WEMax: Virtual Manned Assembly Line Generation

Won Kyung Ham, Kang Hoon Cho, Yongho Chung, Sang C. Park

***Abstract*—**Presented in this paper is a framework of a software 'WEMax'. The WEMax is invented for analysis and simulation for manned assembly lines to sustain and improve performance of manufacturing systems. In a manufacturing system, performance, such as productivity, is a key of competitiveness for output products. However, the manned assembly lines are difficult to forecast performance, because human labors are not expectable factors by computer simulation models or mathematical models. Existing approaches to performance forecasting of the manned assembly lines are limited to matters of the human itself, such as ergonomic and workload design, and non-human-factor-relevant simulation. Consequently, an approach for the forecasting and improvement of manned assembly line performance is needed to research. As a solution of the current problem, this study proposes a framework that is for generation and simulation of virtual manned assembly lines, and the framework has been implemented as a software.

***Keywords*—**Performance Forecasting, Simulation, Virtual Manned Assembly Line.

I. Introduction

PRODUCTIVITY of a manufacturing system is one of the important elements that decide the enterprise competitive power, such as market flexibility and quality management. Manufacturing enterprises must carry out an activity for productivity improvement continuously. The manned assembly line is a process of manufacturing systems, which is suitable to massive manufacture having better flexibility than the automated system. This process has been adopted in the industry for electronic appliances, i.e. television and refrigerator. Because the industry has many different product types and frequent changes, to design the manufacturing system as fully automated using dedicated tools is hindered by the view of cost-effectiveness. The process is structured by three factors of machine, worker and material, and the productivity is determined by machine capacity, worker performance and product design. After built up all the equipment and operation plans of assembly lines, it is difficult to modify the layout or replace the equipment. Therefore, improvement of the worker performance is an appropriate approach to the productivity enhancement of installed lines. Although jobs on an assembly line normally does not require high-skilled workers because of an aggregation of repetitive tasks, such as picking a component from toolset and assembling a component with a base laid on a conveyor, a slow workstation by a low-skilled worker causes delay of former workstations and idle of latter workstations. In other words, poor performance of one workstation affects to the entire assembly line flow, and it causes, as a result, a decline of productivity of the line.

Existing research and tools for the productivity improvement of manufacturing systems can be classified as manufacturing process design and work method design. Manufacturing process design is research to design and manage a system regarding with equipment installation layout, capacity planning, operation process management and operation and resource scheduling. This research is to select process type (i.e. job shop, batch, assembly, continuous) based on the diversity, flexibility and yield of output products of the system and to apply the selected process to the target manufacturing system. Construction of a manufacturing system requires a lot of resources, and it also needs almost equal resources to modify the constructed system. Thus, this research has to be considered seriously before implementation of a system. Former research on this matter is following: Askin and Mitwasi proposed a mathematical heuristic model for facility layout, process selection and capacity planning of a manufacturing system based on the previous approaches [1], such as linear programming [2], heuristic rule based process planning [3], the Lagrangian relaxation techniques for hierarchical production planning [4], quadratic assignment problem (QAP) and graph theory for facilities layout [5]-[7], procedures for assigning operations to machines [8], [9]. Bazargan-Lari reported layout designs in cellular manufacturing for a dynamic food manufacturing and packaging system [10], and Deb and Bhattacharyya adopted fuzzy theory to plan manufacturing facilities layout [11]. Reifur suggested a proper automation degree in assembly lines [12], and Park and Chang proposed a virtual-factory based simulation for verification of productivity and agile stabilization of a production system [13].

Work method design is to research for the effective capacity maximization of a system and it is a key factor to improve productivity of a system after implementation of the system. The research has been applied to the automated system and manned systems. For the automated manufacturing system, much of research was progressed about robot OLP (Off-Line Programming) for machine work process planning, such as cutting, welding and casting [14]-[16]. For manual work in the manned manufacturing system, there are two streams of research: traditional work design and Ergonomics. The traditional work design is a methodology that is based on manual work analysis to remove inefficiency from worker's movements or working process. This methodology analyzes work using various charts for macro motion study; such as flow process chart and operation process chart [17], [18]; and micro motion study; such as man-machine chart, operation analysis chart and SIMO chart (an abbreviation for simultaneous motion cycle chart) [19]. The macro motion study is a research method that breaks a job down into tasks and movements and the micro

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motion study is a method that defines a unit movement as several body motions. Therefore, work design is able to identify inefficient elements of the wide range from a body action to tasks by using charts to describe work. Ergonomics is another methodology to analyze manual work, but it concentrates on the human factors, which are worker's motions, therblig and postures, to measure the workload and identifies overloaded body parts of the worker to maintain well-performance by retaining health and safety of the worker. In order to analyze manual work based on ergonomics, it has been used three methods; video-recording, marker and questionnaire. The video-recording method requires a video that captured the entire work of the workers, and it analyzes the video itself or results of the simulation-based virtual experiment that utilizes a virtual work model converted from the video. The marker based method attaches markers onto the body of the worker to track the motion or measure the change of electromyogram or electrocardiogram. The marker based analysis result exactly indicates problematic motions or postures.

Despite much former research for productivity improvement of manufacturing system, the research for worker performance improvement is still stayed in the traditional approaches that are focuses on partial efficiency issues of manual work which can be described by single chart. Although many latest technologies of ergonomic approaches are adopted in the improvement of a workstation, it demands too much of the costs, efforts and time to apply with every workstation of an assembly line. In the research for the line balancing problem of the assembly line process, productivity of each workstation for line productivity improvement was mentioned, but the research spotlighted the stabilization of cycle-time balance of workstations using cycle-times assumed as constant values. The manned assembly lines are difficult to forecast performance, because human labors are not expectable factors by computer simulation models or mathematical models. Former research is limited to matters of the human itself, such as ergonomic and workload design, and non-human-factor-relevant simulation. Thus, from the current research situation, there is no solution, which meets recent IT based technology trends, for the forecasting and improvement of manned assembly line performance. This study proposes a framework to solve the lack in research of manned assembly lines, and the implemented system of the proposed framework has been tested with many examples.

The overall structure of this paper is as follows. Section II gives description of the approach of this study, and a framework based on the approach and a software tool that is implemented based on the framework is represented in Section III. Finally, the summary and future study of this paper is addressed in Section IV.

II. Approach

A. Human Labor Analysis

Manual work in manned assembly lines is a repetitive work by human workers. Therefore, this paper defines the work as next. Work is made by an aggregation of operation cycles. An operation cycle that means a single operation contains several work elements, and a work element is composed of worker's motions. Fig. 1 depicts this decomposition of work of an assembly line to explain the structure, and an example of a work element is shown in Fig. 2. In the example, a work element of the worker can be described as 'tighten a screw using a power screw-driver'. The task also can be described as three motions; 'grab a power screwdriver', 'move a power screwdriver' and 'tighten a screw'.

Although the manual work is repetitive, every operation and work element is composed of similar, but different, work elements and motions by waste elements or motions from various reasons, such as work environment problems. Therefore, the waste elements or motions have to be eliminated to improve the performance of a worker. In order to analyze the work of a worker, a traditional work design approach is appropriate, such as a macro motion study for work elements and operation cycles, and a micro motion study for unit motions. However, the existing research of the traditional work design approaches independently and separately to the macro and micro motion study. For improvement of worker performance, a method of work analysis, which is based on the view that integrates both of the macro and micro motion studies, is required to simultaneously see both a composition of the unit motions at each work element and a composition of the work elements at each operation cycle.

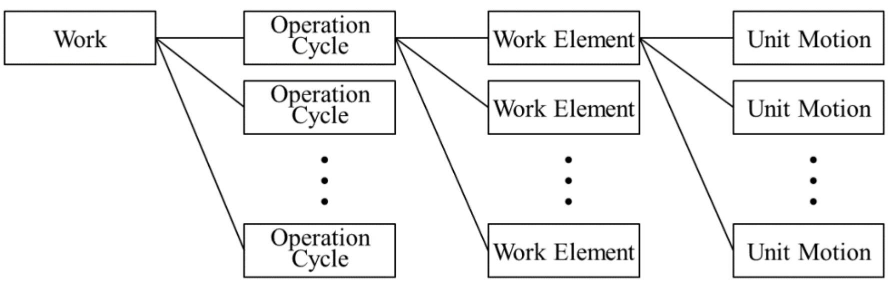


Fig.1 Decomposition of Manual Work

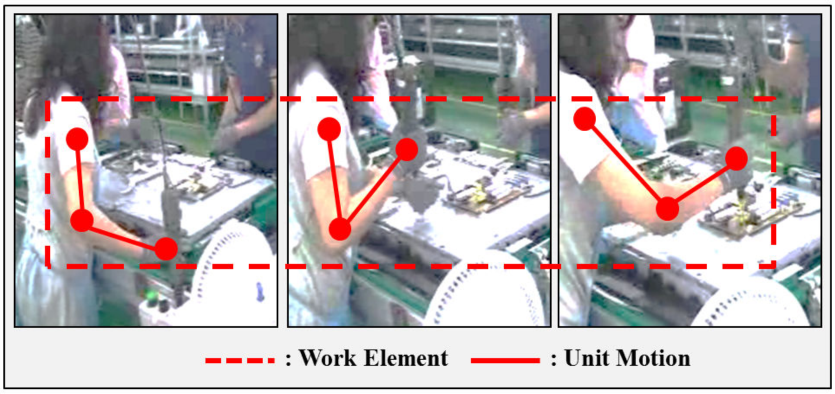


Fig. 2 Example of Element Action and Unit Motions

This study designs a chart template for the integration of different levels of the structure of work decomposition. The designed template in this paper describes a work element with element name and type and a unit motion as motion name and type, waste type, start time and time interval. By the designed template, an element is represented by several unit motions and a single operation is explained by several work elements. Fig. 3 shows a structure and details of the designed template. As a result of the template based analysis, we can acquire detailed information regarding with the current operation state of a worker, such as an average cycle time of a worker, a standard time of one work element, non-uniformed work elements, and scattered unit motions.

B. Assembly Line Construction

After the work analysis, the standard operation and cycle time of each worker in an assembly line are identified. By aligning the analysis results, the entire operation of an assembly line is derived and the longest worker that is a decisive worker of the line productivity is identified. The process for the line generation uses cycle times of every worker which are calculated from the sum of work elements of a standard operation (see Fig.4). The generation process analyzes work of the entire line. A user of the system analyzes work of each worker to decompose work into several operation cycles, an operation cycle into work elements, and a work element into unit motions. According to the decomposition result, none value added unit motions, scattered unit motions, and non-uniformed work elements are identified. The identified defective factors on productivity of a worker lead to high distribution of operation cycle times. The worker performance improvement is executed by elimination of the defective factor to design work on a worker as uniformed repetitive work. The line productivity improvement is executed by reallocation of work elements, which are derived from the work analysis, onto workers. By the line productivity improvement, cycle times of every worker are balanced and the takt time of an assembly line is reduced. For example, a user changes the belonging relationship of 'work element B-d' from worker 2' to worker 3', then the takt time is shorter than before. Finally, a user can perform line balancing experiments based on the real worker cycle times and standard times of work elements.

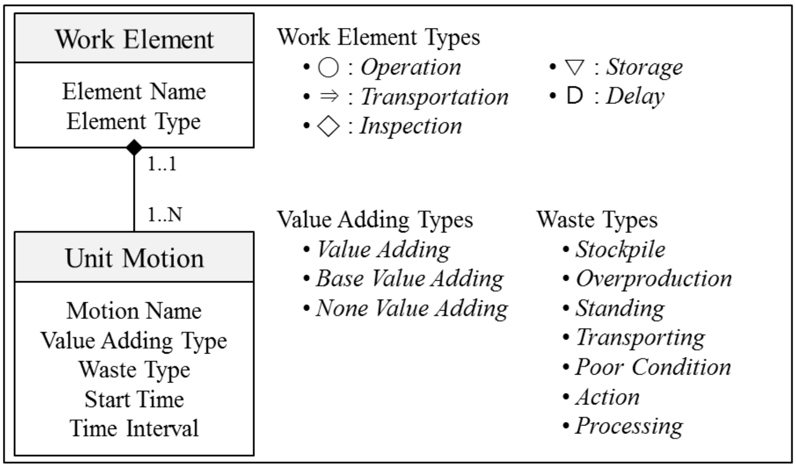
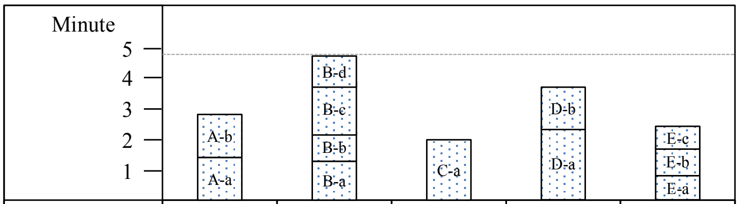


Fig. 3 Designed Template Structure and Detail



Worker #	1	2	3	4	5
Operation	A	B	C	D	E
Standard Time	2.9	4.8	2.0	3.7	2.7

Fig. 4 Line Operation Analysis

III. Framework

In the traditional approaches, an analysis method of work-video has been often adopted to analyze work using macro and micro motion studies. The analysis method provides many benefits, for example, an analyst is allowed to look into the recorded work many times, and this means the analyst can analyze the work for purposes of various dimensions. As explained in the previous chapter, this paper analyzes work on a worker to levels of the operation cycle, work element, and unit motion. For the analysis of a worker, the system adopts the method of the work-video import, and it analyzes the imported video using a chart which is based on the designed template. The system proposed in this study is to help users to analyze a video which was recording work of a worker. The system requires a work video as a resource, and it plays a video file on a screen. A user defines sections of the video, and each section is input an analysis from a user. The system provides a chart for allowing a user to input analysis data and stores the data in the database. The analysis result is displayed using graphs, such as a Gantt chart, bar chart and box plot chart, to represent the current state of a work process. A user is able to revise the work process of a worker based on the analysis result, and the revised work process allows to be simulated in the system by exclusion of poor unit motions from the analysis result. The analyzed and revised work process of a worker is exported as a new standard work process of the field. The result of this work analysis is stored in the standard work analysis result database, and this framework is shown in Fig. 5.

Users select analysis results from the database, and selected results are aligned to construct a virtual assembly line. The generated virtual assembly line represents performance of an entire assembly line based on work analysis results of workers. Users execute activities that modify an allocation state of work elements into workers for improvement of the assembly line. The modified work element design of the assembly line is generated as a virtual assembly line and examined its validity using a simulation. The virtual assembly line is represented by a work flow of work elements among workers and the flow is converted to 3D simulation. Thus, the validity of the modified work element design is able to be verified as shown in Fig. 6.

IV. Conclusion

This paper is research for performance improvement and simulation of manned assembly lines. For the improvement, this paper proposes a framework for a system to analyze a worker and an entire assembly line, and it also introduces a software tool that is implemented based on the proposed framework. Work on a worker is able to be analyzed by the designed chart of this paper that integrates macro and micro motion studies. The system proposed in this paper is developed to help a user to analyze a work process using video playback. A user of the system is able to analyze work videos and write the analysis result onto the designed chart. The work analysis results of every worker of an assembly line are aligned to represent productivity of an assembly line. The aligned results are modified to test performance improvement of an assembly line. The modified work results are applied to simulation and verified its validity.

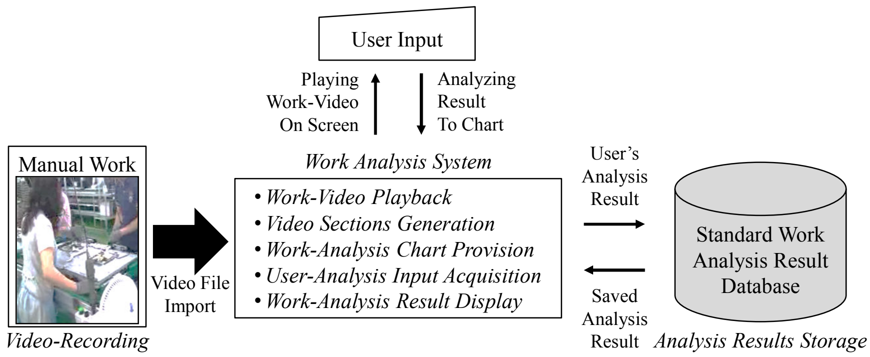


Fig. 5 Work Analysis Framework

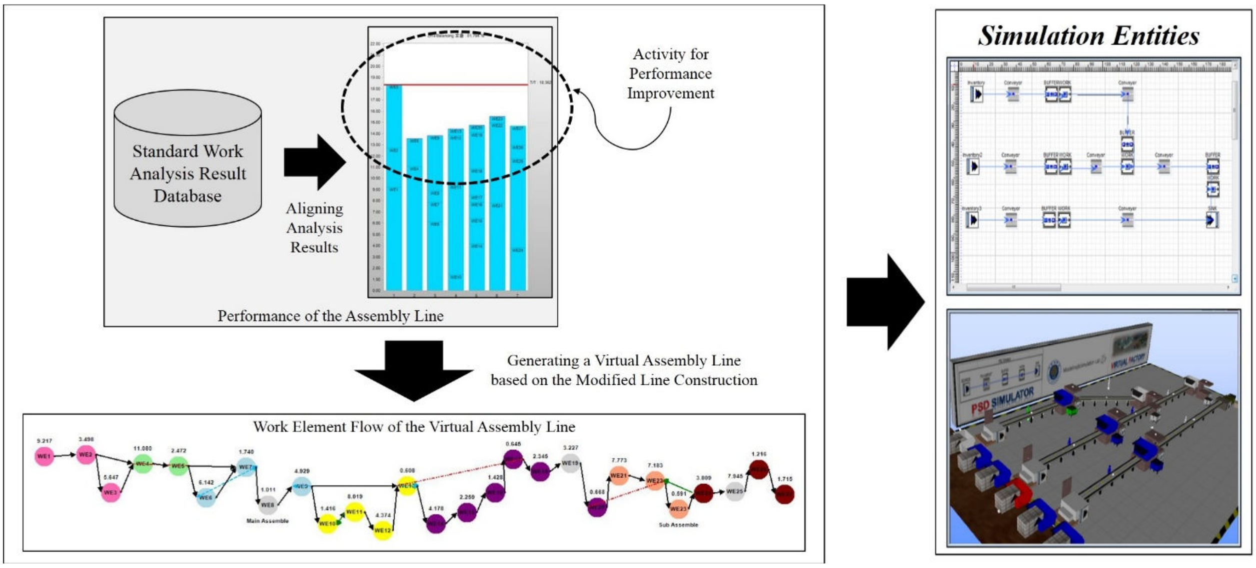


Fig. 6 Generation and Simulation of the Virtual Assembly Line

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REFERENCES

[1] R. G. Askin, and M. G. Mitwasi, "Integrating Facility Layout with Process Selection and Capacity Planning", European Journal of Operation Research, Vol. 57, pp. 162-173. 1992.
[2] L. A. Johnson, and D. C. Montgomery, Operations Research for Production Planning, Scheduling, and Inventory Control, New York: John Wiley. 1974.
[3] T. -C. Chang, and R. A. Wysk, An Introduction to Automated Process Planning Systems, New Jersey: Prentice-Hall. 1985.
[4] S. C. Graves, "Using Lagrangean techniques to solve hierarchical production planning problems". Management Science, Vol. 28(3), pp. 260-275. 1982.
[5] F. S. Hillier, and M. M. Connors, "Quadratic assignment problem algorithms and the location of indivisible activities", Management Science, Vol. 13(1), pp. 42-57. 1966.
[6] B. Golany, and M. J. Rosenblatt, "A heuristic algorithm for the quadratic assignment formulation to the plant layout problem", International Journal of Production Research, Vol. 27(2), pp. 293-308. 1989.
[7] L. R. Foulds, P. B. Gibbons, and J. W. Giffin, "Facilities layout adjacency determination: An experimental comparison three graph theoretic heuristics". Operations Research, Vol. 33(5), pp. 1091-1106. 1985.
[8] H. Co, and A. Araar, "Configuring cellular manufacturing systems", International Journal of Production Research, Vol. 26(9), pp. 1511-1522. 1988.
[9] Askin, R. G., and Chiu, S. "A graph partitioning procedure for machine assignment and cell formation in group technology", International Journal of Production Research, Vol. 28(8), pp. 1555-1572. 1990.
[10] Bazargan-Lari, M. "Case Study: Layout Designs in Cellular Manufacturing", European Journal of Operation Research, Vol. 112, pp. 258-272. 1999.
[11] Deb, S. K., and Bhattacharyya, B. "Fuzzy decision support system for manufacturing facilities layout planning", Decision Support System, Vol. 40, pp. 305-314. 2005.
[12] Reifur, B. "Optimum Assembly Automation Level Selection Module as the Component of Advisory System", Archives of Civil and Mechanical Engineering, Vol. 7(1), pp. 75-83. 2007.
[13] Park, S. C., and Chang, M. "Hardware-in-the-loop Simulation for a Production System", International Journal of Production Research, Vol. 50(8), pp. 2321-2330. 2012.
[14] Park, S. C., and Choi, B. K. "Boundary Extraction Algorithm for Cutting Area Detection", Computer-Aided Design, Vol. 33, pp. 571-579. 2001.
[15] Park, S. C., and Chung, Y. C. "Tool-path Generation from Measured Data", Computer-Aided Design, Vol. 35, pp. 467-475. 2003.
[16] Ruan, J., Eiamsa-ard, K., and Liou, F. W. 2005. "Automatic Process Planning and Toolpath Generation of Multiaxis Hybrid Manufacturing System", Journal of Manufacturing Processes, Vol. 7(1), pp. 57-68.
[17] F. B. Gilbreth, Motion Study: a Method for Increasing the Efficiency of the Workman, New York: Van Nostrand. 1911.
[18] F. B. Gilbreth, and L. M. Gilbreth, Process Charts, New York: The American Society of Mechanical Engineers. 1921.
[19] Freivalds, A., and B. W. Niebel, Niebel's Methods, Standards, and Work Design: Twelfth Edition. New York: McGraw-Hill, 2009

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