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Ergonomic Analysis of a Modified Dishwashing Facility in a Medium Scale Restaurant

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Abstract
Dishwashing is a crucial stage in the production process of restaurants, where ergonomic aspects for the operators play an important role in determining overall productivity. To support the performance improvement of small and medium enterprises (SMEs), this study conducted an experimental analysis to evaluate the ergonomic level of dishwashing activities in a restaurant located in Bandar Lampung. Prior to the assessment, modifications had been made to the design of the dishwashing facility. The evaluation was carried out using the Ovako Work Posture Analysis System (OWAS), energy consumption analysis, the Nordic Body Map (NBM) questionnaire, and an investigation of the relationship between ergonomic levels and operator productivity. The results revealed that the modified design significantly improved the ergonomic quality of the facility and led to a measurable increase in operator productivity. These findings demonstrate that workplace design improvements in SMEs can effectively enhance both ergonomics and business performance.

Keywords: Design for Ergonomic, Productivity, Indonesian SME

1. Introduction

Work productivity in small, and medium enterprises (SMEs) is a crucial aspect that must be continuously improved through enhancements in various areas, including the design of work facilities. Previous studies have shown that well-designed facilities significantly support productivity [1], with ergonomics playing a key role. Ergonomics is a discipline that examines the level of work comfort in relation to human body posture and movement. Comfortable body positions and movements have been proven to enable workers to perform tasks more quickly and sustain their performance over longer periods [2].

Restaurants in Indonesia, as part of the SME sector, play a vital role in providing employment opportunities and supporting a substantial portion of the national economy [3]. Their business processes encompass the preparation of raw ingredients into ready-to-serve meals, the preparation of cooking and dining utensils, and the delivery of meals to customers. Among these processes, dishwashing is one of the critical stages. In most small- and medium-scale restaurants across Indonesia, this task is still performed manually by workers.

The dishwashing process is vital, as its effectiveness and efficiency determine the cleanliness and hygiene of utensils and, in turn, serve as a benchmark for customer trust [4]. However, dishwashing often takes a considerable amount of time due to poorly designed layouts and washing facilities. The ergonomic aspect of

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workers is frequently overlooked, resulting in complaints of fatigue and eventually lowering productivity.

In this study, a restaurant implemented a modified design of its dishwashing facilities, with the primary aim of increasing dishwashing productivity. The expected outcomes of this modification were faster washing processes, reduced labor requirements, and decreased worker fatigue. Therefore, an ergonomic evaluation of the two dishwashing facility designs—before and after modification—was conducted to compare their ergonomic quality and analyze their impact on worker productivity in the dishwashing section.

2. Methodology

This study was conducted experimentally, in which a number of independent respondents performed dishwashing tasks using two experimental setups that replicated the old and modified washing facilities. The experiment was carried out in a studio constructed at the Department of Mechanical Engineering, University of Lampung, with a total of 15 participants involved. Each respondent was assigned an identical dishwashing workload during the trials, equivalent to 137 dirty plates.

The old washing facility consisted of a layout illustrated in Figure 1, where B1 through B3 represented large washing sinks. The green dot indicated a low stool on which the operator would sit while performing the dishwashing task. K1 and K2 denoted water taps, while R referred to the rack where the cleaned utensils were placed. The new washing facility, by contrast, was a dishwashing table specifically designed by the research team at the University of Lampung, as shown in Figure 2.

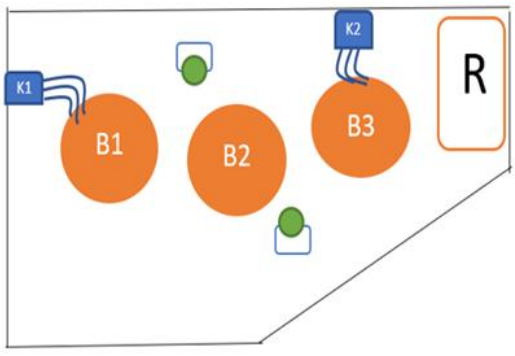

Figure 1. Old Washing Facility Layout

Figure 2. New Washing Facility Model

Each respondent performed the dishwashing task twice, once using the old facility and once using the modified facility. The sequence of facility usage was varied among participants to avoid bias caused by repeated task order. The ergonomic level of each facility was evaluated using three complementary approaches: the Nordic Body Map (NBM) questionnaire, postural assessment with the Ovako Work Posture Analysis System (OWAS), and energy consumption calculated from heart rate measurements taken before and after each dishwashing session.

The Nordic Body Map (NBM) is a survey instrument designed to assess the level of musculoskeletal discomfort across different regions of the human body [5]. Respondents were asked to indicate the degree of pain or discomfort on a body chart divided into anatomical segments such as the neck, back, shoulders, arms, waist, and legs. The questionnaire is widely applied due to its ease of implementation, its subjective yet standardized nature, and its ability to provide an initial overview of body regions at risk of musculoskeletal disorders caused by non-ergonomic workloads [6].

In addition, work posture was analyzed using the Ovako Work Posture Analysis System (OWAS). This method was developed to evaluate workers' body postures during manual activities by classifying the positions of the back, arms, legs, and the load being handled [7]. The classifications are then mapped into risk categories that indicate the urgency of corrective actions, ranging from no corrective action needed to immediate intervention required. OWAS has been widely applied in industrial ergonomics research because it provides a

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quantitative assessment of working postures, particularly in tasks that are repetitive or demand significant physical effort [8].

To complement the two previous methods, energy consumption was also measured using a physiological approach based on heart rate as an indicator [9]. The workers' heart rates were recorded before and after the dishwashing process to estimate the metabolic energy demand during the activity. The underlying principle of this method is the linear relationship between heart rate and energy expenditure during physical activity, where an increase in heart rate reflects the cardiovascular workload of the operator.

In ergonomics literature, energy expenditure is commonly expressed in "kilocalories (kcal)" or, in the International System of Units (SI), in "kilojoules (kJ)," where one kilocalorie (kcal) equals 4.2 kilojoules (kJ). This conversion is particularly useful when energy consumption is expressed in units of "watt," with one watt equivalent to one joule per second. In occupational physiology, energy expenditure can also be measured directly through oxygen consumption, where one liter of O_2 corresponds to approximately 4.8 kcal or 20 kJ.

By combining the NBM, OWAS, and energy consumption measurements, a more comprehensive understanding of the ergonomic aspects of the dishwashing facilities being compared can be obtained. The results from these three methods were then analyzed alongside the work output of each respondent, which served as an indicator of labor productivity.

3. Results and Discussions

The experimental testing of the two dishwashing facilities was conducted in a studio setting involving 15 independent respondents. For each respondent, heart rate measurements were taken before and after the dishwashing process. The dishwashing activities using the old and the modified facilities were performed on different days to minimize the potential effects of fatigue. During the washing process, respondents were recorded from three different camera angles to enable OWAS analysis, while each participant was also asked to complete a questionnaire for the NBM assessment. The results of these measurements and evaluations are presented in Table 1.

Table 1. Result of The Experiment

Meth	Energy Cons. (kcal)		NBM		OWAS	
No	Old	New	Old	New	Old	New
1	268,2	93,55	64	44	9	5
2	134,3	80,83	53	39	9	5
3	160,1	85,02	60	36	9	5
4	222,5	93,76	58	42	9	6
5	251,9	121,1	58	33	9	5
6	169,3	96,94	66	36	9	6
7	257,5	85,88	64	37	9	5
8	235,8	127,0	64	36	9	5
9	175,3	60,52	66	32	9	5
10	167,9	90,27	64	37	8	5
11	116,8	83,24	53	35	9	5
12	123,6	90,72	48	38	8	5
13	137,3	62,95	47	42	9	5
14	91,52	141,5	49	35	9	5
15	170,73	194,8	56	37	9	5

In the OWAS analysis, five representative activities were selected as samples: turning on the water tap, picking up dirty dishes, washing dishes, rinsing dishes, and placing dishes on the rack. According to OWAS evaluation standards, the lowest score is 1, which represents an activity with no significant risk, while the highest score is 4, which indicates a hazardous posture that requires corrective action. The scores from the five activities were summed, resulting in a minimum possible total score of 5 and a maximum of 20. As shown in Table 1, the activities performed using the old facility received scores ranging from 8 to 9, whereas the modified facility yielded lower scores, between 5 and 6. Notably, in the old facility, the activity of placing dishes on the rack was identified as involving postures classified in category 4, indicating a hazardous condition for safety and health. This finding demonstrates that the modified facility effectively eliminated potentially harmful postures and, therefore, is more ergonomic than the old facility based on the OWAS assessment.

In the energy consumption analysis, a simplified approach was applied by calculating the average heart rate obtained from measurements taken before and after the dishwashing activity. This average heart rate was converted to expenditure energy Astrand dan Rodahl formula and was then multiplied by the duration of the washing process to estimate the total energy expenditure for each respondent. As

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illustrated in Figure 3, the energy consumed by respondents when using the old facility was considerably higher compared to the modified facility. On average, the use of the new facility resulted in an energy saving of approximately 46%. This outcome further indicates that the modified facility is not only more comfortable for operators but also reduces their physical energy demands during work.

Figure 3. Energy Consumption Comparison

Meanwhile, the results of the Nordic Body Map (NBM) questionnaire revealed that perceived pain and discomfort levels were substantially higher when respondents used the old facility compared to the modified one. The average NBM score for the old facility was 58, whereas the new facility yielded a lower average score of 37.2. These findings indicate that fatigue, pain, and discomfort were more frequently experienced when working with the old facility, as reported by respondents. In contrast, after using the modified facility, respondents reported feeling less fatigued and experiencing minimal physical complaints, even after completing the dishwashing activity.

In this study, the productivity values of each respondent were also calculated using the standard time (ST), which was derived from the cycle time (CT) and, in turn, from the observed time (OT). The assumptions applied were that the performance rating of all respondents was equal to 1, the allowance factor for dishwashing activities was set at 0.15, and the effective working time per day was considered to be 8 hours. Based on these parameters, the productivity (P) of each respondent was computed, as presented in Table 2. Figure 4 further illustrates that the use of the modified facility led to a substantial increase in respondents' productivity, thereby positively influencing the economic performance of the work unit. The data indicate that the productivity gain achieved through the implementation of the new facility reached nearly 44%.

Table 2. Productivity Calculation

No	Old Facility			New Facility		
	OT (min)	ST (min)	P (unit /day)	OT (min)	ST (min)	P (unit /day)
1	60,8	0,5	941,3	33,0	0,3	1731
2	45,2	0,4	1266	28,1	0,2	2037
3	40,2	0,3	1422	32,8	0,3	1743
4	52,1	0,4	1097	30,1	0,3	1902
5	63,3	0,5	904,1	48,2	0,4	1186
6	41,5	0,3	1377	30,6	0,3	1868
7	51,6	0,4	1108	25,2	0,2	2269
8	47,3	0,4	1210	28,8	0,2	1987
9	55,3	0,5	1033	26,3	0,2	2177
10	60,3	0,5	947,8	29,9	0,3	1915
11	39,9	0,3	1432	29,9	0,3	1912
12	32,2	0,3	1775	35,0	0,3	1633
13	39,2	0,3	1459	30,5	0,3	1874
14	34,7	0,3	1649	60,2	0,5	949
15	45,6	0,4	1254	54,9	0,5	1042

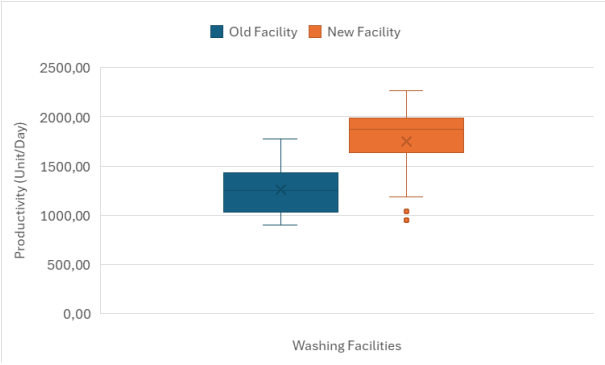

Figure 4. Productivty Comparison

When the relationship between energy consumption and productivity was analyzed, as illustrated in Figure 5, it was observed that lower energy requirements in an activity were associated with higher productivity. The highest R-square value obtained for the trend line of this dataset was 69.4% using a polynomial equation. Although this value cannot yet be considered fully valid, it provides an important indication for the development of related theoretical frameworks in future research. This finding implies that greater attention to operator comfort can lead to higher

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productivity and improved overall unit performance. These results are consistent with previous studies which have reported that the application of ergonomics reduces process energy demands while enhancing worker safety [10] and increases work effectiveness [11].

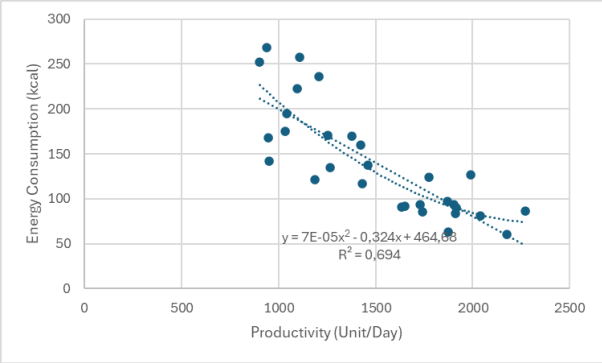

Figure 5. Productivity vs Energy Consumption

4. Conclusion

Workplace facilities within a business unit can be redesigned to enhance productivity and performance by improving the ergonomic quality of their design. Ensuring operator comfort, particularly within small and medium-sized enterprises (SMEs), plays a crucial role in strengthening business capacity and, indirectly, supporting national economic development.

In this study, the washing facility of a medium-scale restaurant was redesigned, and both the original and modified versions were tested through a series of experiments involving 15 independent respondents. The objective was to determine the extent to which operator ergonomics could be improved and whether such improvements would also influence work productivity.

The experimental results demonstrated that the redesigned facility significantly enhanced ergonomic outcomes, as evidenced by reductions in energy consumption, improvements in musculoskeletal comfort measured through the Nordic Body Map (NBM) questionnaire, and safer working postures identified using the Ovako Work Posture Analysis System (OWAS). Specifically, the use of the new facility reduced operators' energy expenditure by 46%, significantly decreased discomfort levels according to the NBM results, and lowered risky postures from an average score of 8.8 to 5.2 in the OWAS analysis. These findings confirm that redesigning workplace facilities can improve operator comfort, reduce health risks, and enhance overall job satisfaction.

Moreover, the improvements in ergonomics were positively correlated with higher productivity. Based on calculations derived from observed working time and workload, productivity among respondents increased by 44% when using the redesigned facility. This provides further evidence that operator comfort not only benefits individual well-being but also contributes directly to the performance of business units, making ergonomics a critical aspect to be considered by SME managers in their efforts to scale up operations.

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