

Designing Industrial Interfaces for Digitally and Functionally Illiterate Users: A Case Study in a Manufacturing Environment

Felipe Dias Abrahão
0009-0003-9824-5697
State University of Londrina
Department of Computer Science
Londrina, Brazil 86057-970
felipeabrahao2002academico@gmail.com

Leandro Durães
Kit's Paraná
Arapongas, Brazil 86703-000
leandro.duraes11@gmail.com

Arthur Pedro Fortes Silva
State University of Londrina
Department of Computer Science
Londrina, Brazil 86057-970
arthur.pedro.fortes@uel.br

Vanessa Tavares de Oliveira Barros
0000-0002-7229-6651
State University of Londrina
Department of Computer Science
Londrina, Brazil 86057-970
vanessa@uel.br

Rodolfo Miranda de Barros
0000-0003-2792-4302
State University of Londrina
Department of Computer Science
Londrina, Brazil 86057-970
rodolfo@uel.br

Abstract—This study investigates how industrial human-machine interfaces can be designed to support manufacturing workers with low digital and functional literacy, a population often overlooked in digital transformation initiatives. The objective is to design, deploy, and evaluate an inclusive production tracking interface that reduces cognitive load and improves usability on the shop floor. Using Design Science Research (DSR) combined with a case study in a real manufacturing environment, the work applies user-centered design through personas, the Double Diamond framework, and WCAG 2.2 accessibility principles. The main contribution is an evaluated artifact (a redesigned industrial interface) together with a replicable design process showing how clarity, color-coded feedback, iconography, and simplified navigation can address literacy-related usability barriers in industrial settings. Following deployment and a habituation period, structured satisfaction questionnaires were administered to machine operators, supervisors, and ERP operators. Results suggest improvements in perceived user satisfaction, task efficiency and ease of use. These findings reflect participant perceptions rather than measured performance gains. Nonetheless, they highlight the role of inclusive interface design in supporting equitable access to digital tools in industrial environments.

Index Terms—Digital transformation, Human-machine interface, Digital Illiteracy, Functional Illiteracy, User-centered design

I. INTRODUCTION

DIGITAL transformation encompasses the integration of digital technologies to enhance operational efficiency, foster innovation, and increase value delivery across industries. However, its successful implementation hinges on the adaptability of the workforce, particularly those operating at the intersection of human labor and machine interaction. In manufacturing settings, workers on the shop floor are often required to interact with complex systems, yet many possess

limited digital experience or functional literacy, creating substantial usability barriers.

Functional illiteracy, characterized by difficulties in applying reading and comprehension skills in practical contexts, and digital illiteracy, the lack of proficiency with basic digital tools, remain prevalent among industrial workers in underdeveloped regions. In Brazil nearly a third of the adult population exhibits functional illiteracy, a condition strongly linked to exclusion from digital transformation initiatives.

Existing literature on industrial HCI and digital transformation provides limited guidance for designing interfaces for workers with low digital and functional literacy in manufacturing environments. Although user-centered design and accessibility standards such as WCAG are well established in web and consumer applications, their application to shop-floor production systems remains scarce.

This research aims to design and evaluate an industrial production-tracking interface adapted to digitally and functionally illiterate users in a real manufacturing environment. To that end, the study addresses the following questions:

- **RQ1:** Which interface design principles improve usability for digitally and functionally illiterate industrial workers?
- **RQ2:** How do users perceive the redesigned interface compared with the legacy system?

Guided by Design Science Research (DSR) and a case study approach, the work applies user-centered design principles and WCAG accessibility guidelines to develop a production-tracking interface that emphasizes clarity, color-coded feedback, and simplified navigation for the ease of users with low literacy levels. Following deployment and a habituation period, structured satisfaction questionnaires were administered across

three user profiles (machine operators, supervisors, and ERP operators) to assess usability, efficiency, and satisfaction.

The remainder of this paper is organized as follows. Section II reviews the theoretical background on functional and digital illiteracy, digital accessibility, user centered design, and usability heuristics. Section III describes the research methodology, including DSR, the case study approach, persona development, and the Double Diamond design framework. Section IV presents the evaluation results and concluding discussion.

II. LITERATURE REVIEW

A. Functional Illiteracy

Functional illiteracy refers to a condition in which individuals, despite formal schooling and basic literacy skills, cannot apply reading and comprehension effectively in real world contexts. Vágvölgyi et al. define it as “the incapability to understand complex texts despite adequate schooling, age, language skills, elementary reading skills, and IQ” [1]. On the shop floor, this manifests as difficulty following standard operating procedures, completing production reports, or understanding safety signage, correlating with reduced productivity, higher error rates, and increased workplace accidents [2].

A 2016 INAF report found that 27% of Brazilian shop floor workers are functionally illiterate [3], while 29% of the broader population remained functionally illiterate as of 2023 [4]. The INAF framework places such individuals in the lowest proficiency tiers, characterized by difficulties interpreting texts, applying arithmetic, and navigating routine informational contexts [5].

B. Digital Illiteracy

Digital illiteracy is the inability to use digital tools effectively for accessing, evaluating, and producing information [6], [7]. Despite expanding digital infrastructure, insufficient skills continue to exclude large population segments from digital transformation benefits [7], [8]. In Brazil, more than 30% of adults cannot perform basic digital tasks such as sending emails or accessing institutional websites [8], limiting both personal development and equitable access to industrial and public digital systems [6], [7].

C. Digital Accessibility

Digital accessibility concerns the inclusive design of digital environments so that users with disabilities can access content and services. Common barriers include poor contrast, complex navigation, and unreadable interfaces, which restrict access to employment and operational systems [9], [10]. The Web Content Accessibility Guidelines (WCAG) define principles of perceivability, operability, understandability, and robustness, with testable success criteria applicable throughout the development lifecycle [10], [11].

D. User Centered Design

User centered design (UCD) places end users at the core of development, emphasizing contextual understanding, iterative involvement, and refinement driven by evaluation [12]. Personas, fictional archetypes built from user evidence, help teams internalize goals, behaviors, and pain points across design decisions [13], [14]. Structured questionnaires are commonly used to capture perceived usability, often combined with qualitative field observations to explain satisfaction patterns [12].

E. Jakob Nielsen’s Usability Heuristics

Jakob Nielsen’s usability heuristics are a widely recognized set of design principles aimed at improving the usability of interactive systems. First published by Nielsen in 1994, the ten heuristics serve as general guidelines that help identify common usability issues in digital interfaces. Rather than prescribing specific interface elements, the heuristics focus on core user experience principles such as visibility of system status, error prevention, consistency, and user control [15].

III. METHODS

A. Type and Nature of the Research

The research and analysis methodology used in this project was Design Science Research (DSR) by [16], which consists of five stages: Awareness, Proposal, Development, Evaluation, and Conclusion. These steps are described in Table I, along with the key points to be addressed in each stage. The DSR was developed with the aim of operationalizing the process of developing and analyzing artifacts, with a view to solving problems, communicating the results obtained, and the development achieved in the process.

In the first stage of the process, Awareness, the complexity of the problem is understood, with the main outcome being the definition and formalization of the framework for the research question, as well as the limitations and possible solutions (Proposal). In the next stage, Suggestion, alternative solutions are conceived that could address the proposed problem, of which one or more will be selected for development (Attempt). As this stage is inherent to the creative process and relatively subjective, it is difficult to standardize within the DSR process.

During the Development phase, the artifact itself must be constructed. It is at this point that the artifact’s internal environment (the processes necessary to achieve the desired result) is established, since the foundations and objectives (external environment) were developed in the previous phase, allowing the creation of the applicable component of the research (Artifact) to proceed. Following development comes the Evaluation phase, the examination of the artifact’s behavior must be conducted when it is placed in the environment for which it was developed (Performance Measures). To this end, multiple procedures must be carried out to verify the artifact’s behavior (validations). In the final stage of the DSR process, Conclusion, the overall development process are formalized and communicated to the academic and professional communities (Results).

TABLE I
STAGES OF CONDUCTING DSR AND KEY POINTS TO ADDRESS

Conduct Stage	DSR Outputs	Key Points to Address
Awareness	Proposal	- Highlight the problematic situation - Describe the environment and its main points of interaction with the artifact - Define metrics and criteria for accepting the artifact solution - Describe the classes of problems, existing artifacts, and their limitations
Suggestion	Attempt	- Define assumptions and requirements for building the artifact - Record all development attempts of the artifact - Document the reasons that led to discarding development attempts
Development	Artifact	- Justify the choice of tools for artifact development - Explain the components of the artifact and the causal relationships that produce the desired effect - Describe how the artifact can be tested
Evaluation	Performance Measures	- Detail the mechanisms used to evaluate the artifact - Present results in relation to the initially defined metrics - In qualitative evaluations, specify participants and potential biases - Indicate what worked as expected and what adjustments are necessary
Conclusion	Results	- Summarize the main learnings across all project phases - Justify the contribution of the work to the addressed problem class

B. Case Study

This study was conducted at Kit's Paraná, a kitchen furniture manufacturer based in Arapongas, Paraná, Brazil, specializing in the production of modular kitchen kits and related cabinetry for domestic and export markets. The case study method was used to conduct the research, as the aim of the project was to understand how users interacted with the interfaces used on a daily basis on the factory floor in this manufacturing environment. According to [17], a case study is an empirical investigation that examines contemporary phenomena within the real-life context in which the researcher operates, particularly in situations where the relationship between context and phenomenon is not clearly established.

Rather than sampling multiple sites at scale, this study adopts a single, in-depth case design, a choice well supported in HCI and applied social science literature [17] for three epistemological reasons. First, industrial systems do not operate in isolation, and a single-case design enables usability analysis under real factory conditions, including ambient noise, dust, shift work, and the use of personal protective equipment, preserving contextual richness that is often lost in large-scale studies. Second, from a UX perspective, designing for the most demanding scenario and the most specialized users supports system robustness, which is when operators responsible for the critical production task perceive the interface as usable, the design can be considered valid within that operational scope. Finally, unlike large-scale UX studies that often isolate variables to produce aggregate metrics, a single-case approach embraces the complexity of real workflows, allowing the iden-

tification of usability bottlenecks arising from the interaction of cognitive, physical, and organizational factors.

C. Analysis Methods

In conducting this study, the deductive analysis method was used, which, according to [18], proceed from general facts to specific conclusions by clarifying information that has already been obtained previously. This type of analysis aims to clarify the information contained in the premises of a scientific process with precision, without the need to expand upon the content of a project's assumptions, thereby providing solid conclusions that leave no room for ambiguity. In processes that use deductive analysis, the proposed statements may be true or false. In the latter case, it is possible to determine which premise led to the inconsistency in the process, since the analysis starts from a comprehensive sample, making it a robust method of analysis when compared to models such as the inductive method, which uses a partial sample to develop a conclusion. This is an exploratory study, which, according to

[19], it seeks to explore and uncover new areas and contexts of study, as well as to define and present novel concepts. Furthermore, this research is descriptive in nature and qualitative in approach, beginning with broad questions that are clarified as the scientific investigation progresses.

D. Personas

According to [14], personas are fictional profiles developed from user research to help teams understand whom the design is intended to serve. In this study, personas were used not to

identify new user groups, as stakeholders (machine operators, supervisors, and ERP operators) were already known from the factory context, but to synthesize behavioral patterns, literacy limitations, and operational needs observed during fieldwork into actionable design requirements. Each persona consolidates interview findings, shop-floor observations, and workflow constraints into a shared reference that guided screen layout, language choices, and interaction rules throughout the Double Diamond process.

The three personas developed represent the primary user groups affected by the system redesign:

- John, 52 years old, machine operator with incomplete secondary education. He has limited digital familiarity, uses messaging apps occasionally, and often needs help from his children to interact with technology. He has difficulty locating relevant data on-screen and tends to feel anxious when facing complex interfaces.
- Andrew, 45 years old, factory supervisor with technical training. He uses social media and messaging apps, but has limited experience with digital tools beyond that. His role involves supervising operators and verifying production data. He values centralized access to production information and believes some corrections could be done directly by the operators.
- Anna, 35 years old, ERP system operator with a university degree. She is highly proficient with digital tools and has extensive experience using enterprise software. Her workflow often includes verifying and correcting production records, which she finds repetitive. She seeks more automation and a broader view of operational data.

E. Project Methodology

The Double Diamond methodology, developed by the [20], was used to develop the project. It consists of four main stages: Discover, Define, Develop, and Deliver. The first stage, Discover, marks the start of the project, during which user needs are identified. In the next stage, Define, user needs are interpreted and aligned, and the project's objectives are established. In Develop, the third stage, solutions and proposals are developed, refined, and tested with the user in an incremental manner. In Deliver, the final stage of the methodology, the developed artifacts are finalized and made available to users.

When applying the methodology to the development process of this project, through the case study, it became apparent during the Discover phase that training employees to use the interfaces was costly, as was helping them understand the system. Furthermore, the low level of education among some employees prevented them from understanding and navigating the software, thereby limiting its use.

During the Define phase, the main pain point to be addressed was identified: the system connecting factory production and the company's ERP. This was due to the age of the software, which dated back to around 2010, making it impossible to reuse the software. Thus, building a new system from scratch was defined as the project's objective. The system's stakeholders and users were also defined in this

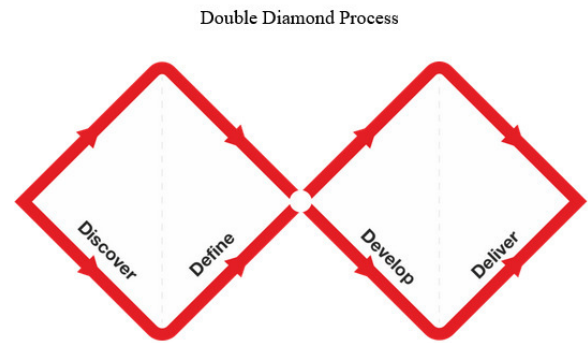


Fig. 1. Double Diamond methodology [20]

phase, including factory floor workers, supervisors, and ERP operators. Additionally, guidelines for designing the system screens were established for development, directly impacting the subsequent phase of the project. In the Develop phase, the interface was built according to three main rules:

- 1) Each color should be associated with a specific action within the software.
- 2) Each screen in the system should cover only one feature.
- 3) User actions should not confuse the user or be confusing to perform.

Consequently, during the Delivery phase, the system underwent WCAG analysis, user evaluations, and comparative analyses. This made it possible to deliver a system that participants perceived as easier to understand and use. The evaluation procedure and instruments are detailed in the following subsection. Results are reported in Section IV.

F. Technical Analysis Based on WCAG Guidelines

The redesigned interface was evaluated using three principles defined in the Web Content Accessibility Guidelines (WCAG) 2.2:

- Perceivable: Visual elements were adjusted to ensure high contrast, clear feedback, and minimal text dependency. Color was applied meaningfully to indicate production statuses and system states.
- Operable: Touch-based navigation was optimized with larger targets and simplified flows. The number of menu layers was reduced, and interaction paths were designed to require fewer steps.
- Understandable: Interface language was adapted to reflect terminology familiar to the users on the shop floor. Ambiguous technical terms were replaced with plain language and icons that matched user expectations and domain knowledge.

G. Usability Evaluation Procedure

1) *Questionnaire Instrument and Response Scale*: Perceived usability was assessed through structured satisfaction questionnaires tailored to each user profile (machine operators, supervisors, and ERP operators). All instruments employed a

five-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree*) to capture comparative judgments about the redesigned interface relative to the legacy system. For machine operators, item wording and response labels were simplified to reduce cognitive load. Supervisors and ERP operators received profile-appropriate variants with the same underlying scale structure.

The questionnaires addressed the following dimensions:

- Clarity of visual elements
- Ease of navigation
- Learning curve and onboarding experience
- System responsiveness and reliability
- Impact on task efficiency and productivity
- Overall user satisfaction

All instruments were reviewed by domain experts and piloted with a small subset of users before final deployment.

2) *Participant Selection and Sample Composition:* Participants were recruited through deliberate convenience and purposive sampling [12]: every respondent was an active system user directly involved in production workflows at Kit's Paraná. Inclusion required hands-on experience with both the legacy interface and the redesigned system after deployment. Table II summarizes the sample by user group.

TABLE II
EVALUATION PARTICIPANTS BY USER PROFILE

User group	N
Machine operators (floor workers)	11
Supervisors	2
ERP operators	2
Total	15

Although numerically small, the sample reflects the actual population density of the studied context. This quantitative limitation is justified by three factors. The evaluated system is highly specialized, operating exclusively within a restricted industrial niche on a single production line. Tested interactions occur on the factory floor under severe operational conditions (time pressure, ambient noise, and shift-based workflows), requiring motor and cognitive competencies that preclude testing with lay or generalist users. The required user profile also comprises scarce professionals tied to active production windows, and expanding the sample beyond available operators would have disrupted manufacturing operations.

In highly specialized industrial settings, the depth of user experience outweighs the need for large statistical volumes [17]. The eleven participating machine operators hold accumulated practical knowledge of the production process and encounter the system's real bottlenecks daily. The sample therefore achieves high vertical representativeness within this worker category. Data are not generalizable to the global population, but carry strong predictive validity for the specific industrial scenario the product serves.

3) *Evaluation Procedure and Timing:* Evaluation was conducted on the live factory floor at Kit's Paraná, under authentic time pressure, noise levels, and workflow constraints, not in

a laboratory or simulated environment. Following system deployment, users underwent a habituation period during which they used the redesigned interface in their regular production routines. Questionnaires were then administered individually to each participant during or immediately after their work shifts, while their experience with both systems remained fresh.

Each respondent completed the profile-specific questionnaire in a single session. Items prompted direct comparison between the legacy and redesigned interfaces across the dimensions listed above. No facilitator intervened during daily system use. The questionnaire captured retrospective perceived usability after sustained operational exposure. This high-fidelity context and the surgically targeted participant profiles compensate for the absence of a larger sample, supporting the ecological validity of the findings reported in Section IV.

Study participants were not simulated users or generalist personas. They were the actual professionals responsible for daily production tasks. In HCI, validation involving extreme users and domain specialists helps ensure that collected data rests on observed behavior rather than design assumptions [12]. The tacit knowledge these operators possess about the product and the industrial process allows qualitative signals (expressions of frustration, hesitations, and workarounds observed during fieldwork) to complement the Likert responses as credible usability diagnostics, even in the absence of quantitative productivity metrics.

H. Before-and-After Interface Comparison

Table III summarizes the main design differences between the legacy and redesigned interfaces. These contrasts reflect the user-centered design decisions applied during the Develop and Deliver phases and provide a structured account of the artifact's contribution beyond visual appearance alone.

Figures 2 and 3 illustrate the visual transformation of the system. The legacy interface, shown in Figure 2, suffered from dense visual information, unclear navigation, and inconsistent design patterns. In contrast, the redesigned interface in Figure 3 presents a clean layout, improved iconography, color-coded feedback, and touch-friendly elements that align with the users' profiles and needs.

IV. RESULTS AND CONCLUSION

A. Machine Operator questionnaire results

The questionnaire results from the eleven machine operators ($N = 11$) show a highly favorable reception of the new production system. All respondents rated the interface as more visually modern, better organized, and easier to use compared to the previous system. Every operator reported a fast learning curve, suggesting that participants perceived the interface as intuitive and aligned with their needs.

Even among a group with limited formal education and varying digital comfort, where 54% had not completed their basic schooling and the remaining 46% had completed it but had not pursued further education (e.g., technical or higher education), and where only 18.2% felt very comfortable

TABLE III
COMPARATIVE OVERVIEW OF THE LEGACY AND REDESIGNED PRODUCTION-TRACKING INTERFACES

Aspect	Legacy Interface	Redesigned Interface
Navigation	Text-heavy menus with multiple layers and unclear paths	Icon-based navigation with fewer menu levels and simplified touch flows
Data entry	Multiple fields per screen, fragmented input steps	Streamlined workflow with one feature per screen and fewer interaction steps
Accessibility	Limited contrast, small targets, and inconsistent patterns	WCAG 2.2-inspired design: high contrast, larger touch targets, and meaningful color coding
Cognitive load	Dense screens, ambiguous terminology, and visual overload	Reduced information density, plain-language labels, and domain-aligned iconography
Visual hierarchy	Weak structure, critical data difficult to locate	Improved layout with color-coded status feedback and clearer text and icon sizing
Interaction design	Inconsistent actions and confusing multi-purpose screens	Color-action mapping, single-purpose screens, and predictable interaction patterns

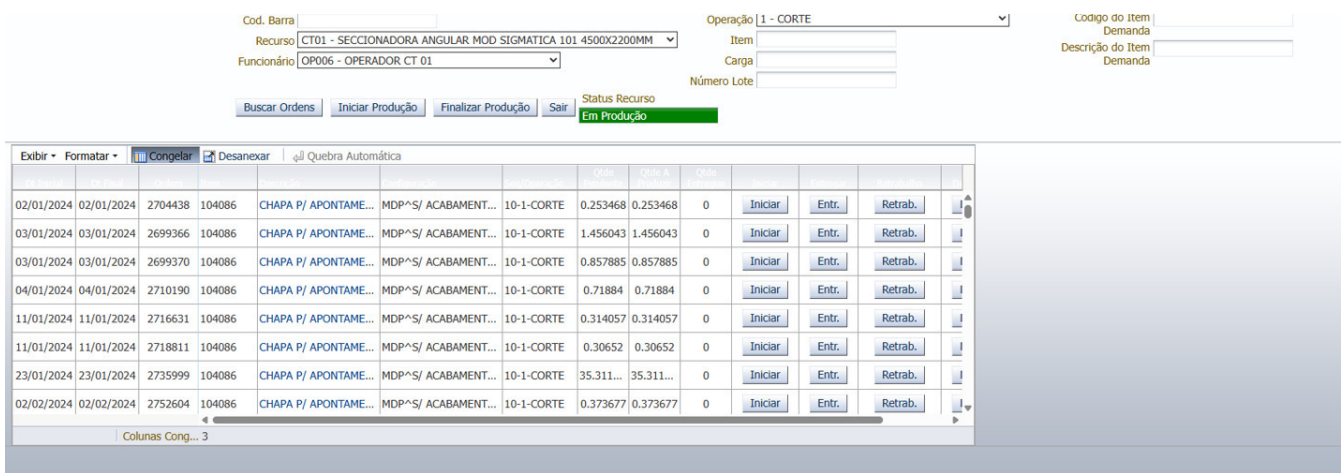


Fig. 2. Legacy system interface, characterized by overloaded screens and inaccessible structure

using technology and over half were above 40 years old, the feedback was unanimously positive. One hundred percent of respondents stated that the new system improved their work. Regarding system performance, 90.9% reported experiencing fewer technical issues than before, and 63.6% perceived faster response times during daily production-related operations.

These results align with the persona of John, the machine operator with low digital proficiency. John represents users who depend on clarity, simplicity, and direct interaction. The high satisfaction and ease of use reported suggest that the new system may have addressed the challenges associated with this user profile. The outcomes are also consistent with the goals of the user-centered design process, which was informed by interviews and field observations with real users similar to John.

B. Supervisor

The supervisor group consisted of two participants with differing educational backgrounds and age ranges. One participant was aged between 41-50 years and had completed technical education, while the other was between 51-60 years old with incomplete primary education. Despite this variation,

both supervisors reported feeling either comfortable or very comfortable using technology.

In terms of digital habits, both participants reported daily use of messaging apps. No usage was reported for banking apps, social media or other service apps, indicating a preference for simpler, communication-focused applications.

Regarding their experience with the new production system, both supervisors unanimously rated the interface as clearer, more objective, and easier to interpret than the previous version. They also reported improvements in information organization, readability of texts and icons, and overall system usability. Both agreed that the layout changes helped them locate and interpret production data more easily.

The learning curve was perceived as fast by one participant and moderate by the other, suggesting that onboarding was perceived as straightforward. Both supervisors evaluated the new system as a general improvement over the previous one, stating that it facilitated their work. Additionally, the color scheme was unanimously praised for enhancing readability and highlighting relevant information.

These results suggest that even users with limited formal



Fig. 3. Redesigned interface with improved readability, intuitive layout, and inclusive design elements

education or older age perceived the new system as accessible, as long as the interface remained simple, legible, and consistent with familiar digital patterns.

C. ERP Operator

The ERP group was composed of two participants, both of whom reported feeling very comfortable using technology. They were relatively young, one aged 21–30 and the other 31–40, and both had completed higher education. This demographic profile aligns with high digital fluency.

In terms of daily digital behavior, both participants reported using social media, delivery services and banking apps. These results indicate familiarity with a broad range of digital services beyond basic communication, suggesting a user profile accustomed to interacting with complex interfaces.

Regarding the production tracking system, both participants positively evaluated the interface. They considered the organization of information to be clearer and easier to understand compared to the previous system. They also found improvements in the visual layout, including better text and icon sizing. The color scheme was praised for aiding readability and effectively highlighting relevant data.

As for system integration, one participant stated that the integration between the new system and the ERP system was fully functional, while the other reported minor issues without operational impact. Despite these comments, both agreed that the data generated, such as production metrics and work orders, were reliable and needed little manual

correction. Overall, both users perceived the new system as an improvement that facilitated their work.

D. Limitations

This single-case study at Kit's Paraná enables in-depth observation under real factory conditions but limits generalization to other industries, production lines, or organizational contexts. Fifteen participants completed the questionnaires (see Table II), including only two supervisors and two ERP operators, which restricts statistical inference and profile-specific conclusions despite reflecting the factory's actual user population.

Evaluation relied exclusively on custom five-point Likert questionnaires, without standardized instruments (e.g., SUS, UEQ, or PSSUQ) or objective metrics such as productivity, error rates, or task completion times. All participants also had prior experience with the legacy system, so positive perceptions may partly reflect familiarity and habituation rather than interface improvements alone.

E. Future Work

Building on the limitations identified above, future research should replicate the design process in other manufacturing sectors and multiple sites, recruit larger and more balanced samples across all user profiles, and complement custom questionnaires with validated instruments such as SUS, UEQ, or PSSUQ. Studies should also record objective indicators (productivity, error rates, task completion times, and training duration) and conduct longitudinal follow-ups to determine

whether perceived usability gains translate into sustained operational benefits.

F. General Conclusion

The evaluation of the redesigned production tracking system across three distinct user profiles (machine operators, supervisors, and ERP operators) suggests that a user-centered design approach can support perceived usability improvements across users with varying age, education level, and digital literacy.

Machine operators, who typically possess low digital proficiency, reported the highest levels of satisfaction, highlighting the intuitiveness and visual clarity of the interface. Supervisors also expressed positive perceptions, particularly regarding the improved organization and readability of information, suggesting the system met their intermediate digital expectations. ERP operators, already fluent in digital environments, appreciated the refined layout and integration capabilities, reinforcing the system's perceived adaptability to more advanced users.

A comparative analysis revealed that, while all user groups perceived the system as an improvement, the underlying reasons varied. Operators valued clarity and ease of use, supervisors emphasized data accessibility, and ERP users appreciated perceived efficiency and integration. These differences underline the importance of tailoring design decisions to the specific needs and contexts of diverse user groups.

Overall, the results suggest that inclusive design principles may help bridge gaps in digital literacy. Participant feedback indicates that the redesigned manufacturing production tracking system was perceived as accessible and functional across a heterogeneous workforce. These findings reinforce the value of user-centered design in digital transformation processes. Nonetheless, the limitations discussed above caution against overgeneralizing perceived benefits to measurable efficiency gains. The future work directions outlined in the preceding subsection provide a roadmap for addressing these gaps in subsequent studies.

GENERATIVE AI USE DISCLOSURE

The authors used ChatGPT for translation support during preparation of the English manuscript, and updating the on-screen labels in Figure 3 from Portuguese to English. These uses did not affect the research design, data collection, analysis, or substantive conclusions of this study.

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