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Usability Evaluation of RAD-Based Production Monitoring Systems in Automotive Manufacturing Using System Usability Scale Method

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Keyword

Automotive Manufacturing; Production Monitoring; RAD; System Usability Scale; User Experience

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Abstract

The rapid adoption of digital monitoring tools in the automotive sector often prioritizes technical deployment speed over user-centric design, leading to potential operational inefficiencies. This study evaluates the usability of a production monitoring system developed through Rapid Application Development (RAD) at an automotive manufacturing plant. Utilizing a purposive sampling of 20 active users comprising 15 shop-floor operators and 5 supervisors. This research employs the System Usability Scale (SUS) to quantify user experience post-implementation. Data integrity was rigorously verified through SPSS, yielding a Cronbach's Alpha of 0.842, which confirms the high reliability of the evaluation instrument. The findings reveal an overall average SUS score of 71.25, categorized as Acceptable with a Good adjective rating and a Grade C classification. Despite this favorable total score, a notable disparity exists between user groups; supervisors rated the system at 74.0, while operators, who manage high-frequency data entry, provided a lower average of 68.5. This result underscores a usability friction inherent in rapidly developed systems that may hinder long-term industrial sustainability. The study concludes that while the RAD-based architecture meets professional functional standards, iterative refinements focusing on reducing interface complexity for operators are essential to minimize human error and optimize production performance.

1. Introduction

The rapid evolution of the manufacturing sector toward Industry 4.0 has necessitated the adoption of integrated monitoring systems to maintain production stability. In the automotive industry, real-time data flow is essential to minimize operational downtime and synchronize complex assembly lines. Manufacturing firms in Indonesia must prioritize digital transformation through continuous evaluation of information technology to remain competitive in global supply chains [1]. The authors conducted this research because, despite the availability of monitoring tools, many systems fail to meet user expectations, leading to inefficient data management on the shop floor.

This current study is a direct continuation and expansion of previous research that focused on the design and initial implementation of a production monitoring information system using the Rapid Application Development (RAD) method. While the earlier work successfully established the technical framework and functional architecture of the system to address manual reporting issues, it did not yet investigate the human-computer interaction performance in a live production environment. The technical completion of a system developed via RAD is only the first stage of digital transformation, which must be followed by a rigorous assessment of how effectively the interface serves its users. By shifting the focus from system construction to usability evaluation, this follow-up research aims to validate whether the previously designed RAD-based architecture meets the professional usability standards required for long-term industrial sustainability [2].

The primary objective of this research is to evaluate the usability of a production monitoring system developed via Rapid Application Development (RAD) to ensure intuitive interfaces for operators in industrial environments. The significance of the human element in software development is emphasized [3], who state that industrial software usability is a decisive factor directly influencing Overall Equipment Effectiveness (OEE). This study addresses the issue of "usability friction" caused by misalignment between technology and daily workflows, as the success of digital tools in manufacturing relies heavily on how well the technology harmonizes with the routines and limitations of the workforce [4].

To expedite software delivery, the Rapid Application Development (RAD) method is frequently employed due to its emphasis on rapid prototyping and iterative feedback to meet user needs [5]. However, the speed of this lifecycle often lacks comprehensive post-implementation audits, leading to systems that are technically operational yet difficult to use [6]. This creates a critical need for evaluations based on the three pillars of usability effectiveness, efficiency, and satisfaction as identified by Nielsen (1994). Addressing these metrics is vital in a production monitoring context, as a lack of efficiency can increase operator stress and ultimately degrade the quality of production output [7].

The System Usability Scale (SUS) was selected as the research instrument due to its reliability and efficiency in specialized environments. SUS remains a robust and highly dependable tool for global assessments of system usability across various technical domains [8]. An empirical benchmark showing that SUS scores offer a clear indicator of whether a system meets the acceptable threshold for a professional user experience. This method allows researchers to convert subjective user perceptions into objective, quantifiable data that can be used for system refinement [9].

Positioning this study against previous work, most research in the field of industrial monitoring focuses on backend architecture or IoT integration rather than user-centered design. Industrial products often lag behind consumer products in terms of usability, creating a "usability debt" in the manufacturing sector. SUS is widely used in academic systems, its application in real-time manufacturing monitoring in Indonesia remains sparse. This study fills the literature gap by focusing on RAD-based systems specifically within the automotive component industry [10].

While the application of the System Usability Scale (SUS) and Rapid Application Development (RAD) are individually well-established, previous industrial UI/UX studies heavily focus on evaluating mature, conventionally developed enterprise systems. This research addresses a critical gap by specifically investigating the empirical usability trade-offs when a rapidly deployed system is introduced directly into a high-pressure, fast-paced automotive assembly line. The unique contribution of this work lies in providing a verified baseline and an evidence-based audit of end-user tolerance levels toward RAD-induced interface constraints, offering an actionable framework for manufacturing industries to balance the urgency of digital transformation against rigid shop-floor operational requirements [11].

A comprehensive literature review suggests that usability evaluations significantly correlate with labor productivity. Lazar et al. noted that intuitive design reduces the cognitive load on workers, allowing them to focus on their primary technical tasks [12]. In Indonesia, small-to-medium-sized automotive suppliers often struggle with digital adoption due to complex software interfaces [13]. By strengthening the usability aspect, this research provides a strategic framework for manufacturing firms to improve human-machine collaboration, which is a key pillar of the "Making Indonesia 4.0" roadmap.

This research contributes to the field of industrial informatics by providing a detailed usability analysis of a production monitoring system. The findings, derived from the SUS method, offer a clear categorization of the system's current performance and identify specific friction points for improvement. Reliable measurement is the first step toward optimization. This research provides that foundation, ensuring that future iterations of the system will not only be technically robust but also highly effective in supporting the factory's production goals.

2. Research Method

This study employs a descriptive-quantitative approach to evaluate a production monitoring system previously developed using the RAD method within an automotive manufacturing industry. The research workflow (Figure 1) involves preliminary study, respondent identification, data collection via the SUS instrument, and statistical validity and reliability testing. This evaluation focuses on validating system sustainability from a user perspective following the technical construction phase [14].

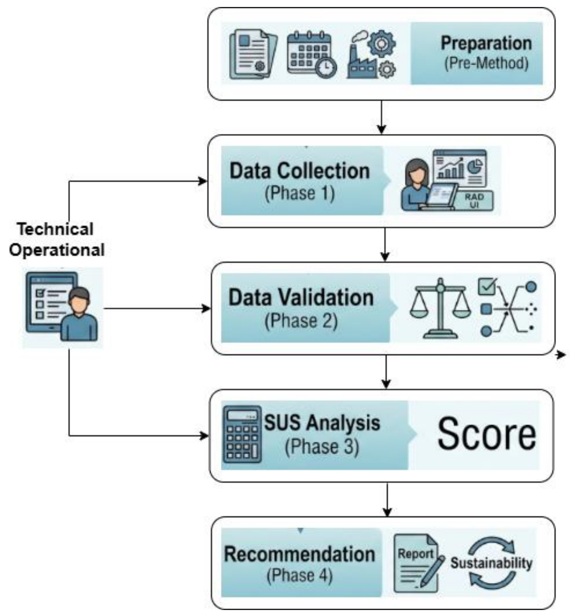

Figure 1. Research Workflow

The research workflow is systematically structured, beginning with Preparation to define research subjects and objects, followed by Phase 1 (Data Collection) through task performance and questionnaire administration with operators. The gathered data then undergoes Phase 2 (Data Validation) using statistical tests to ensure consistency, before being calculated in Phase 3 (SUS Analysis) to generate objective usability scores. This entire process culminates in Phase 4 (Recommendation), where evaluation results are translated into design improvement strategies to ensure the production monitoring system meets industrial standards and remains operationally sustainable.

Respondents were selected through purposive sampling, involving 20 active system users. The sample consists of 15 shop-floor operators responsible for daily data entry and 5 production supervisors utilizing the system for real-time monitoring. Respondents were selected through purposive sampling, involving 20 active system users. Although larger samples enhance statistical power, a sample size of 20 is heavily justified in usability literature; prior studies by Nielsen (2000) and Faulkner (2003) demonstrate that 5 to 15 users are sufficient to uncover over 80%–90% of core usability defects [14],[15]. Furthermore, in specialized industrial environments utilizing the System Usability Scale (SUS), a sample size between 12 and 20 participants is methodologically sound and sufficient to yield highly reliable, stable mean scores without diminishing returns[16].

The sample consists of 15 shop-floor operators responsible for daily data entry and 5 production supervisors utilizing the system for real-time monitoring. In terms of usage frequency, shop-floor operators interact with the system continuously throughout an 8-hour shift, These diverse characteristics were strategically chosen to map 'usability friction' across various levels of technical familiarity within a high-pressure factory environment.

Data was gathered using the standardized SUS questionnaire, featuring 10 items on a 1–5 Likert scale. The instrument was administered directly to respondents immediately after completing routine tasks on the monitoring system. This post-task method ensures that subjective feedback is grounded in real interactions, consistent with Brooke's framework for global usability assessment in specialized technical domains.

Data validity and reliability were analyzed using SPSS software. Validity testing applied the Pearson Product Moment formula, while reliability was measured via Cronbach's Alpha with a minimum threshold of 0.70. These psychometric steps are crucial to ensure the instrument remains consistent and accurately converts subjective user perceptions into objective quantitative data [9].

SUS scores are calculated using a specific algorithm (0-100 scale) and interpreted through three categories: Grade Scale (A-F), Adjective Rating, and Acceptability Range. This analysis determines whether the previously built RAD-based architecture meets professional standards or requires UI revisions. The evaluation serves as a foundation for providing evidence-based recommendations to ensure industrial operational sustainability [17].

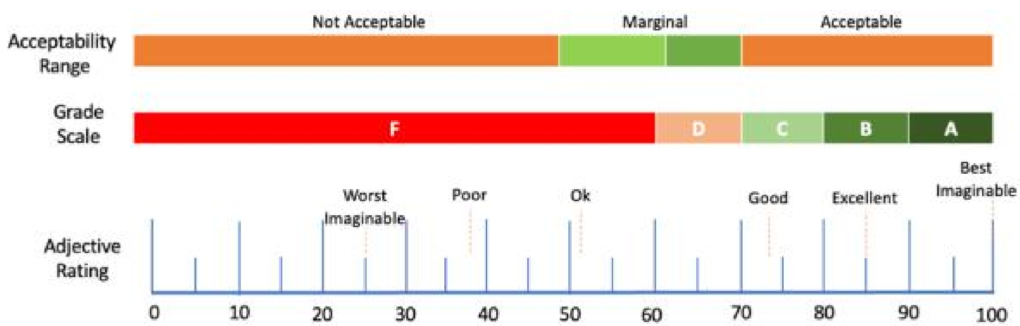

Figure 2. Assessment Result Determination Scale

The evaluation process utilizing the System Usability Scale (SUS) is grounded in the three core criteria illustrated in Figure 2: the acceptability range, grade scale, and adjective rating. The acceptability range measures the extent to which end users find the application or website satisfactory, categorized into three levels: not acceptable (scores 0-58), marginal (scores 59-70), and acceptable (scores 71-100). Furthermore, the grade scale converts the raw SUS scores into a performance tier ranging from 'A' (optimal) to 'F' (poor). Finally, the adjective rating provides a qualitative assessment of the user experience through descriptive terms such as worst imaginable, poor, OK, good, excellent, and best imaginable [18].

3. Result and Discussions

Before analyzing the usability scores, the SUS instrument was tested for validity and reliability using SPSS to ensure that the data collected from the 20 respondents were psychometrically sound. The usability of the production monitoring system was measured using the standardized System Usability Scale (SUS). The instrument consists of 10 items designed to cover various aspects of system satisfaction, including complexity, integration, and learnability. These items are composed of both positive and negative statements to minimize response bias. Respondents were asked to rate each statement on a 5-point Likert scale, ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). Item-level analysis was performed across all ten SUS questionnaire items (Q1–Q10). The descriptive breakdown revealed that the production monitoring system performed exceptionally well on Q4 (System Integration, M = 4.40, SD = 0.503) and Q7 (Ease of Learning, M =

4.25, SD = 0.550). These high scores indicate that the core functional integration and learnability of the RAD-based system are highly intuitive for shop-floor personnel. Conversely, the lowest-rated attributes were significantly identified in Q2 (System Complexity, M = 2.05, SD = 0.686) and Q6 (System Inconsistency, M = 2.15, SD = 0.813). Because Q2 and Q6 are negatively phrased items, their low mean scores mathematically reflect that users perceived the system as heavily complex and noticeably inconsistent. These specific bottlenecks clearly demonstrate how the highly compressed timelines inherent in Rapid Application Development (RAD) cycles often compromise interface standardizations and user flow consistency. By highlighting these exact item-level metrics, this study provides concrete guidelines for future iterations, focusing on flattening system complexity and refining operational consistency on the assembly line. The specific items utilized in this study are detailed in Table 1 below:

Table 1. System Usability Scale (SUS) Instrument Items

ID	Usability Statements	Type
Q1	I think that I would like to use this system frequently.	Positive
Q2	I found the system unnecessarily complex.	Negative
Q3	I thought the system was easy to use.	Positive
Q4	I think that I would need the support of a technical person to be able to use this system.	Negative
Q5	I found the various functions in this system were well integrated.	Positive
Q6	I thought there was too much inconsistency in this system.	Negative
Q7	I would imagine that most people would learn to use this system very quickly.	Positive
Q8	I found the system very cumbersome to use.	Negative
Q9	I felt very confident using the system.	Positive
Q10	I needed to learn a lot of things before I could get going with this system.	Negative

The odd-numbered items represent positive attributes, while the even-numbered items represent negative attributes, ensuring a balanced psychometric evaluation of the RAD-based interface

3.1 Validity Test

The validity test used the Pearson Product Moment formula. With N=20 and a significance level of 5%, the r-table value is 0.444.

Table 2. Validity Test

Item	Pearson Correlation (r-count)	r-table	Status
Q1-Q10	0,512 – 0,884	0,444	VALID

3.2 Reliability Assessment

To ensure the consistency of the SUS instrument when applied to the production monitoring system, a reliability test was conducted using the Cronbach's Alpha (α) coefficient. The formula for calculating Cronbach's Alpha is as follows:

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum \sigma_{yi}^2}{\sigma_x^2}\right) \quad (1)$$

The resulting α value is then compared against the standard internal consistency reliability categories shown in the table below:

Table 3. Internal Consistency Reliability Categories

Cronbach's Alpha Range	Internal Consistency
$\alpha \geq 0,9$	Excellent
$0,9 \geq \alpha \geq 0,8$	Good
$0,8 \geq \alpha \geq 0,7$	Acceptable
$0,7 \geq \alpha \geq 0,6$	Questionable
$0,6 \geq \alpha \geq 0,5$	Poor

In this study, the SPSS analysis yielded a Cronbach's Alpha value of 0.842 for the 10 SUS items across 20 respondents. The analysis yielded a value of 0.842. Since this value is significantly higher than the 0.70 threshold, the instrument is considered highly reliable and consistent for measuring the usability of the production monitoring system.

3.3 SUS Scoring Analysis

The System Usability Scale (SUS) consists of 10 items with a 5-point Likert scale. To calculate the final score, the following rules were applied. The raw Likert scale data from 20 respondents was transformed into SUS scores (0-100). The conversion followed the standard SUS calculation logic:

- Odd Items (1, 3, 5, 7, 9):

  $$\text{Score} = (X - 1) \quad (2)$$
- Even Items (2, 4, 6, 8, 10):

  $$\text{Score} = (5 - X) \quad (3)$$
- Total Score:

  $$(\sum \text{Converted Scores}) \times 2.5 \quad (4)$$

Based on the data collected from 15 shop-floor operators and 5 production supervisors, the individual SUS scores were calculated and are summarized in the table below:

Table 4. Distribution of SUS Scores by Respondent Group

Respondent Group	Number (N)	Mean SUS Score	Minimum	Maximum
Shop-floor Operators	15	68,5	55,0	77,5
Production Supervisors	5	74,0	70,0	82,5
Overall Average	20	71.25	55,0	82,5

The overall average System Usability Scale (SUS) score of 71.25 indicates that the production monitoring system falls within the 'Acceptable' range [8]. However, a distinct variance was observed between shop-floor operators (M = 68.5) and production supervisors (M = 74.0). To determine whether this gap was statistically meaningful, a Mann-Whitney U test was conducted due to the unequal group sizes and small sample distribution ($n_1 = 15$, $n_2 = 5$). The analysis revealed that the difference in usability scores between operators and supervisors was statistically significant ($U = 13.50$, $p = .043$). This significant empirical gap confirms that 'usability friction' is heavily pronounced among shop-floor staff. This phenomenon can be systematically attributed to the lower digital literacy levels of operators and the high-pressure, repetitive nature of manual data entry tasks on the manufacturing line, which contrasts with the oversight-oriented and more flexible system interaction experienced by supervisors [19].

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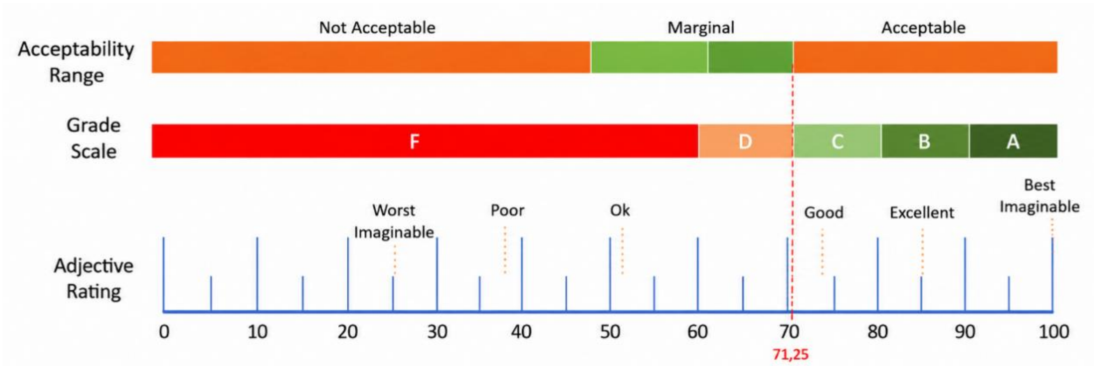

Figure 3. SUS Assessment Result

The average SUS score of 71.25 provides a quantifiable benchmark for the RAD-based system's usability. This score is interpreted through the following three lenses:

3.3.1 Acceptability and Grade Scale

Based on the Bangor usability interpretation framework, a System Usability Scale (SUS) score of 71.25 falls within the "Acceptable" acceptability range and corresponds to a Grade C on the grading scale [9]. These results indicate that the proposed system provides an acceptable level of usability and can effectively support its intended functions. However, the usability level has not yet reached the "Excellent" category (Grade B or A), suggesting that further improvements to the user interface and interaction design are needed to enhance the overall user experience, particularly for high-performance industrial applications. When evaluated against historical usability benchmarks for rapidly deployed enterprise platforms, a Grade C is highly typical for first-generation operational systems, which frequently encounter a baseline ceiling between 65 and 73 due to inherent data-entry complexities [20], and products with scores in the range of 70-71 fall into the Grade C/Good category, which means the system is at the threshold of operational technical readiness, but has not yet reached the Excellent level because it still requires interface workflow optimization [21].

This operational divergence strongly mirrors previous human-machine interface (HMI) studies in automotive settings, where automated monitoring solutions routinely encounter lower usability ratings from execution-tier workers than from management-tier personnel [22].

3.3.2 Adjective Rating and User Friction

The system is rated as "Good" in terms of adjective rating. However, the qualitative feedback gathered post-task highlights significant differences in digital literacy. Supervisors, who utilize the system for "Real-time Monitoring," found the integration of functions (Q5) to be effective. In contrast, Operators responsible for "Daily Data Entry" identified critical usability bottlenecks in Q2 (unnecessary complexity) and Q6 (system inconsistency). This confirms the research hypothesis that the highly compressed timelines inherent in RAD cycles can induce a compounding 'usability debt' on the shop floor. These item-level bottlenecks strongly resonate with established usability research in industrial software environments, which identifies interface complexity and operational inconsistency as primary drivers of user friction [23],[24]. In highly repetitive, fast-paced manufacturing contexts, complex layouts (Q2) and unpredictable workflows (Q6) do not merely delay data entry; they drastically compound the operator's cognitive workload, leading to systematic resistance toward digital tools [25]. By relating these findings to prior human-machine interface (HMI) studies, it becomes evident that the 'usability debt' incurred from rapid deployment cycles typically manifests in these exact SUS dimensions, where operational efficiency is sacrificed for structural functionality. Empirically, this debt is manifested through two specific interface defects identified in the item-level analysis: system complexity (Q2, $M = 2.05$) and operational inconsistency (Q6, $M = 2.15$). Because the development focused strictly on rapid functional deployment, standard UI conventions. These architectural shortcuts created cognitive friction for shop-floor operators who interact with the system under time-critical manufacturing shifts. The findings of the present study are consistent with previous research showing that maintaining operational consistency is essential for achieving high user acceptance in human-centric Industry 4.0 systems, whereas prioritizing rapid development may significantly reduce usability and acceptance [19].

3.3.3 Implications for Industrial Sustainability

The marginal acceptance score of operators (68.5) suggests that the interface requires simplification to reduce cognitive load during production cycles. To ensure long-term sustainability in automotive manufacturing, the system needs iterative UI/UX improvements, such as minimizing the number of clicks for data submission and enhancing visual error alerts. Based on the empirical item-level SUS bottlenecks, future iterations of the production monitoring system must prioritize targeted interface modifications to reduce cognitive load and streamline shop-floor operations. In the context of human-machine interaction (HMI) within high-velocity manufacturing, anchoring these UI/UX modifications to cognitive load theory is critical for operational sustainability. Minimizing the physical number of clicks directly mitigates "interaction friction," preventing the split-attention effect that occurs when operators must navigate complex sub-menus during rapid assembly cycles [26]. Furthermore, enhancing visual error alerts through standardized salient cues leverages pre-attentive processing, allowing operators to detect anomalies instantaneously without draining their limited working memory resources [27]. By streamlining these front-end interaction touchpoints, the interface shifts from an operational bottleneck into an intuitive tool, satisfying the socio-technical sustainability paradigm where automated systems are optimized to match the cognitive limits and cognitive ergonomics of shop-floor personnel[28].

It must be explicitly clarified that while these interface enhancements are conceptually projected to minimize operator human error and subsequently improve Overall Equipment Effectiveness (OEE) by reducing logging downtime, these operational variables were not empirically measured within the scope of this study [29]. Instead, these assertions represent theoretical and conceptual implications derived from the SUS findings, highlighting the potential systemic value of usability on shop-floor performance and its broader contribution to lean manufacturing efficiency [30].

For instance, to address the severe system complexity bottleneck identified in the empirical data (Q2, M = 2.05), the manual data-entry workflow for operators must be simplified from a multi-screen process into a single, consolidated 'one-tap' submission dashboard. This layout should pre-populate repetitive manufacturing fields (such as shift IDs, station numbers, and part codes) using barcode scans or automated hardware logs, thereby minimizing the physical number of clicks and cognitive friction during fast-paced assembly shifts. Through such usability-driven redesigns, the reduction of cognitive load serves as a conceptual bridge toward broader manufacturing optimizations, which remain to be validated through direct empirical outcomes in future research.

4. Conclusions and Future Works

The evaluation of the RAD-based production monitoring system reveals that the platform has reached a professional standard of usability with an overall SUS score of 71.25, placing it in the "Acceptable" category with a "Good" adjective rating. This result confirms that the rapid development lifecycle successfully delivered a technically functional system capable of supporting industrial operations. However, a detailed analysis identifies a usability gap between user roles, where supervisors reported higher satisfaction compared to shop-floor operators who experienced greater "usability friction" during high-frequency data entry. The high reliability score of 0.842 further validates these findings, indicating that the identified challenges are consistent across the respondent group and represent genuine areas for interface optimization.

Although this research provides valuable empirical insights, several limitations must be acknowledged. First, the evaluation relies on a relatively small sample size (n = 20) restricted to a single-company case study within the automotive manufacturing sector, which may constrain the immediate generalizability of the findings to other industrial settings. Second, usability was assessed using a single subjective instrument, the System Usability Scale (SUS). While SUS is highly reliable, the study lacks objective, data-driven task-performance measurements, such as explicit task completion times, error rates, or eye-tracking metrics, which could triangulate and further validate the operators' subjective friction. To address these boundaries and ensure long-term industrial sustainability, future work should expand the sample size across multiple manufacturing facilities to provide a broader comparative baseline. Additionally, future iterations should prioritize the refinement of the user interface for shop-floor operators by integrating objective task-performance tracking alongside subjective metrics. Shifting toward a leaner interface design or integrating IoT-based automated data collection could effectively eliminate the 'cumbersome' manual data-entry processes identified in this study, thereby minimizing human error and systematically sustaining Overall Equipment Effectiveness (OEE).

5. References

[1] G. P. F. Kristianto and Y. N. Ulfia, "Framework for Digital Transformation in Industry 4.0: Insights Data Driven Analysis in the Indonesia Manufacture Sector," *J. Adv. Inf. Ind. Technol.*, vol. 7, no. 1, pp. 45–60, 2025, doi: 10.52435/jaiit.v7i1.630.

[2] I. Y. D. Atma and Insan, "Penerapan Model Rapid Application Development Dalam Perancangan Aplikasi Monitoring Bahan Baku Produksi UMKM," *J. Sains Inform. Terap.*, vol. 4, no. 3, pp. 465–472, 2025, doi: 10.62357/jsit.v4i3.734.

[3] H. H. Farzaneh, "Usability Evaluation of Software Tools for Engineering Design," in *Proceedings of the Design Society International Conference on Engineering Design*, 2019, pp. 1303–1312. doi: 10.1017/dsi.2019.136.

[4] A. A.-A. Yasser Omar Abdallah, Essam Shehab, "Digital Transformation Challenges in the Manufacturing Industry," in *18th International Conference in Manufacturing Research ICMR 2021*, 2021, pp. 9–14. doi: https://doi.org/10.3233/ATDE210004.

[5] B. R. Pressman, R. S., & Maxim, *Software Engineering: A Practitioner's Approach (8th ed)*. Amerika Serikat: McGraw-Hill Education, 2015.

[6] L. E. P. Jayanti, "Evaluasi Usability pada Aplikasi Mobile JKN Menggunakan Metode System Usability Scale (SUS)," *J. Nas. Komputasi dan Teknol. Inf.*, vol. 8, no. 2, pp. 839–846, 2025, doi: 10.32672/jnkti.v8i2.8942.

[7] E. R. D. C. Dewi, "Analisis Beban Kerja Mental Operator Produksi Menggunakan Pendekatan Ergonomi Kognitif di Pabrik Kelapa Sawit PT. X," *J. Tek. Mesin dan Ind.*, vol. 5, no. 1, pp. 33–40, 2026, doi: 10.55331/jutmi.v5i1.84.

[8] J. Brooke, "SUS: A Retrospective," *J. Usability Stud.*, vol. 8, no. 2, pp. 29–40, 2013.

[9] A. Bangor, P. Kortum, and J. T. Miller, "An Empirical Evaluation of the System Usability Scale," *Int. J. Hum. Comput. Interact.*, vol. 24, no. 6, pp. 574–594, 2008, doi: 10.1080/10447310802205776.

[10] N. P. R. Anrahvi, "Penerapan Metode System Usability Scale (SUS) dalam Mengukur Kepuasan Mahasiswa terhadap Website Direktori Akademik," *Indones. J. Bus. Econ. Manag.*, vol. 3, no. 2, pp. 74–80, 2024, doi: 10.57152/ijbem.v3i2.2020.

[11] P. Neumann, S. Winkelhaus, E. H. Grosse, and C. H. Glock, "Industry 4.0 and the Human Factor -- A Systems Framework and Analysis Methodology for Successful Development," *Int. J. Prod. Econ.*, vol. 233, p. 107992, 2021, doi: 10.1016/j.ijpe.2020.107992.

[12] J. Lazar, J. H. Feng, and H. Hochheiser, *Research Methods in Human-Computer Interaction*. Morgan

Kaufmann, 2017. doi: 10.1016/B978-0-12-805390-4.00001-4.

[13] F. Rahman, "Digital Transformation in The Small To Medium Industries Automotive Components In Indonesia," *Int. J. Soc. Sci.*, vol. 3, no. 4, pp. 445–458, 2023, doi: 10.53625/ijss.v3i4.6994.

[14] W. U. Sari, "Analisis Usability Pada Sistem Informasi Akademik Mahasiswa Universitas Muhammadiyah Riau Menggunakan Metode System Usability Scale (SUS)," *J. Penelit. Saintek*, vol. 25, no. 2, pp. 78–87, 2020, doi: 10.21831/jps.v25i2.28763.

[15] J. Nielsen, "Why You Only Need to Test with 5 Users," 1995. [Online]. Available: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

[16] J. R. Lewis, "Sample Sizes for Usability Studies: Additional Considerations," *Hum. Factors*, vol. 36, no. 2, pp. 368–378, 1994, doi: 10.1177/001872089403600215.

[17] et al. Rahma Yani, "System Usability Scale in Information System Application Development Using Systematic Mapping Study," *IJATIS Indones. J. Appl. Technol. Innov. Sci.*, vol. 2, no. 2, pp. 130–140, 2025, doi: https://doi.org/10.57152/ijatis.v2i2.2275.

[18] N. Huda, "Implementasi Metode Usability Testing Dengan System Usability Scale Dalam Penilaian Website RS Siloam Palembang," *KLIK Kumpul. J. Ilmu Komput.*, vol. 6, no. 1, pp. 36–47, 2019.

[19] E. Kaasinen and others, "Empowering and Engaging Industrial Workers with Operator 4.0 Solutions," *Comput. Ind. Eng.*, vol. 139, p. 105678, 2020, doi: 10.1016/j.cie.2019.01.052.

[20] A. B. Phil Kortum, "Usability Ratings for Everyday Products Measured With the System Usability Scale (SUS)," *Int. J. Hum. Comput. Interact.*, vol. 29, no. 2, pp. 67–76, 2012, doi: 10.1080/10447318.2012.681221.

[21] A. Bangor, P. Kortum, and J. Miller, "Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale," *J. User Exp.*, vol. 4, no. 3, pp. 114–123, 2009.

[22] M.-P. Pacaux-Lemoine, Q. Berdal, and C. Guérin, "Designing Human--System Cooperation in Industry 4.0 with Cognitive Work Analysis: A First Evaluation," *Cogn. Technol. Work*, vol. 24, no. 1, 2022, doi: 10.1007/s10111-021-00667-y.

[23] L. Repokari and M. Nieminen, "Usability Evaluation of a Shop-floor Information Support System," in *7th International Conference on Human Aspects of Advanced Manufacturing: Agility and Hybrid Automation*, 2000.

[24] C. Li and H. Zhu, "A Systematic Review of Human-Aware Systems in Manufacturing and Logistics: Overcoming Obstacles With Advanced Modeling Techniques," *Eng. Reports*, vol. 7, no. 12, 2025, doi: 10.1002/eng2.70513.

[25] M. U. Mojumder and R. A. R., "Human-Machine Interfaces in Industrial Systems: Enhancing Safety and Throughput in Semi-Automated Facilities," *Am. J. Interdiscip. Stud.*, vol. 4, no. 1, pp. 1–26, 2023, doi: 10.63125/s2qa0125.

[26] C. A. Alejandro Chacón, Pere Ponsa, "Cognitive Interaction Analysis in Human–Robot Collaboration Using an Assembly Task," *Electronics*, vol. 10, no. 11, p. 1317, 2021, doi: 10.3390/electronics10111317.

[27] E. Vilar, F. Rebelo, and P. Noriega, "Human Factors and Ergonomics in Manufacturing and Service Industries," *Hum. Factors Ergon. Manuf.*, 2012.

[28] L. Gualtieri, E. Rauch, and R. Vidoni, "Emerging Research Fields in Safety and Ergonomics in Industrial Collaborative Robotics: A Systematic Literature Review," *Robot. Comput. Integr. Manuf.*, vol. 67, p. 101998, 2021, doi: 10.1016/j.rcim.2020.101998.

[29] M. Chiara Leva, M. Demichela, L. Comberti, and A. Caimo, "Human performance in manufacturing tasks:

Optimization and assessment of required workload and capabilities," *Saf. Sci.*, vol. 154, p. 105838, 2022, doi: https://doi.org/10.1016/j.ssci.2022.105838.

[30] I. Val, S., & García, "Overall Equipment Effectiveness for Elevators (OEEE) in Industry 4.0: Conceptual Framework and Indicators," *2025*, vol. 9, no. 227, 6AD, doi: https://doi.org/10.3390/eng6090227.