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A Comparison of the Effects of Worker-Related Variables on Process Efficiency in a Manufacturing System Simulation

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Abstract

Purpose: The goal of this study was to build an accurate digital factory that evaluates the performance of a factory using computer simulation. To achieve this goal, we evaluated the effect of worker-related variables on production in a simulation model using comparative analysis of two cases. **Methods:** The overall work process and worker-related variables were determined and used to build a simulation model. Siemens PLM Software's Plant Simulation was used to build a simulation model. Also, two simulation models were built, where the only difference was the use of the worker-related variable, and the total daily production analyzed and compared in terms of the individual process. Additionally, worker efficiency was evaluated based on worker analysis. **Results:** When the daily production of the two models were compared, a 0.16% error rate was observed for the model where the worker-related variables were applied and error rate was approximately 5.35% for the model where the worker-related variables were not applied. In addition, the production in the individual processes showed lower error rate in the model that included the worker-related variables than the model where the worker-related variables were not used. Also, among the total of 22 workers, only three workers satisfied the IFRS (International Financial Reporting Standards) suggested worker capacity rate (90%). **Conclusions:** In the daily total production and individual process production, the model that included the worker-related variables produced results that were closer to the real production values. This result indicates the importance of worker elements as input variables, in regards to building accurate simulation models. Also, as suggested in this study, the model that included the worker-related variables can be utilized to analyze in more detail actual production. The results from this study are expected to be utilized to improve the work process and worker efficiency.

Keywords: Building block method, Digital factory, Human factors, Utilization rate, Working process analysis

Introduction

Manufacturing processes mainly consist of workers and work facilities and their interactions are essential to operate a manufacturing system (Carey and Gallway, 2002). Thus, workers and work facilities are the key factors in successful production, and should be considered in the design and improvement of production processes (Siemieniuch and Sinclair, 2002, 2006). However, most existing processes manage information only on the elements that are related to work equipment. There are many difficulties associated with systematic measurements and management of worker-related variables, which makes it difficult for companies to manage worker efficiency using the ERP (Enterprise Resource Planning) system (Kim and Moon, 2011). However, when worker-related variables are not considered during planning, frequent injuries occur and work efficiency can be reduced due to improper working passage design and excessive workloads, which ultimately delays the operation time and causes a financial loss

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(Carey et al., 2002; Otto and Scholl, 2011). Therefore, there is a need to develop a novel process design or improve current process design approaches that consider the workers (Dul and Neumann, 2009).

A worker is only relevant in the early stages of a design process; however, the success of the design with worker consideration can only be determined when an actual plant operation starts, and data measurement and analysis of the workers are performed. Moreover, a series of processes requires additional cost and effort in the long-term; even with the problem analysis and an improved scheme, production lines have already been built in the state, so the drawn schema cannot be applied immediately (Kim et al., 2011). Thus, simulation based process designs are used to perform analysis and evaluations in a computer (Arndt et al., 2006), and allow to draw an optimum design (Azadeh et al., 2011). This kind of simulation methods have been used for the large manufacturing factories, but demands for more customized solutions for small and medium manufacturing factories have been continued: more suitable for factory dimension and less expensive (Souza et al., 2006; Mancini et al., 2004). Especially, the number of agricultural manufacturing factories in Korea is increasing annually (Lee et al., 2011), and there are possibilities to utilize the simulation method. In addition, there are researches done related to the production increase in small size agricultural manufacturing factories using simulation method (Zanoelo et al., 2008; Simpson and Abakarov, 2009). However, the application of this approach can only be made after a simulation model has been demonstrated to accurately predict the actual production line in a factory. For accurate verification of the simulation model, key elements representing the process must be used as input data, and previous studies have also used to determine the most relevant input variables. Baines et al. (2004) proposed worker skills and time shift as worker-related variables, and found that simulation models using worker-related variables increased the validity and accuracy of the model. Battini et al. (2011) reported that environmental & technological variables had a significant effect on the simulation model design, including the assembly system layout, process time, process line design, automation level, and minimum requirement of equipment/workers. In these two studies, however, verification process requiring comparison to the actual process of production (Baines et al., 2004), was not performed. In addition, the correlation between the mechanical elements and the workers in a qualitative way during the application of the simulation model was not determined (Battini et al., 2011). Brendan et al. (2011) also evaluated worker-related variables, including shift schedules, worker skills, work space, and process requirements, and proposed to the potential of using worker-related variables in quantitative ways. However, the effects of worker-related variables were not verified in a simulation model.

The simulation results, only considering the logistic input and output data without worker-related data, tend to overestimate the production (Becker et al., 2005 and Neumann et al., 2006). Thus, there is a need to build simulation models that use worker-related variables.

Therefore, the aim of this study is to evaluate the effect of the worker on the output of the entire simulation model by comparing the results of the simulation model with the worker-related variables with ones without the worker-related variables.

Materials and Methods

Target process

The subjects used in this study were domestic traditional Korean sweets manufacturer A, and the operation system of the factory was collaborated with the worker and automated production lines. The target process included all individual processes needed to make Yukwa, typical traditional Korean sweets, which included a total of 13 individual processes from the soak process to the packaging process, and 22 workers were responsible for the management of the equipment and manual tasks (rice soak, ingredient figuration, etc.). In addition, the entire processes were divided into three group processes: soak~figuration, frying~coating, and packaging (Figure 1).

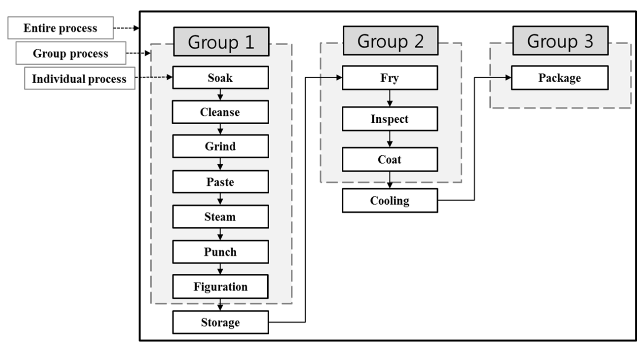

Figure 1. Schematic of the process flow.

Table 1. Worker arrangement and description of the work

Individual process	Process in detail	Number of workers* (number)
Soak	Soak rice in water	1
Cleanse	Cleanse rice in soak tube	1
Grind	Grind soaked rice	1
Paste	Paste with flour and liquor	2
Steam	Steam ingredient for an hour	2
Punch	Knead steamed ingredient	2
Figuration	Figurate in product form	3
Storage	Storage for supply regulation	0
Fry	Put product in mold and fry	5
Inspect	Sort out faulty	2
Coating	Coat with syrup and popped rice	3
Cooling	Cooling and storage before packaging	0
Packaging	Packaging product in a container	7

*In the table, the number of workers is 29. However, the workers in the factory are still 22 because different processes are done by same workers, and there are overlaps in the worker number.

Table 2. Comparison of the worker-related variables

Sort	Baines et al. (2004)	Battini et al. (2011)	Brendan et al. (2011)	Present study (2012)
1	Shift-schedule	Worker arrangement	Shift-schedule	Shift-schedule
2	Work skill (working speed)	Work hours	Work circulation	Work circulation
3		Work posture	Worker arrangement	Work hours
4				Worker arrangement
5				Working speed

The each group produces daily assigned goals and stores the ingredients to be used next day at storage and cooling process. In here, the storage and cooling process were excluded from the groups because of their auxiliary role. Figure 1 shows an overview of the target factory, and the details of the worker placement and individual processes are as shown in Table 1.

Data measurement and worker-related variable selection

Data selection in the production process is very important to produce an accurate a simulation model that reflects the factory process (Kim, 2003). The design variables used to build the simulation model are presented in Table 2 and were based on the results of previous studies (Battini et al., 2011; Baines et al., 2004; Brendan et al., 2011). Among the variables used in the previous studies, the worker-related variables (the working speed, the work hours, worker circulation, initial worker arrangement, and shift schedule, were obtained using work operation sheets, spot inspection, and interviews with the workers. Especially, the working speed, work hours, and worker circulation were shown to significantly affect the production rate and process time. In addition, the initial placement of workers is necessary to determine the optimum work circulation and number of workers, and it was used to evaluate the worker efficiency. To measure the worker-related variables, each unit of work was recorded on a video, and the actual work of an individual worker was simulated using the collected data.

Design simulation model

The Siemens PLM Software's Plant Simulation (Siemens PLM Software Inc., Texas, USA) was used to create the simulation model. Each process was designed using the building block method based on the measured input from

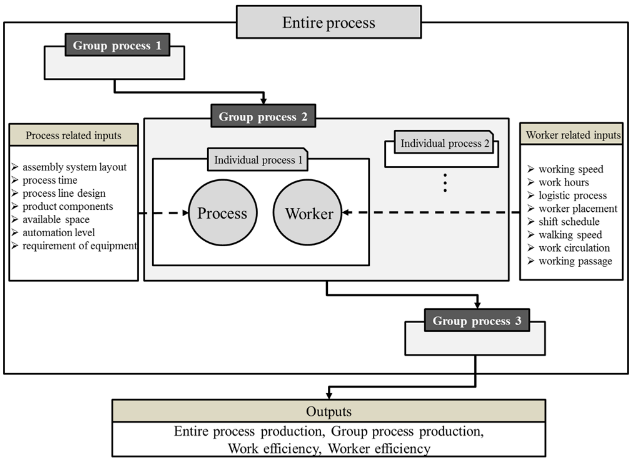

Figure 2. Schematic of the simulation model and variables.

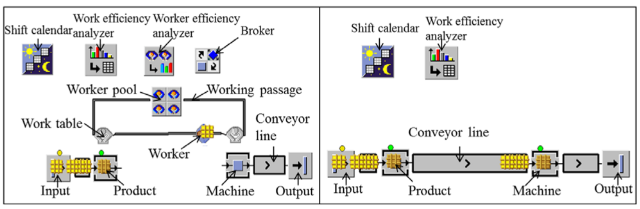

Figure 3. Simulation model of the single task in the packaging process with (left) and without (right) the worker-related variables.

the actual plant. The building block method, which is proposed by Cubert and Fishwick (1998) and Pegden et al. (2001), designs individual processes of a plant in an object-oriented structure. An individual process modeled as a building block can be utilized for independent design/analysis/modification in a closed system, and configuring a full factory simulation model with multiple building blocks is possible (Zhou and Venkatesh, 1998).

The simulation model built in this study uses input data measured in actual process. The input variables are divided into process related inputs (process time, process line design, available space, etc.) and worker-related ones (worker placement, work speed, shift schedule, etc.). The outputs are following: entire process production, group process production, work efficiency, and worker efficiency. Schematic of the simulation model is shown in Figure 2.

Moreover, two models, one including the worker-related variables and the other not, were developed in this study and the total daily production using the same input were compared. Figure 3 shows same single task in the packaging process modeled with and without the worker-related variables. The components added to the simulation with worker-related variables are following: work table where workers perform tasks, working passages which allow workers to move between the workplaces, worker pool as waiting room for workers, broker which distributes tasks to workers, and personal information of workers.

Results and Discussion

Work process analysis

Production comparison

In order to compare the results of two simulation models, the total daily production was calculated and compared. To start with, the productions were adjusted depending on the peak or non-peak season, and there is relatively large gap in the daily production during the two different seasons. Therefore, daily production was obtained through interviews with a production director, and the value, 80,000 pieces, was set as the daily production of an actual process. Two more production values (160000 and 14000) were used in the simulation. The reason for the higher production in the group processes was the individual processes of storage and cooling at the end of each group process, and product can be stored until the products move to the next process. In the actual production line, the daily production is adjusted according to the peak and non-peak season.

The daily production outputs in the entire process were 84280 pieces and 79870 pieces with and without the worker-related variables, respectively (Since the packaging process is possessed at the last of the entire processes, the entire daily production and the packaging process production is same). These values were evaluated with the actual production process; the error rates were 5.35% for the former and 0.16% for the latter (Table 3). The error rate was calculated as described in Equation (1). The daily production of the figuration, coating, and packaging process, which were placed at the end of the group process and were affected by the cumulated work amount and time delays from the previous individual processes, was also compared at these both conditions. Simulation results including the worker-related variables were better than ones at the non-worker-related variables in entire daily process and group process as well.

$$\text{Error rate}(\%) = \frac{|\text{Actualproduction} - \sim\text{ulationproduction}|}{\text{Actualproduction}} \times 100 \qquad (1)$$

Table 3. Daily production of the three individual processes

Process	Real value	Simulation model value	
		With worker (measuring efficiency)	Without worker (measuring efficiency)
Figuration	160000	160650 (0.41%)	177600 (11.00%)
Coating	140000	139680 (0.23%)	142320 (1.66%)
Packaging (Entire daily output)	80000	79870 (0.16%)	84280 (5.35%)

Work efficiency analysis on tasks in the three individual processes

In order to compare the two models specifically, tasks in figuration, coating and packaging process were analyzed. These three individual processes are placed in the last of group processes and are considerably meaningful, because the cumulated impacts of the workers from the preceding individual processes appear at their own last processes. The workplace, distribution line, and storage were used to configure the simulation model, and differences due to the inclusion of the workers were observed in the simulation model. The performance in the tasks was categorized into groups: working, waiting, and blocked. Working (which is equal to the working efficiency) is the state where the action takes place in the workplace, waiting is the state where the workplace does not have a product to handle, and blocked refers to the process within the bottleneck that is caused by the process time. The performance in the tasks (working, waiting, and blocked) are calculated as time portion within the total daily work hour, and the simulation software automatically measures the portions. The results of the task performance in the three individual processes are in Table 4~6, and the working efficiency at each task is shown in bold.

Large differences in the efficiency were observed between the two models. The working rate of the tasks in figuration process, molding machine, receiving products in a tray, and carrying the tray, the working rates were 20.00%, 43.65%, and 2.00%, with worker-related variables, and 22.37%, 44.31%, and 2.21% with non-worker-related variables, respectively. In all tasks, the working rates at the worker-related variables were low. The difference in the working rate for each task appeared as the differences in production. The tasks (popped rice supply, product supply) in the coating process also had different working efficiencies, 50.86%, 49.95% and 51.42%, 50.74%, respectively, and a decrease in efficiency was also observed when the worker-related variables were included in the simulation. In the packaging process, since the primary packaging tasks are dependent on the speed of the packing machine, the working rate did not differ (98.60%); however, the box packing (3EA), which putting 1 package 3 pieces products into a box, showed different working efficiency with 56.3% and 58.06%, respectively.

Production is dependent on the efficiency of the tasks in individual processes, and a decrease in the process work efficiency was observed in the model that included worker-related variables. When the worker-related variables were added to the simulation model (work circulation, walking speed, and maximum accommodate amount, time difference between the work of each worker, groundwork time, etc.) time delays such as products carrying, and discontinued operations, were observed as well as work time delays. For instance, at molding machine operating and tray carrying in the figuration process, the work efficiency decreased by 2.37% and 0.21%, respectively. A decrease was also observed for the receiving task (0.67%). The differences in the work efficiencies were led to the decrement in production from 177,600 to 160,650 between the two models. It can be said that the decrement in work efficiency by adding worker-related variables prevents a tendency to overestimate the production. According to Baines et al., (2004), the reason for the high predictive production value in the simulation model is the lack of important inputs into the model. They considered worker-related variable as a major element, and showed a decrease in production when the variables were added. Similar results were observed in this study, where a decrease in production was observed when worker-related variables were used, which indicates that the inclusion of worker-related variables to the simulation gives us more accurately predicted production.

Worker efficiency analysis

The worker efficiency was expressed as a percentage of the two categories: working and waiting. The working

Table 4. Work efficiency of the figuration process depending on the use of worker-related variables

	Figuration						
	With worker			Without worker			
Tasks	waiting	working	blocked	waiting	working	blocked	working rate difference
molding press	1.06	**20.00**	23.38	0.00	**22.37**	22.07	2.37
product receive	0.79	**43.65**	0.00	0.13	**44.31**	0.00	0.67
tray transit	42.44	**2.00**	0.00	42.23	**2.21**	0.00	0.21

Table 5. Work efficiency of the coating process depending on the use of worker-related variables

	Coating						
	With worker			Without worker			
Tasks	waiting	working	blocked	waiting	working	blocked	working rate difference
popped rice supply	49.14	**50.86**	0.00	48.58	**51.42**	0.00	0.56
product supply	47.65	**49.95**	2.40	49.26	**50.74**	0.00	0.79

Table 6. Work efficiency of the packaging process depending on the use of worker-related variables

	Packaging						
	With worker			Without worker			
Tasks	waiting	working	blocked	waiting	working	blocked	working rate difference
primary packing	0.00	**98.60**	1.40	0.00	**98.60**	1.40	0.00
box packing (3EA)	0.06	**56.30**	43.64	0.00	**58.06**	41.94	1.76
box packing (2EA)	0.04	**52.47**	47.49	0.00	**52.47**	47.53	0.00

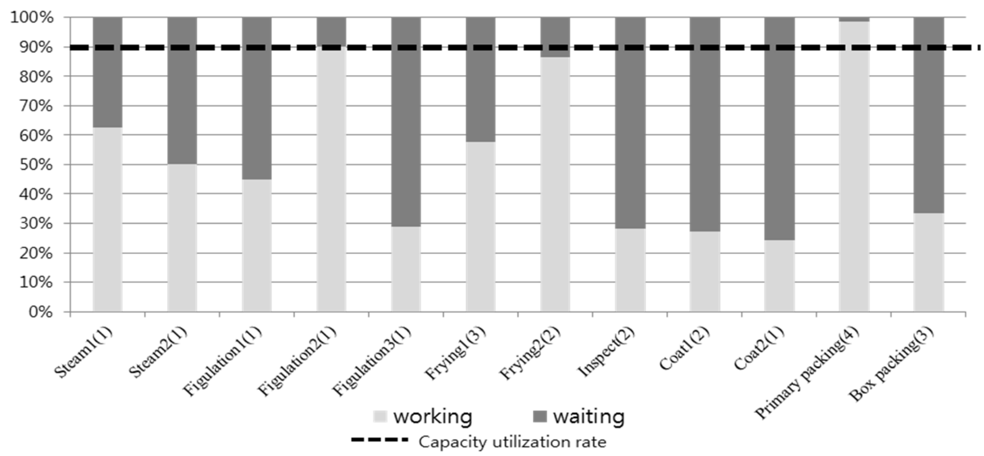

Figure 4. Worker efficiency analyses result in the each task.

ratio contains the rate of practical working, such as assembling or packing products into box, and transporting from one task to another task. In contrast, the waiting ratio includes waiting time during an operation and waiting time between an existing work and new one. Analysis of the worker efficiency is shown in Figure 4.

Different tasks performed in a single individual process were defined separately based on the number behind the individual process name, and the average value for workers doing the same work is presented. Additionally, the capacity utilization rate of a worker, 90% which proposed in the "A Guide through IFRS" (International Accounting Standards

Committee Foundation, 2012), was used for worker efficiency analysis. As shown in Figure 4, worker efficiency in figuration2 task was approximately 90.0%, two workers in frying2 task was about 86.6%, and four workers in the primary packing task was about 98.6%. The remaining workers showed a significantly low working rate, approximately 27.3% to 62.5%.

If the work efficiency is analyzed with the performance in the fixed workstations, the worker efficiency is analyzed by the actions (work, movement, carrying, rest, and waiting) of the individual workers conducted in the entire factory. Typically, workers move back and forth between several tasks in an actual plant, so there are limitations when predicting the worker efficiency with a model not including the worker-related variables. Therefore, by applying worker-related variables to the simulation model and analyzing the results, systematic worker management and worker-centered alternative designs are possible. In this study, the efficiency of workers was analyzed using the capacity utilization rate of workers (90%). The capacity utilization rate includes all variables that can be used to separate machines and worker; within the limit, it may increase production of factory without increasing labor costs or additional equipment purchase. As shown in Figure 3, except for the workers in figuration2 task, frying2 task, and primary packing task, most of the workers had a working efficiency below the level of the capacity utilization rate, between 27.3-62.5%. The worker utilization problems resulted from too many workers being assigned to a process, or a low speed of the assembly line when compared to the workload. The lowest worker efficiency (27.3%) was observed in the inspection process. Considering the frequency of failure in the inspection process, which is less than 5%, alternatives to utilizing workers should be recommended, such as reducing the two workers in the inspection process to one or using an automated process. On the contrary, the worker efficiency in the primary packing task was 98.6%, which exceed the capacity utilization rate, since the performances of the workers are dependent on the fast speed of the packing machine. According to the “A guide through IFRS”, worker efficiency exceeding 90% may be led to a decrease in the working efficiency or musculoskeletal disorders in the long term, which requires adjustments.

Conclusions

The results and significances of this study are summarized as follows.

(1) The results of the simulation model were dependent on the application of the worker-related variables, and more accurate results were observed when the worker-related variables were included. These results indicate that a more realistic model can be developed if worker-related variables are included in the analysis.
(2) The worker efficiency was calculated as the simulation results, and the workers were evaluated based on the utilization capacity (90%). The workers in the targeted process of this study mostly had low work efficiency. The results of the worker analysis were only acquirable when the worker-related variables were included; thus, inclusion of this data can result in more accurate analysis.

This study demonstrated the importance of utilizing worker-related variables in the simulation model. However, there were some limitations of this study, including a lack of verification using a time-series data, and optimization using the process simulation. In future studies, the model reliability should be improved by using a more exhaustive verification method, and methods are needed to improve the productivity of the real factory by optimizing the process and worker placement.

Conflict of Interest

The authors have no conflicting financial or other interests.

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