈 조립공정을 현재 수작업으로 하고 있는데 자동화시스템을 개발하기로 결정하였으며 이를 위해 3D 시뮬레이션 기술을 도입하기로 하였다. 3D 시뮬레이션 기술은 시스템 개념설계단계에서부터 적용이 되었는데, 단위 장비 개발을 위해서는 CATIA® 와 IGRIP®이 활용되었으며, 시스템 설계를 위해서는 이산사건 시뮬레이션 도구인 QUEST®가 활용되었다. 논문의 목적은 새로운 자동화 설비의 기술적, 경제적 타당성을 검증하는 것이다. 개발 결과 takt time 이 기존의 수작업에 비해 4분의 1 수준으로 감소되었으며, 이에 따른 작업자 인원도 대폭 감소되었다.

주요어 : 3D 시뮬레이션, 렌즈모듈, 조립라인, 자동화, 설계

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1. Introduction

A camera phone is a device that has the combined function of a mobile phone and a camera. When the camera phone was introduced, it rapidly replaced the traditional mobile phone. It became highly popular in the global mobile phone market, therefore, the demand for a phone-camera module which is the core component of the camera phone substantially increased as well. In the report of Gartner Dataquest[3], the global demand of mobile phone as of 2006 will be 900 millions, and will be increased up to 987 millions in the year 2007. In the near future, the percentage of the demand for camera phones will increase up to 80% of the demand of mobile phones. Thus, optical manufacturing factories are trying to increase their production capacity and enhance their competitiveness in terms of quality and cost.

As shown in Figure 1, a lens module is composed of multiple lenses, spacers, and masks. In the case of a mega-pixel lens module, three lenses, two spacers, and one mask are assembled together in the lens module assembly process. Then the lens module is assembled with the PCB(Printed Circuit Board) in the packaging process. The packaged sub-assembly(packaging module) is assembled with a case, making up the phone-camera module. Figure 1 shows the lens module, the packaging module, and the phone-camera module, respectively[5].

The resolution of the phone-camera has been improved rapidly since the year 2000 when SONY developed the camera phone with a lens module of 100 thousand pixels. This had been replaced by Video Graphics Array (VGA, 300 thousands pixels), and then VGA had been replaced by one with one mega-pixels. These days, the camera phone with 1.3 mega-pixel lens module is the most popular, but it is being replaced gradually by one with two mega-pixels. Although the camera phone with the 10 mega-pixel lens module was developed in the year 2006, it is not commercialized yet.

A lens unit with eight(or 16) lenses is produced by injection operation. The number of lenses in a lens unit depends on the cavity of the mould. Then the lens unit goes to the gate-cutting machine for the removal of the lenses from the spine. After the inspection is finished, the lens is transported to the lens module assembly line. Figure 2 shows the structure of a 1.3 mega-pixel lens module. In the first assembly operation, a lens is inserted to the lens holder(barrel). Then two additional lenses, a spacer, a shield and a mask are stacked into the holder one by one as in Figure 2. For the two mega-pixel lens module, the number of parts assembled changes from six to eight. This is the reason why companies adopt the design concept of assembly line as modular system.

The factory considered in this paper produces many kinds of phone-camera modules, from Video Graphics Array(VGA, 300,000 pixels) to two mega-pixel lens. However, most of the assembly and inspection operations are done manually. Recently, the factory became interested in changing its operations from manual to automatic because labor and material costs are increasing. Furthermore, in spite of the substantial increase in market demand, the selling price is continuously going down.

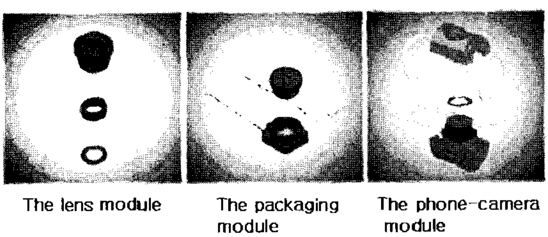


Fig. 1. Main subassemblies of camera module

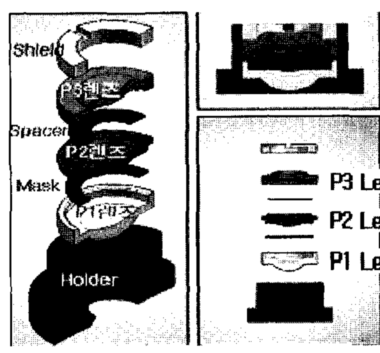


Fig. 2. Structure of a lens module(1.3 mega-pixels)

The benefits of an automated operation are as follows:

- Lower labor cost
- Consistent level of quality
- Reduction of work space
- Better overall yield

Virtual manufacturing(VM) is a powerful tool especially when used for developing a new manufacturing system. There are at least two views of the production system that needed to be supported for VM: Representation of the system's capabilities and performance(static view), and representation of the system's dynamic behavior (dynamic view) (see[6]). With the convenient modeling and simulation environment of VM, we can simulate the fabrication or assembly of any product, including the associated manufacturing processes in computer prior to actual production[1].

Thus, as a core technology of VM, 3D simulation plays a very important role in the design of a new product, device, or even a manufacturing system. 3D simulation involves both mechanical simulation and discrete event simulation. In the design phase of developing individual equipment, mechanical simulation is helpful for detecting the design errors without production. Meanwhile discrete event simulation is widely used for estimating the performance of the system which is composed of multiple equipment and workers.

Recently, 3D simulation has become popular in many industrial areas, especially in the automotive industry. Wöhlke and Shiller[7] described the aspect of digital planning validation using simulation in automotive industry. Fowler and Rose[2] suggested some challenging topics in the modeling and simulation of a complex manufacturing system. However, they focused more on the discrete event simulation. Although the integration of mechanical simulation and discrete event simulation is difficult due to the complexity of a 3D model, the need for integration has been on the rise.(See Moon, Cho and Baek[4]).

This paper introduces a case study of applying 3D simulation technology to the development of an automatic assembly line in a Korean optical factory. This optical factory produces lens modules for phone-camera. Although the global demands of phone-camera are increasing explosively, the assembly and inspection processes of the lens modules are conducted manually in most of the factories, because high-precision technologies are required for the assembly operations. The competitiveness of the factory is lowered down gradually due to labor cost and thus the factory is determined to develop an automatic assembly line. 3D simulation technology is adopted from the early stage of the development. In the conceptual design and the initial design phases for individual equipment, 3D mechanical simulation using CATIA® and IGRIP® was applied. 3D discrete event simulation with QUEST® was applied to the detailed design of the equipment and the design of the whole system.

2. ASSEMBLY LINE DESIGN

2.1 Line concept

The assembly processes of a 1.3 mega-pixel lens module are shown in Figure 3. The mechanisms of the six assembly operations are the same. In each assembly operation, the vision system for detecting the assembly position is required. This is the reason why the company wanted to adopt the automatic assembly line consisting of assembly modules. If the resolution of the lens module is changed from 1.3 mega-pixels to 2 mega-pixels, two additional assembly operations can be added to the existing line. Then there are eight assembly operations. Another important constraint considered in

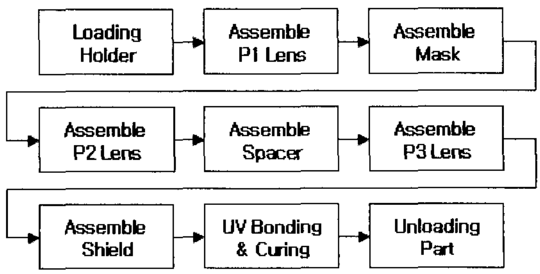


Fig. 3. Processes of an assembly line(1.3 mega-pixels)

the line design is to minimize the footprints of machines because this assembly line should be installed in a clean room. However, the construction cost of a clean room is very expensive.

With these constraints in the design phase, two types of line concept were compared, the rotary type and the linear type. A brief discrete event simulation was conducted and the linear type was determined as the relevant line concept[5].

2.2 Development processes

This system was developed through the cooperation of mechanical engineers, control system engineers, simulation engineers and users. Figure 4 shows the development flow of the automatic assembly line. Two types of simulation were used for the system design.

Various targets for designing the system included takt time, precision of assembly, yield of the system, number of worker and so on. The company wanted to develop a line with a target takt time of 2.5 seconds. The company also wanted that the number of operators in the line would be limited to two including material handling tasks.

2.3 Structure of the line

The automatic assembly line considered is consisted of six cells as shown in Figure 5. Cell 2, cell 3, and

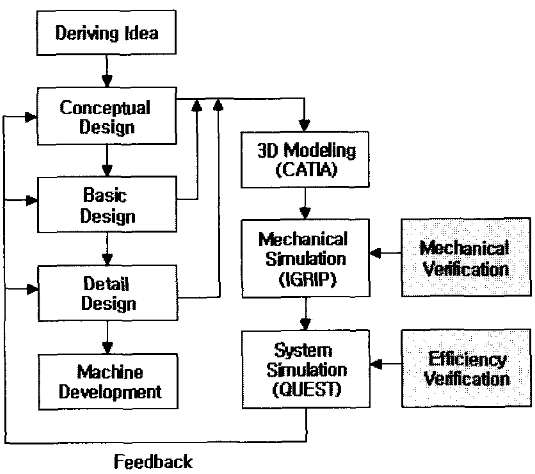


Fig. 4. Development flow of the assembly line

cell 4 are the same cells. In an assembly cell, a lens and a spacer(or mask, or shield) are assembled sequentially. As stated earlier, the target takt time was set to 2.5 seconds. However it was technically difficult to finish a cycle within 2.5 seconds. Thus, the concept of the dual system was applied to develop the cell. This means that two identical modules should be installed in a cell to decrease the mean cycle time.

3. MECHANICAL SIMULATION

Two types of 3D simulations were conducted for the development of the system. These included the mechanical simulation for determining the mechanism of the equipment, and the system simulation for evaluating the performance of the line.

Mechanical simulation was conducted using IGRIP® which has been developed by the Dassault-Delmia Corporation. It is used to develop a 3D robot simulation model including Off Line Programming (OLP). It is also used for detecting the collisions between products and fixtures(or jigs), products and robots, and fixtures(or jigs) and robots in a dynamic state. Another useful function is to simulate the cycle time using velocity, acceleration, type of motion, moving distance, location of the TCP(Tool Center Point), and so on.

There are two primary objectives in the mechanical simulation. The first objective is to verify the mechanism of the machine to be developed. Dynamic motions of parts can be modeled with kinematics, and the collisions among parts can be detected. The second objective is to verify the cycle time. In the automatic machine, more than one component moves at the same time. Programmable Logic Controller(PLC) is used for operating an automatic machine, and it is possible to

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Holder Loading	Assembly Cell	Assembly Cell	Assembly Cell	Bonding & Curing	Part Unloading

Fig. 5. Structure of the assembly line

define motions similar to PLC in IGRIP®. Figure 6 shows a sample sequence chart that defines the motions in a machine.

With the mechanical simulation, many design errors were detected and corrected in the basic design and detailed design phases. This was also helpful for understanding the design concept in the conceptual design phase and the basic design phase. Figure 7 shows the IGRIP® models of the four types of machines. Using these IGRIP® models, various design errors considering dimension, position and sequence program were verified. For example, the transportation mechanism adapted in Figure 7(b) was a transfer type. But it was changed to conveyor-type after verification.

The requirement from the company was that the takt time of the assembly line should be 2.5 seconds. Thus, a dual parallel system was implemented to the loading machine, assembly cell, and bonding machine. From the mechanical simulation, it was proven that the cycle times of all the equipments were less than 2.5 seconds.

4. SYSTEM SIMULATION

After finishing the development of 3D mechanical simulation models in IGRIP®, the 3D system simulation model was constructed with QUEST®. The simulation model considered in this paper is composed of six machines(cells) as shown in Figure 5. In addition, we adopted the microscopic discrete event simulation as all motions of the equipment were considered. Moreover material handling and worker's jobs were considered in the system simulation model.

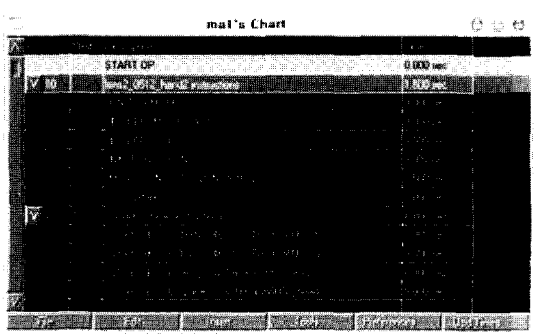
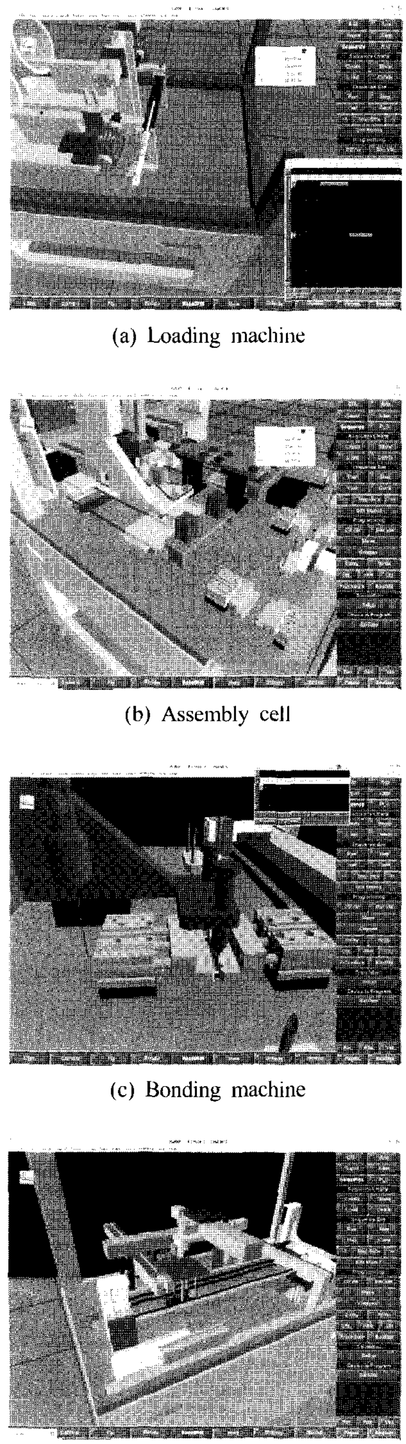


Fig. 6. Example of a sequence chart



(a) Loading machine

(b) Assembly cell

(c) Bonding machine

(d) Unloading machine

Fig. 7. IGRIP models for mechanical simulation

4.1 Performance measures

The following performance measures are defined for the simulation analysis.

- Throughput
- Manufacturing lead time
- Takt time
- Utilization of the line
- Worker utilization

4.2 Part supply system

Three types of tray are used in the system. These are lens tray, spacer(mask, shield) tray, and assembly tray. One hundred lenses(or spacers) are contained in a tray. Two identical assembly modules are mounted in an assembly cell for achieving the required takt time. Thus there are four cassettes(two for lens and other two for spacers) in an assembly cell, and five trays are stacked in each cassette as shown in Figure 8. When five trays in a cassette are empty, the operator should exchange the cassette, not the tray. Therefore, stacking five trays in a cassette is the job of the worker. The cycle time of feeding a tray from the cassette to the machine was computed as 3.1 seconds.

4.3 Transportation system between cells

The transportation method between cells is an important factor of design. Two kinds of mechanism are usually used in an automatic assembly system. The first is a conveyor having two sensors to control the upper limit and the lower limit of Work in Process(WIP). Although the merit of the conveyor is to secure the buffer space easily, its demerit is the difficulty of maintaining the small part in the right position.

The second is the transfer system. This is similar to the automatic loading/unloading system. Generally, the transfer system is synchronized to the cycle time for the machine. To secure enough buffer spaces between cells, the transfer system should be long enough for the mechanism. Thus, only a couple of parts are allowed as the WIP when the transfer type is adopted in the automatic system which has a limited space.

In the early stage of design, a transfer system was suggested as illustrated in Figure 7(b). However, it was changed to a conveyor system using positioning jigs as in Figure 9, after the initial simulation considering the importance of the buffer. Thus, the buffer size between two assembly cells is 10(five jigs). A conveyor without positioning jig is installed between the bonding machine and the unloading machine, and the buffer size is 40.

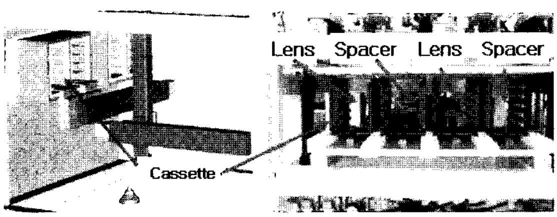


Fig. 8. Structure of part supply in an assembly cell

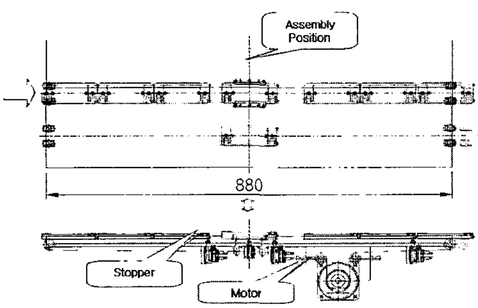


Fig. 9. Structure of transportation system

4.4 Jobs of the worker

The jobs of the worker are another consideration in the system simulation. These jobs are categorized into two types: internal jobs and external jobs. An internal job means that the machine should be stopped when the worker conducts the job. An external job means that the machine can be operated during the worker's job. Table 1 shows the various kinds of a worker's jobs.

Table 1. Worker's jobs

Equipment	Job	MTBF	MTTR
Loading machine	Supply Holder	1000EA	15sec
Assembly cells	Exchange cassette	Cassette is empty	15Sec
	Miscellaneous stop	TRIA (10,60,180)min	TRIA (30,60,90)sec
	Replenish trays in a cassette	Three trays are empty	60sec
Unloading machine	Unloading trays	Five trays are full	15sec
	Supply tray and cap	1hr	15sec

4.5 Defects

Two types of defects, namely part-defect and assembly-defect, are considered in the design phase. Part-defect means that a part is detected as the defect in the inspection. If the centers of all parts assembled in an holder are not exactly aligned, the sub-assembly is removed and it is called as the assembly-defect. The vision system detects both types of defects. If the vision system finds a defective part in a tray before assembly, the picker moves to the next position of the tray to find and pick a good part. The defect rate of each part is 1%. If the vision system finds a defect after assembly, that sub-assembly is removed in the unloading machine.

Since two parallel assembly modules(for convenience of explanation, we call them as the assembly head of the left side and that of the right side, respectively) are equipped in an assembly cell, two sub-assemblies are assembled in a cycle. Although two heads are operated independently, the transfer device moves simultaneously two subassemblies to the jigs for conveying. Thus, when the vision system of the left head finds a defective part before assembly and it moves to the next position, the right head should wait for the time of the movement.

When a sub-assembly of the left side in the assembly cell 1 is recognized as defective, the operation on the same side of assembly cells 2, 3, and the bonding machine will automatically stop. In this case, only one, not two, lens module is assembled in a cycle.

4.6 Other input data

The cycle time was set to constant because the system developed is highly automated. The cycle time of the assembly machine is 4.6 seconds per assembly module. Thus, the average cycle time considering the two parallel modules is 2.3 seconds. Similarly, the cycle time of the assembly machine is 3.0 seconds per bonding module, and the average cycle time considering the two parallel bonding modules is 1.5 seconds. The loading machine can feed the holder continuously. In the unloading machine, a picker picks up four lens modules at once and puts them in the tray. The cycle time is 3.0 seconds, and the average cycle time is 0.75 seconds.

In the simulation, we did not consider the severe failures of the machine because it is not easy to repair them, and it takes a long time to do so. If severe failure happens, the defective machine will be disconnected from the line, and the respective operation will be changed to manual operation. The trivial failures were considered as the miscellaneous stops.

4.7 Simulation Model

Figure 10 shows the system simulation model developed with QUEST®. The 3D models developed for the mechanical simulation were transformed to the QUEST® models. In the transformation process, we simplified the 3D models developed with IGRIP® because the file sizes are too big for the system simulation.

4.8 Experiments and results

The simulation run length was set to 331days(24 hours per day) and the warm up period was set to 3days. Three scenarios were prepared for the experiments as shown in Table 2. The purpose of S1 is to validate the simulation model and to obtain the maximum production quantity. The difference between S2 and S3

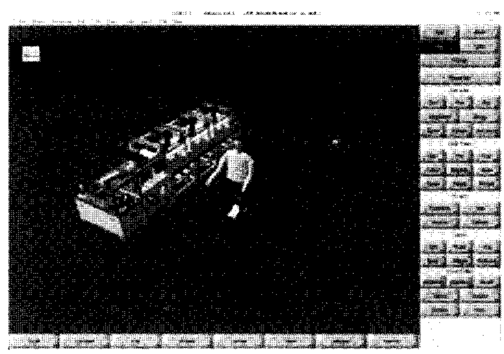


Fig. 10. 3D system simulation mode

Table 2. Scenarios of the experiments

Scenarios / Factors	S1	S2	S3
Miscellaneous stop	X	O	O
Defects	X	O	O
Worker's job	X	O	O
Number of workers	0	1	2

is the number of workers. From the results shown in Table 3, one worker can operate this line, and the takt time obtained(2.44 sec) meets the target takt time(2.5 sec).

5. ECONOMIC ANALYSIS

The validity of investment was carried out as follows. The investment for developing the new assembly line was estimated to $700,000. The usable life of the equipments was assumed as three years and the salvage value was 10% of the intial investment $70,000. The life cycle time of a model was assumed to six months. It means that new positioning jigs and pickers should be developed at every six months. The investment cost of manufacturing new jigs and pickers were $50,000 for every year. 17 workers could be reduced and the annual salary was set to $20,000 per person. The annual salary increases 5% at every year. The defect rate decreased was estimated to 3%.

Straight Line Method was adapted as the depreciation policy and the tax rate was 30%. The MARR(Marginal Attractive Rate of Return) of the company was 10% and it was used for calculating the present values of the cash flows. The effect of inflation and the space savings due to the automation did not considered in the analysis.

As a result, the net present value of the investment problem was $754,719 and the IRR(Investment Rate of Return) was calculated as 62.7%. Furthermore, the payback period was 1.19 years. Thus, this company determined to invest in this automatic assembly line. Table 4 shows the data for economic analysis.

6. CONCLUSIONS

Virtual manufacturing is a powerful methodology for developing a new product, equipment, or manufacturing system. It enables the verification of errors in the design before production. This paper is a case study of virtual manufacturing in an optical manufacturing factory which produces a lens module for camera phone.

Particularly, this paper introduces the implementation processes of VM in the development of an automatic assembly line producing a phone-camera module. A 3D model of individual equipment was built with CATIA®, and the CATIA® model is transformed into IGRIP® to conduct the mechanical simulation(verifying the collision in a dynamic state) and the estimation of the cycle time. After finishing the mechanical simulation, a system simulation model is developed with QUEST®.

The mechanisms of machines, the material handling system and the workload of a worker are considered in the system simulation. From the results of the experiments, we conclude that the target takt time of 2.5 seconds can be achieved. The automatic assembly line is put into

Table 3. Results of the experiments

Scenarios / Measures		S1	S2	S3
Throughput(EA)		12,340,200	11,639,200	11,674,600
Mean Flow Time (sec)		114.12	133.8	133.4
Takt time(sec)		2.3	2.439	2.431
Machine Utilization	Assembly 1	100.0	97.21	97.51
	Assembly 2	100.0	96.24	96.53
	Assembly 3	100.0	95.28	95.57
	Bonding	65.22	63.40	63.59
	Unloading	32.61	30.75	30.85
Worker Utilization (%)		-	23.64	11.89

Table 4. Results of the experiments

Cost		Start	1st Year	2nd Year	3rd Year
Investment Cost		700,000	50,000	50,000	50,000
Salvage Value					70,000
Additional Operating Cost			40,000	40,000	40,000
Cost Savings	Labor Cost		408,000	428,400	449,800
	Defect Cost		136,000	136,000	136,000
	Manual Operation Cost		20,000	20,000	20,000
	Depreciation		233,300	233,300	233,300
	Tax Savings		70,000	70,000	70,000
Cash Flow		-700,000	544,000	564,000	645,800

Fig. 11. Automatic assembly line developed

operation and is running now. The initial investment cost amounts to $700,000, and 17 workers were reduced relative to the manual system.

From the economic analysis, the automatic assembly line suggested in this paper has worth of investment. When they developed the system as shown in Figure 11 and operated it in the field, the takt time is little bit longer than that being expected. The main reason is the speed of vision system. This result is the limitation of simulation. Thus, they are developing the algorithms of vision systems to reduce the takt time.

REFERENCES

1. Chan, D.S.K. (2003), "Simulation Modeling in Virtual Manufacturing Analysis for Integrated Product and Process Design", Assembly Automation, Vol. 23, No. 1, pp. 69-74.
2. Fowler, J. A. and Rose, O. (2004), "Grand Challenges in Modeling and Simulation of Complex Manufacturing Systems", Simulation, Vol. 80, No. 9, pp. 469-476.
3. Gartner Inc. (2006), Gartner Dataquest Market Insight.
4. Moon, D.H., Cho, H.I. and Baek, S. G. (2006), "A Case Study of the Design of Robot Welding Station in an Excavator Factory Using 3D Simulation", Journal of the Korea Society for Simulation, Vol. 15, No. 1, pp. 51-58.
5. Moon, D.H., Baek, S.G., Zhang, B.L., Jung, J.Y., Kim, Y.K. and Song, J.Y. (2006), "Application of Virtual Manufacturing in Developing Manufacturing System for the Lens Module of Phone-Camera", In Preprints of 12th International Symposium on Information Control Problems in Manufacturing(INCOM 2006) (Industrial Supplement and Discussion Paper), Saint Etienne, France, May 17-19, IFAC, pp. 93-98.
6. Virtual Manufacturing Technical Workshop, "Compiled and Edited by Lawrence Associates Inc.", 25-26 October 1994.
7. Wöhlike, G. and Schiller, E. (2005), "Digital Planning Validation in Automotive Industry", Computers in Industry, Vol. 56, No. 4, pp. 393-405.

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