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Prototyping Method for Developing a Product Barcode Validation System in Manufacturing Industry

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Abstract: Manual validation of product barcode labels within industrial manufacturing production lines is highly vulnerable to human errors and completely lacks an automated audit trail system for quality assurance. This study aims to design, implement, and evaluate a specialized desktop-based barcode validation scanning application to eliminate operational labeling risks and ensure absolute data traceability. The Prototyping method was utilized to iteratively develop the application using React.js and Electron.js frameworks, seamlessly integrating hardware components including a 125-kilohertz Radio Frequency Identification reader for authentication security and a barcode scanner connected to a centralized database. This robust integration ensures that all scanning transactions are instantly verified against the master data without experiencing any system latency or connectivity issues. Furthermore, the usability of the developed system was quantitatively evaluated using the standard System Usability Scale approach by involving 35 active respondents directly from the manufacturing quality inspection department. The empirical implementation results demonstrated that the software successfully automated the highly accurate verification of four distinct production label types and comprehensively enforced secure role-based access control. The quantitative usability evaluation yielded an exceptional average score of 80.57, which strategically positions the desktop application within the highly acceptable category with a good performance rating. The absence of complex terminologies and the straightforward navigation flow were key factors contributing to this positive user reception. In conclusion, the developed scanning system effectively eliminates manual verification defects, guarantees operational report data integrity, and offers a highly intuitive interface that minimizes the users' cognitive workload, thereby significantly enhancing quality control standards in the manufacturing environment.

Keywords: Barcode Validation, Desktop Application, Manufacturing Industry, Prototyping Method, System Usability Scale

INTRODUCTION

In the fast-paced health care and personal care electronics manufacturing industry, maintaining rigorous quality control and product traceability is paramount to safeguarding operational integrity and customer satisfaction (Fortuna & Gaspar, 2022). One of the critical operational milestones in the packaging assembly line is the precise verification of product barcode labels. Currently, many manufacturing setups still rely heavily on manual visual inspections by production operators to validate these labels. This conventional approach is highly vulnerable to human error, fatigue, and cognitive overload, which frequently leads to catastrophic defects such as mislabeling or shipping incorrect product variants (Stanisławek et al., 2021). Furthermore, manual validation completely lacks an automated data logging mechanism, creating a significant gap in the real-time audit trail required for comprehensive quality assurance. Therefore, transforming this manual process into a secure, automated validation ecosystem is an urgent operational necessity. The transition towards digital technologies in industrial operations is increasingly recognized as a vital step to empower traceability, eliminate physical bottlenecks, and support sustainable quality control management (Sica et al., 2024).

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To resolve this pervasive industrial challenge, this study introduces a dedicated desktop-based barcode validation scanning application engineered to eliminate manual verification risks. The software architecture leverages React.js to construct a highly responsive, modern user interface alongside Electron.js to deliver a robust and secure desktop runtime environment (Peguero & Cheng, 2021). To achieve absolute operational integrity and security at the production line, the software is natively integrated with specific hardware components. A 125 kHz Radio Frequency Identification (RFID) reader and card system are implemented to enforce secure, role-based operator authentication, while an EZCODE barcode scanner is deployed to capture physical label data instantaneously. All validation transactions are synchronized in real-time with a centralized SQL Server database, effectively establishing a reliable, tamper-proof digital audit trail.

However, introducing automated software into an established manufacturing workflow requires extensive validation regarding user acceptance and interface friction (Kheder, 2023). A poorly designed user interface can disrupt line balancing and trigger user resistance among operators. To mitigate these deployment risks, the software engineering process strictly incorporates the Prototyping methodology, enabling continuous, iterative refinements based on direct feedback from the quality inspection team (Azman et al., 2023; Nelson et al., 2016). Subsequently, to ensure the application truly aligns with user workflows without inducing unnecessary operational stress, a quantitative evaluation is conducted using the standardized System Usability Scale (SUS) involving 35 active manufacturing respondents (Brooke, 1996). This paper details the structural development, hardware integration, and empirical usability performance of the proposed barcode validation system.

LITERATURE REVIEW

The implementation of robust traceability and automated validation systems within the manufacturing sector has been extensively explored to minimize operational vulnerabilities. Previous research emphasizes that digitalizing the tracking process significantly safeguards product integrity and prevents quality defects on the production floor. (Fortuna & Gaspar, 2022) demonstrated that automated industrial traceability systems effectively mitigate material handling risks and secure data consistency across production lines. Similarly, (Stanisławek et al., 2021) highlighted that substituting manual visual inspections with digital verification frameworks drastically reduces the probability of human error and ensures consumer protection. In the context of software engineering frameworks utilized to build these systems, selecting an adaptive development life cycle is highly critical. While traditional sequential models like the Waterfall methodology offer a structured approach, they often lack the necessary flexibility to incorporate rapid user feedback during UI/UX development. To bridge this gap, the Prototyping method is widely recognized as a superior alternative for user-centered desktop systems. (Azman et al., 2023; Nelson et al., 2016) argued that iterative prototyping enables continuous evaluation and active user participation, which drastically reduces software rejection rates upon factory deployment. Furthermore, employing iterative prototyping methods has proven highly effective in bridging the gap between specific hardware integration and software functionalities in modern industrial applications (Guevara et al., 2024).

In addition to system development, ensuring optimal software usability in high-pressure manufacturing environments is vital to prevent operational friction and cognitive overload (Kheder, 2023). The System Usability Scale (SUS), originally formulated by (Brooke, 1996), stands as a globally standardized, highly reliable, and cost-effective instrument for measuring human-computer interaction quality. The SUS architecture consists of ten alternating positive and negative statements evaluated through a five-point Likert scale. To accurately interpret the raw numerical metrics derived from this instrument, (Bangor et al., 2009) introduced an adjective rating scale and grade framework, which systematically maps the scores into clear qualitative categories ranging from Poor to Excellent. The empirical validity of utilizing the SUS framework to evaluate automated applications has been widely documented in recent literature. (Isal et al., 2021; Thamilarasan et al., 2023; Welda et al., 2020) confirmed that the standard SUS calculation yields high statistical consensus regarding user satisfaction, interface learnability, and system acceptancy, making it the most suitable evaluation metric for industrial software integration. Recent studies emphasize that the System Usability Scale remains a highly reliable metric for evaluating interactive technological platforms, ensuring that the developed software meets user satisfaction before widespread deployment (Dewi & Abdillah, 2024). Furthermore, adopting a structured usability evaluation framework is critical to objectively measuring how end-users interact with newly deployed technological interfaces (Choong et al., 2022).

METHOD

This research employs the Prototyping methodology to systematically design, develop, and evaluate the barcode validation application. The iterative nature of this method ensures that the software aligns perfectly with the specific operational requirements of the quality inspection department. The research procedure initiates with a comprehensive requirements gathering phase conducted directly on the manufacturing floor to identify the exact

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parameters needed to replace the manual barcode checking process. This initial stage involves analyzing the workflow constraints, understanding the types of production labels, and establishing the technical requirements for automated data logging. The systematic stages and iterative loops of the proposed prototyping methodology are illustrated in Fig. 1.

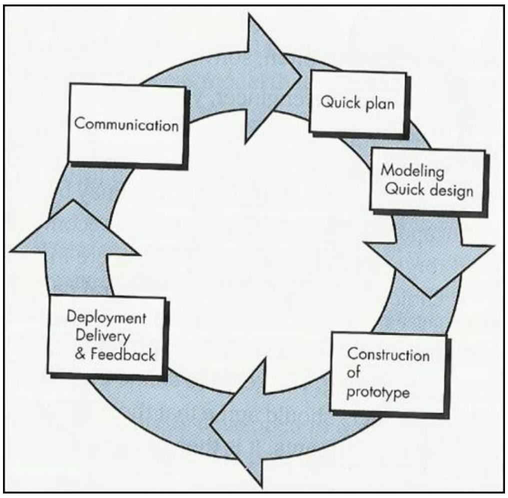

Fig. 1. Metode *Prototyope*

Following the requirements analysis, the system architecture was formulated and implemented. The desktop application was constructed utilizing React.js to build a highly responsive user interface and Electron.js to establish a stable, secure desktop runtime environment. A critical aspect of this development is the seamless integration of physical hardware to authenticate users and read physical product labels reliably. The comprehensive hardware integration architecture of the proposed system is shown in Fig. 2.

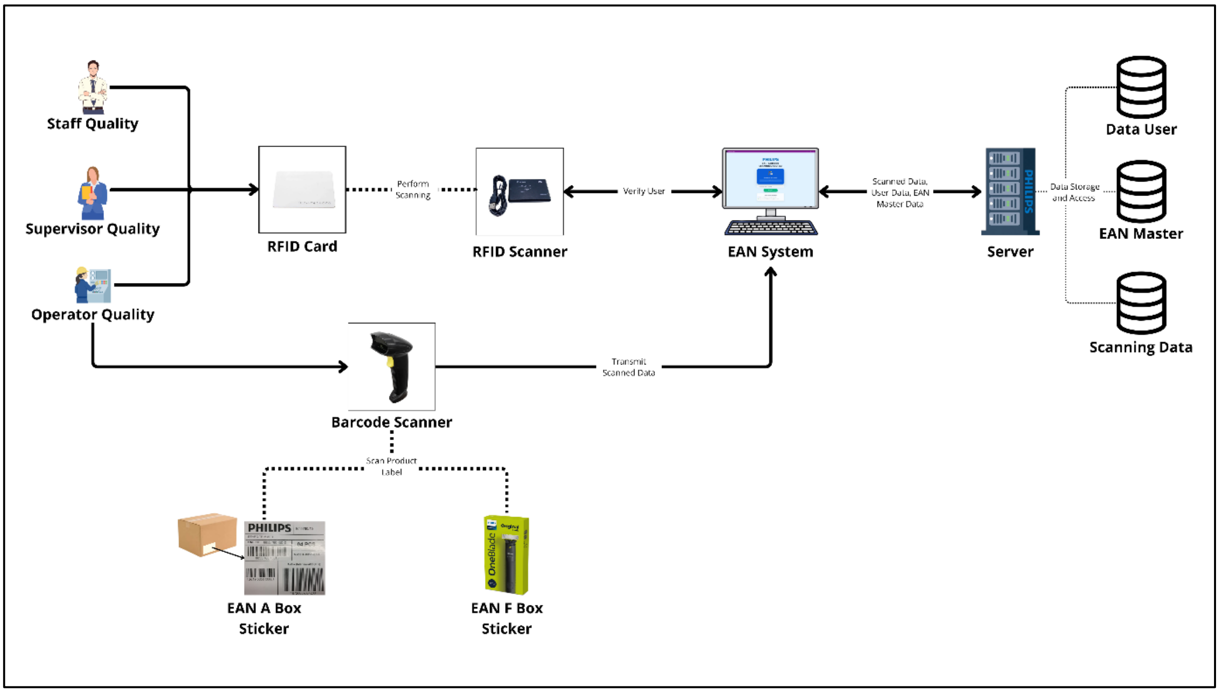

Fig. 2. Hardware Integration Architecture

As depicted in the architecture, a 125 kHz Radio Frequency Identification (RFID) reader is integrated to enforce secure Role-Based Access Control (RBAC) by authenticating the operators' ID cards. Simultaneously, an EZCODE barcode scanner is configured to accurately capture and decode physical product labels. All transaction logs and validation results are synchronized in real-time with an SQL Server database to maintain a reliable audit trail.

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The final phase involves a rigorous empirical evaluation using the System Usability Scale (SUS) instrument. The fully functional prototype was deployed and tested by 35 active respondents from the quality inspection team. The respondents interacted with the application in a real-world scenario and completed the SUS questionnaire, which utilizes a five-point Likert scale. To calculate the final usability score from the questionnaire, a specific mathematical rule is applied to the five-point Likert scale responses. The sum of all item score contributions is multiplied by 2.5 to obtain the overall system usability score, which ranges from 0 to 100, as formulated in (1).

$$\text{SUS Score} = \left(\sum x + \sum y\right) \times 2.5 \qquad (1)$$

Where:
x = Scale position minus 1 (for odd-numbered statements)
y = 5 minus scale position (for even-numbered statements)

The resulting score provides an objective, standardized metric to determine the system's usability performance and acceptance level prior to full-scale industrial deployment. To prevent generalization bias and ensure statistical representation, the quantitative calculation was strictly limited to 35 respondents (31 Operator Quality and 4 Staff Quality), deliberately excluding a single Supervisor respondent.

RESULT

The engineering phase successfully delivered a fully functional desktop-based barcode validation scanning application tailored for the health care electronics manufacturing environment. The system achieves absolute operational synergy by executing backend data validation via Electron.js while rendering a highly responsive, intuitive interface through React.js framework components. To verify the final layout design and the core user interaction flow of the developed prototype, the primary user interface during an active production label verification session is displayed in Fig. 3.

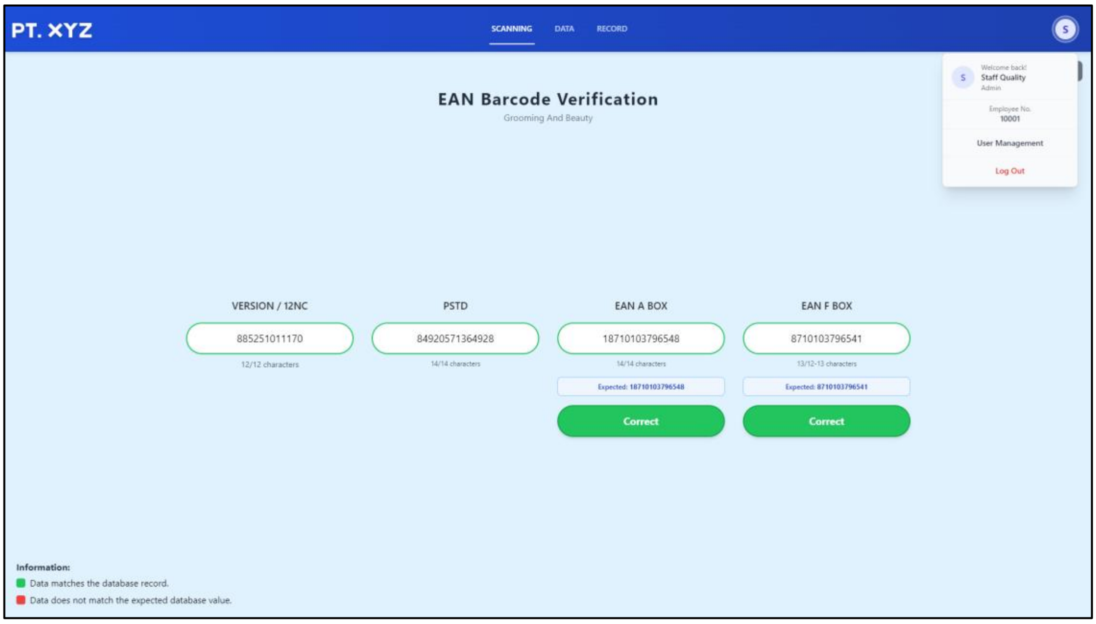

Fig. 3. Interface of Barcode Validation Application

Following the successful iterative deployment of the desktop prototype on the quality inspection production floor, the empirical usability evaluation was rigorously conducted. The evaluation involved 35 active manufacturing respondents from the inspection quality department who operated the scanning software during their regular operational shifts. Upon completing the extensive system test sessions, the respondents filled out the standardized ten-item System Usability Scale (SUS) questionnaire framework. The raw metrics collected via the five-point Likert scale were subsequently converted and computed using the standard SUS scoring algorithm. The comprehensive structural distribution of the individual questionnaire item scores and the final average calculation are organized and presented in Table 1.

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Table 1. Results of the SUS Score Calculation Process

Respond	Score Calculated Results		Respond	Score Calculated Results	
	Sum	Value		Sum	Value
R1	40	100	R19	40	100
R2	28	70	R20	34	85
R3	33	82,5	R21	36	90
R4	38	95	R22	29	72,5
R5	34	85	R23	32	80
R6	28	70	R24	29	72,5
R7	35	87,5	R25	21	52,5
R8	35	87,5	R26	26	65
R9	31	77,5	R27	35	87,5
R10	31	77,5	R28	27	67,5
R11	35	87,5	R29	20	50
R12	28	70	R30	40	100
R13	34	85	R31	23	57,5
R14	40	100	R32	39	97,5
R15	36	90	R33	33	82,5
R16	26	65	R34	33	82,5
R17	32	80	R35	30	75
R18	37	92,5			
Average System Usability Scale (SUS) Score					
80.57					

As detailed by the empirical parameters within the structured matrix, the collective quantitative assessment from the 35 manufacturing practitioners yielded a final average SUS score of 80.57.

DISCUSSIONS

The empirical final score of 80.57 provides critical qualitative and quantitative insights into the software's performance, interface intuitiveness, and user acceptance. To evaluate these findings rigorously, the resulting score is mapped against the standardized adjective rating scale and grade acceptability criteria established by Bangor (Bangor et al., 2009). A score of 80.57 strategically positions the barcode validation application within the "Acceptable" threshold, specifically securing a "Good" adjective rating and a definitive Grade B classification. This high usability consensus mathematically demonstrates that the user interface design is highly intuitive and successfully accommodates the operational habits of the quality inspection personnel. Despite the introduction of multi-layered hardware steps, including mandatory 125 kHz RFID card authentication and physical EZCODE label scanning, the system layout effectively minimizes user friction and prevents additional cognitive workload. The Prototyping methodology proved highly effective in this context, as early user feedback directly guided the elimination of confusing interface terminologies, thereby maximizing learnability. Furthermore, the evaluation instrument demonstrated a high internal consistency with a Cronbach's Alpha reliability coefficient of 0.80. A deeper subscale analysis revealed that the system excelled significantly in the Usability dimension (score 82.14), while maintaining a solid Learnability dimension (score 74.29). A stratification analysis further confirmed high acceptance across different operational roles, with Staff Quality scoring 84.37 and Operator Quality scoring 80.08.

From an industrial quality control perspective, the successful implementation of this integrated system comprehensively resolves the manual verification bottlenecks. By replacing the previous unintegrated, Excel-based manual verification system with an automated, SQL Server-driven application, the probability of human verification error and double-version data input is entirely eliminated. Furthermore, because every scanning transaction is instantly synchronized with the centralized SQL Server database, the management is provided with a secure, tamper-proof digital audit trail. This automated logging capability guarantees total data traceability and

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significantly elevates the operational quality assurance standards within the manufacturing ecosystem, proving that the application is fully optimized for immediate, large-scale industrial deployment.

CONCLUSION

This research successfully designed, implemented, and evaluated a comprehensive desktop-based barcode validation scanning application tailored to overcome material tracking issues in the health care electronics manufacturing line. By integrating React.js and Electron.js with specialized hardware infrastructure, including a 125 kHz RFID reader for operator authentication and an EZCODE barcode scanner, the developed prototype completely automates the product label verification process and establishes a secure digital audit trail. The quantitative usability evaluation involving 35 active manufacturing respondents yielded an exceptional average score of 80.57, which places the system firmly within the acceptable threshold with a "Good" adjective rating and a Grade B performance classification. These empirical findings demonstrate that the application is highly user-friendly and successfully minimizes the user interface friction for operators. For future study, it is highly recommended to perform a Time and Motion Study to quantitatively measure the exact percentage increase in operational processing speed compared to traditional manual inspections. Furthermore, given the high acceptance rate, future iterations could expand the system infrastructure to establish it as a primary traceability standard across other production departments.

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