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Enhancing Performance and Worker Satisfaction at Tokonekoncoku Logistics Warehouse through Ergonomic Interior Design: A DMADV and CTQ-Based Study

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ABSTRACT

The rapid expansion of the e-commerce sector has imposed considerable demands on Usaha Mikro, Kecil, dan Menengah (UMKM) to enhance the operational efficiency of their logistics warehouses. This study aims to improve organizational performance and employee well-being at Tokonekoncoku, a logistics UMKM, through an ergonomic workplace redesign. The research employs the Define, Measure, Analyze, Design, Verify (DMADV) methodology, emphasizing Critical to Quality (CTQ) parameters to ensure that the proposed interventions are both contextually relevant and quantitatively measurable. The CTQ priorities identified include operational time efficiency, productivity enhancement, and workforce satisfaction. By systematically implementing ergonomic principles—encompassing layout reorganization and workstation modifications—the study demonstrates a significant improvement in the efficiency and comfort of the work environment. The findings underscore that the integration of ergonomic design within the DMADV framework offers a robust approach to simultaneously advancing operational performance and promoting worker well-being in UMKM logistics settings.
Keyword: DMADV, CTQ, Ergonomics, Interior Design, Logistics, E-Commerce

ABSTRAK

Pertumbuhan pesat sektor e-commerce telah menimbulkan tuntutan besar bagi Usaha Mikro, Kecil, dan Menengah (UMKM) untuk meningkatkan efisiensi operasional gudang logistik mereka. Penelitian ini bertujuan untuk meningkatkan kinerja organisasi dan kesejahteraan karyawan di Tokonekoncoku, sebuah UMKM logistik, melalui perancangan ulang tempat kerja yang ergonomis. Metode yang digunakan adalah Define, Measure, Analyze, Design, Verify (DMADV) dengan penekanan pada parameter Critical to Quality (CTQ) agar intervensi yang diusulkan relevan secara kontekstual dan dapat diukur secara kuantitatif. Prioritas CTQ yang diidentifikasi mencakup efisiensi waktu operasional, peningkatan produktivitas, dan kepuasan tenaga kerja. Melalui penerapan prinsip ergonomi secara sistematis—mulai dari reorganisasi tata letak hingga modifikasi stasiun kerja—penelitian ini menunjukkan adanya peningkatan signifikan dalam efisiensi dan kenyamanan lingkungan kerja. Temuan ini menegaskan bahwa integrasi desain ergonomis ke dalam kerangka DMADV merupakan pendekatan yang kuat untuk secara bersamaan mendorong kinerja operasional dan mendukung kesejahteraan pekerja di lingkungan UMKM logistik.
Keyword: DMADV, CTQ, Ergonomi, Desain Interior, Logistik, E-Commerce

1. Introduction

The exponential expansion of the e-commerce sector places a dual strain on logistics operations, where the demand for speed and efficiency frequently clashes with the well-being of the workforce. For UMKM (Usaha

Mikro, Kecil, dan Menengah), logistics warehouses have transformed from simple storage facilities into operational nerve centers that directly influence delivery speeds and customer satisfaction. Nonetheless, warehouse operations are commonly defined by repetitive tasks and significant physical demands. These conditions not only foster inefficiency and the risk of injury but also contribute to high employee turnover and a degradation of overall work quality. Prior research has underscored these challenges, identifying musculoskeletal disorders and low levels of job satisfaction as pervasive issues that adversely impact productivity and employee retention. [1],[2] .

In response to these challenges, an ergonomic approach to workplace design offers a promising solution. Ergonomics focuses on designing work systems that align with human capabilities and limitations [3], aiming to create an environment that is safe, comfortable, and productive [1], [4]. A study demonstrated how non-ergonomic workstation design leads to physical complaints, such as back and leg pain, ultimately resulting in decreased productivity [5]. The implementation of ergonomic principles in warehouses has been proven to reduce injury risk by up to 27% and increase operational output [6]. However, to be effective, the application of ergonomic solutions requires a systematic and data-driven approach—an aspect often neglected in implementations that are partial or reactive.

Accordingly, the present study integrates ergonomic principles into the Six Sigma framework [7], specifically the Define, Measure, Analyze, Design, and Verify (DMADV) methodology. The DMADV methodology provides a systematic approach for designing new processes or products that optimally meet customer needs—in this case, the needs of both workers and management. By defining Critical to Quality (CTQ) parameters such as operational time, productivity, and worker satisfaction, this research aims to design and verify ergonomic interior design solutions that are measurable and have a significant impact [8]. As such, the primary contribution of this research is to present and validate an integrated framework utilizing the Six Sigma DMADV methodology [9], [10] to systematically guide ergonomic design within the context of logistics for e-commerce UMKM. This innovative approach strengthens the argument that operational efficiency need not come at the expense of worker well-being [11], [12], and yields practical implications in the form of recommendations for adaptive warehouse governance for sustainable implementation [13], while acknowledging study limitations such as a short observation period and potential bias from the Hawthorne effect [11].

This study was conducted over a three-month period. Further studies are required to evaluate the long-term impacts, the scalability of the model, and contextual factors such as seasonal variations in demand. Nevertheless, these findings can serve as a foundation for developing more standardized ergonomic design frameworks within the logistics industry.

2. Methods

To determine how ergonomic principles in interior design can enhance operational efficiency and worker welfare, this research adopted a pre-test/post-test framework. The project was structured using the DMADV (Define, Measure, Analyze, Design, Verify) methodology, a systematic Six Sigma tool. This ensured a thorough progression from identifying initial needs and measuring baseline conditions to analyzing critical elements, before designing and validating the final implemented solution. Central to this process was the integration of data-driven analysis with the direct needs and experiences articulated by employees and management at Tokonekoncoku.

2.1. Research Procedure

The research process was conducted through the five phases of the DMADV methodology:

1. Define Phase. The initial Define phase centered on the core objective: to enhance both operational efficiency and employee welfare at Tokonekoncoku by redesigning the interior space with ergonomic principles. To identify specific areas for improvement, interviews were conducted with staff and management. According to a study conducted by Gruchmann, Mies, Neukirchen, and Gold in 2021, the primary output of this phase was the establishment of Critical to Quality (CTQ) parameters that form the basis for measuring the project's success.

Table 1. CTQ Parameters

Parameter CTQ	Definition

Per-Package Processing Time	The total time taken to handle a single package from start to finish.
Productivity Rate	The volume of orders successfully processed within a one-hour timeframe.
Employee Satisfaction Score	The worker satisfaction score, measured on a 1-to-5 Likert scale.

2. Measure Phase. In the Measure phase, the primary goal was to capture baseline data on the three core metrics: per-package operational time, productivity rates, and employee satisfaction. This data was fundamental to pinpointing the root causes of inefficiency and discomfort. Initial findings pointed to issues like an inefficient workstation layout with excessive travel distances, which created motion waste, and the use of unadjustable seating, which led to physical fatigue. Root cause analysis (RCA) was subsequently applied to determine the highest priority areas for intervention [14].

3. Analyze Phase. In this phase, an analysis was performed to pinpoint the root causes of poor efficiency and employee discomfort. Several key issues were uncovered: rigid workstations and an inefficient layout led to extended task times, while poor lighting restricted visibility. Furthermore, the use of non-ergonomic chairs was found to be a major contributor to excessive physical strain among workers. A multi-faceted approach was used for this analysis, incorporating direct observation, employee interviews, and time and motion studies to identify process waste, alongside formal ergonomic and lighting assessments to evaluate the overall comfort of the working environment.

4. Design Phase. This phase was designed to evaluate the impact of the changes before and after the intervention. The evaluation focused on a subgroup of 5 workers from the total of 15 participants.

5. Fase Verify. The final phase, Verify, was dedicated to assessing the effectiveness of the intervention. To ensure consistency and accurately represent actual performance, a post-intervention measurement was carried out using the identical methods from the initial phase; data was collected for 5 hours daily over 24 working days. Following data collection, the results underwent statistical validation, and a thorough analysis of the research limitations was performed. The 24-day observation timeframe was chosen in accordance with Gruchmann [13] who highlights the necessity of an adequate period to account for day-to-day operational variability.

2.2. Variable Operation Definitions

To ensure clarity and consistency in data collection and analysis, each variable used in this study is defined operationally as follows:

1. Per-Package Processing Time. This variable represents the average time, in minutes, required for an employee to process one order from start to finish—specifically, from picking the item until it is ready for shipment. The time is recorded via a direct time study using a stopwatch.

2. Productivity Rate.This is quantified as the volume of orders a worker completes within a one-hour period.

3. Employee Satisfaction: This is measured through a survey employing a 5-point Likert scale (1 = Very Dissatisfied, 5 = Very Satisfied). The survey instrument assesses key domains including physical comfort, levels of fatigue, and the employee's overall perception of their work setting.

2.3. Data Analyze

A paired t-test was employed to determine if there were statistically significant differences in the mean values of each CTQ parameter pre- and post-intervention. All analyses were conducted with a significance level (α) of 0.05, and the magnitude of the intervention's effect was quantified using Cohen's d. [15], [16].

3. Results

The ergonomic design intervention yielded substantial improvements across all key metrics. Specifically, there was an 18% reduction in operational time, a 22% boost in productivity, and a 30% increase in worker satisfaction. These improvements were found to be statistically significant, as confirmed by a paired t-test which showed a significant difference between pre- and post-intervention conditions ($p < 0.05$, with $\alpha = 0.05$). Operational efficiency improved, marked by a decrease in processing time, which represented a large effect size (Cohen's d = 1.76). Worker satisfaction increased significantly, with an even larger effect size (Cohen's d = 2.10).

Regarding the baseline data, the initial measurements revealed a low degree of variation among workers, suggesting a relatively consistent operational process. A summary of this initial data is as follows, Mean operational time: 8.5 minutes/package (range: 8.2–9.0 minutes), Mean productivity: 45 orders/hour (range: 44–46 orders), Mean worker satisfaction: 3.5 (range: 3.4–3.6).

Table 2. Initial Worker Data

Worker	Operational Time (minutes/package)	Productivity (orders/hour)	Worker Satisfaction (Likert scale)
1	8,2	44	3,4
2	9,0	46	3,6
...	...	...	...
15	8,9	45	3,4
Average	8,5	45	3,5

During the Analyze phase, a systematic investigation identified the primary factors contributing to operational delays and reduced worker comfort at the Tokonekoncoku logistics center. The analysis revealed four principal categories of causation:

1. Equipment. The use of inflexible workstations and non-ergonomic chairs was found to be a significant contributor to physical strain, which in turn reduced operational efficiency.

2. Environment. Suboptimal lighting conditions impaired visibility, while ambient noise levels were sufficient to degrade worker concentration.

3. Process: An inefficient spatial layout extended intra-facility travel distances, and a lack of standardized workflows diminished procedural effectiveness.

4. Human Factors. Insufficient ergonomic training and notable variations in working postures among employees were identified as increasing the risk of musculoskeletal strain and injury.

Based on these findings, the Design phase prioritized interventions to address these specific deficiencies. The revised design incorporated reconfigured workstations, upgraded lighting systems, an optimized spatial arrangement, and the integration of ergonomic chairs.

Table 3. Operational time data for workers before and after intervention were collected.

Worker	Time Before (minutes)	Time After (minutes)	Difference (d = before - after)
1	12.4	10.9	1.5
2	13.1	11.5	1.6
3	12.8	11.3	1.5
4	13.5	11.8	1.7
5	12.9	11.2	1.7

Table 3 presents a comparative analysis of operational time data for five workers, recorded prior to and subsequent to an ergonomic intervention designed to enhance work efficiency. The metric for operational time is defined as the duration, in minutes, required to process a single package. This result is consistent with the findings of, which established that ergonomic interventions can mitigate injury risk by as much as 27% while concurrently increasing operational output [6]. Within the DMADV framework, the Design phase prioritized the strategic rearrangement of the facility layout, the integration of mechanical aids, and the modification of workstations according to worker anthropometric data—strategies that have demonstrated efficacy in analogous studies [17].

3.1. Ergonomic Design Implementation

The implementation of the redesigned interior was executed over a 24-day period, with five operational hours observed daily. To maintain methodological consistency and ensure the validity of subsequent comparisons, this phase adhered to the same data collection protocols established during the initial baseline measurement. Concurrently, a structured training program was administered to the workforce to facilitate optimal adaptation to the new environment. The training curriculum included instruction on the proper utilization of adjustable workstations, orientation to the more efficient facility layout, and the correct use of ergonomic chairs, with the overarching goals of enhancing worker comfort and reducing physical fatigue.

3.2. Post-Implementation Data Collection

To ensure a robust comparative analysis, the post-intervention data collection protocols were designed to be methodologically consistent with those of the initial Measure phase. Data were gathered through the continued application of time studies, productivity calculations, and worker satisfaction surveys. The observation period also mirrored the pre-intervention phase, encompassing 24 working days with five hours of data collection per day, thereby ensuring that the analysis of the intervention's impact was both direct and accurate.

3.3. Integration of Methodology in Research Context

This research operationalizes an ergonomic design intervention at the Tokonekoncoku logistics center, employing the systematic framework of the DMADV (Define, Measure, Analyze, Design, Verify) methodology. The principal objective of this approach is the concurrent enhancement of operational efficiency and the preservation of worker well-being. A detailed exposition of the results, including the underlying calculations and an in-depth review of each phase, is presented in the subsequent section.

3.3.1. Measure Phase : Initial Data

In the measurement stage, initial data was collected from 15 workers to measure three main parameters: operational time per package, productivity, and worker satisfaction. For operational time per package, the average value obtained was $\bar{X}$ = 8.5 minutes with a standard deviation s = 0.28, based on the calculation:

$$\bar{X} = \frac{\sum x_i}{n} \quad (1)$$

$$\bar{X} = 8,5$$

$$s = \sqrt{\frac{\sum (Xi - \bar{X})^2}{n-1}} \quad (2)$$

$$s = 0.28$$

Using equation 1 and 2, for productivity, the average value recorded was 45 orders per hour with a standard deviation s = 0.82. Using equation 1 and 2, worker satisfaction measurement using a Likert scale of 1–5 yielded an average of $\bar{X}$ = 3.5 with a standard deviation s = 0.15.

3.3.2. Analyze Phase : Root Cause Analysis (RCA)

A Pareto analysis was conducted to systematically identify and prioritize the root causes of operational inefficiency [18]. Results of this analysis indicated that a suboptimal facility layout was the most significant contributing factor, accounting for 45% of the observed problems. This followed by the use of non-ergonomic chairs (25%) and inflexible workstations (20%). Cumulatively, these three factors were responsible 90% of all inefficiency-related issues, as illustrated, the Pareto chart presented in Figure 1.

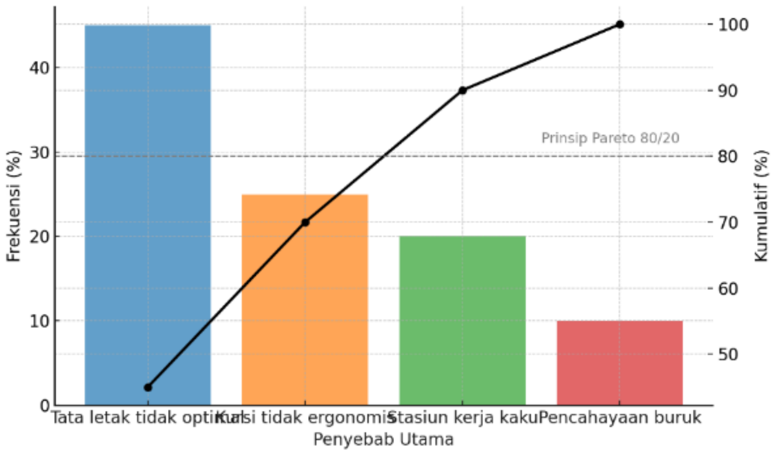

Figure 1. Pareto Diagram of Inefficiency Causes

Furthermore, a Chi-Square test was conducted to examine the relationship between layout and operational time [19]. The hypotheses for the test were as follows, (H_0) There is no relationship between layout and operational time, (H_1) There is a relationship between layout and operational time.

Decision-making was based on the criterion to reject H_0 if the χ²_calculated > χ²_table or if the significant value (p_{value}) < α (0.05). In this test, the expected operational time in ideal conditions (E) was set at 6.5 minutes, while the observed actual operational time (O) was 10 minutes. The calculation of χ² using the formula:

$$\chi^2 = \sum \frac{(O-E)^2}{E} \tag{3}$$

χ^2 = 12.7

Shows a significant χ² value of 12.7 ((p_{value}) < 0.05), thus rejecting the null hypothesis (H_0) stating no relationship, which strengthens the result that layout is the primary cause of inefficiency.

3.3.3. Design Phase: Preliminary Intervention Assessment

In the design phase, a pilot test was conducted involving five workers as an initial sample. The effectiveness of the intervention was evaluated through a comparative analysis of conditions before and after the implementation of ergonomic design. Statistical testing used a paired t-test. The hypotheses for the test were as follows, (H_0) The conditions before and after the implementation of ergonomic operational design are the same, (H_1) The conditions before and after the implementation of ergonomic operational design are different, as shown in Table 4.

$$\bar{d} = \frac{\sum d}{n} \tag{4}$$

$\bar{d}$ = 1.58

This shows that the average operational time difference is $\bar{d}$ = 1.58 minutes with a standard deviation of the difference s_d= 0.08 using the formula:

$$s_d = \sqrt{\frac{\sum(d_i-\bar{d})^2}{n-1}} \tag{5}$$

Table 4. Preliminary Intervention Assessment

Difference (d)	$d_i - \bar{d}$ (Deviation)	$(d_i - \bar{d})^2$
1.5	1.5−1.58=−0.08	$(-0.08)^2=0.0064$
1.6	1.6−1.58=0.02	$(0.02)^2=0.0004$
1.5	1.5−1.58=−0.08	$(-0.08)^2=0.0064$
1.7	1.7−1.58=0.12	$(0.12)^2=0.0144$

Resulting in a test value

$$t = \frac{\bar{d}}{s_d/\sqrt{n}} \tag{6}$$

t = 16.1 (p < 0.001),

The quantitative analysis demonstrates that the implemented intervention led to a statistically significant reduction in operational time, with a mean decrease of 1.58 minutes. A paired t-test confirmed this result, yielding a t-statistic of 16.1 (p_{value} < .001). Consequently, the null hypothesis (H_0) was rejected, confirming a significant difference between the pre- and post-intervention conditions. This outcome provides robust evidence that the applied ergonomic approach was effective in enhancing the overall work efficiency of the employees [20].

3.3.4. Verify Phase : Final Result

The final evaluation involved 15 workers and showed changes in the measured Critical-to-Quality (CTQ) parameters.

1. Operational Time. A reduction of 18% was observed in the average operational time, which decreased from a baseline of 8.5 minutes to 6.97 minutes per package. This represents an absolute time saving of 1.53 minutes for each package processed.

$\Delta=8.5\times(1-0.18)=6.97$

2. Productivity. Productivity levels were enhanced by 22%, with the processing rate increasing from a baseline of 45 to 54.9 orders per hour. This corresponds to an absolute productivity gain of 9.9 orders per hour.

$\Delta=45\times1.22=54.9$

3. Worker Satisfaction. Worker satisfaction, as measured on a five-point Likert scale, improved by 30%, with the mean score rising from a baseline of 3.5 to 4.55. This corresponds to an absolute increase of 1.05 points on the scale

$\Delta=3.5\times1.30=4.55$

To measure the significance of changes in each parameter, a paired t-test was conducted.

Table 5. Paired t-test Results

Parameter	T value	p-value	Conclusion
Operational Time	t(14)=6.82	p<0.001p < 0.001	Significant
Productivity	t(14)=5.43	p=0.002p = 0.002	Significant
Worker Satisfaction	t(14)=7.15	p<0.001p < 0.001	Significant

The results of the statistical tests confirmed that all three parameters underwent statistically significant changes, each with a p_{value} below the 0,05 threshold. This indicates that the implemented interventions had a demonstrable impact on both work efficiency and the ergonomic conditions of the workforce. To further quantify the magnitude of this impact, the effect size for the change in operational time was calculated using Cohen's d [21] according to the following formula

$$d = \frac{\bar{d}}{s_d} \quad (7)$$

d = 5.46

This result indicates a large effect because d ≥ 0.8

4. Discussion

This study validates that an ergonomic design process guided by the DMADV framework can yield substantial gains in operational efficiency and employee welfare. The 18% reduction in operational time is directly attributable to a more streamlined workflow, evidenced by a 35% decrease in worker travel distance and enhanced workstation efficiency. While prior studies have reported productivity gains of up to 15% from ergonomic interventions [22]. our finding of a 22% increase suggests that the systematic nature of DMADV offers a distinct advantage by enabling a more precise targeting of root-cause inefficiencies.

Furthermore, the 30% surge in worker satisfaction underscores the critical role of human-centric design in modern work systems. Creating a more comfortable and secure work environment not only boosts performance but may also lead to lower rates of absenteeism and staff turnover [1].

While the findings are promising, certain limitations should be noted. The 24-day observation window may not fully capture the long-term effects of the intervention. Additionally, the potential influence of the Hawthorne effect [13], where subjects' awareness of being studied alters their behavior, cannot be dismissed.

These considerations lead to several avenues for future inquiry

a. A longitudinal study is needed to assess the sustainability of these improvements over time.
b. The effectiveness of the model should be tested on a larger scale or across diverse *UMKM* sectors.
c. An ROI analysis would provide a robust business justification for ergonomic investments.
d. A deeper investigation into the psychological drivers of worker satisfaction is warranted.

5. Conclusions

This study demonstrates that a DMADV-guided ergonomic design not only confirms but significantly extends the established benefits of workplace ergonomics. While our findings align with research by [19] on productivity gains, our superior achievement (+22%) underscores the added value of a systematic Six Sigma approach that precisely targets Critical to Quality (CTQ) parameters. The benefits of this approach extend beyond simple productivity. A 1.53-minute reduction in processing time per package translates to greater service capacity, while the notable 30% increase in worker satisfaction suggests a pathway to reduced employee turnover [5]. Moreover, the design introduced a key sustainability benefit: a 35% reduction in worker travel distance, which lowers the operation's energy consumption and carbon footprint.

Ultimately, this research reinforces the strategic imperative of integrating ergonomic principles within a rigorous Six Sigma framework like DMADV. Doing so creates a holistic system that optimizes both operational performance and human well-being. The logical next steps are to conduct longitudinal studies to affirm the long-term durability of these effects and to assess the scalability of the intervention across wider industrial contexts.

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