Paperless Checklist for Process Validation and Production Readiness: An Industrial Use Case

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Keywords: Industrial Information System, Manufacturing Process Control, Validation Checklist.

Abstract: The Digital Model concept of factory floor equipment allows simulation, visualization and processing, and the ability to communicate between the various workstations. The Digital Twin is the concept used for the digital representation of equipment on the factory floor, capable of collecting a set of data about the equipment and production, using physical sensors installed in the equipment. Within the scope of data visualization and processing, there is a need to manage information about parameters/conditions that the assembly line equipments must present to start a production order, or in a shift handover. This study proposes a paperless checklist to manage equipment information and monitor production ramp-up. The proposed solution is validated in a real-world industrial scenario, by comparing its suitability against the current paper-based approach to log information. Results show that the paperless checklist presents advantages over the current approach since it enables multi-access viewing and logging while maintaining a digital history of log changes for further analysis.

1 INTRODUCTION

An information system is a collection of interconnected components that work together to gather, process, store, and distribute information within an organization or a specific context. These components include people, hardware, software, data, and procedures. The primary purpose of an information system is to support the management, operations, and decision-making processes of an organization. It enables the efficient and effective collection, storage, processing, and dissemination of data and information to various stakeholders.

In comparison with traditional approaches to facilitate communication, collaboration, and data management, an information system is characterized by: I) Improved Decision-Making, i.e., enables informed decision-making based on data-driven insights; II) Enhanced Efficiency and Productivity (automate repetitive tasks and improve workflow efficiency); III) Effective Communication and Collaboration; IV) Improved Data Management, i.e., efficiently store, organize, and retrieve large volumes of data, while ensuring data integrity, security, and accuracy.

In an industrial setting, information systems play a vital role in optimizing operations, improving efficiency, and ensuring smooth coordination across various departments. The main use cases are:

- Supply Chain Management (Gunasekaran and Ngai, 2004): Information systems are used to manage the entire supply chain, from procurement of raw materials to distribution of finished products. They help in tracking inventory levels, managing suppliers, optimizing procurement processes, and monitoring logistics activities. This ensures timely availability of materials and efficient delivery of products to customers.
- Production Planning and Control (Palade and Møller, 2023): Information systems assist in pro-

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Cosme, J., Pinto, T., Ribeiro, A., Filipe, V., Amorim, E. and Pinto, R.
Paperless Checklist for Process Validation and Production Readiness: An Industrial Use Case.
DOI: 10.5220/0012186800003584
In *Proceedings of the 19th International Conference on Web Information Systems and Technologies (WEBIST 2023)*, pages 95-103
ISBN: 978-989-758-672-9; ISSN: 2184-3252

duction planning and control by providing real-time data on production capacity, resource availability, and scheduling. They help in optimizing production processes, monitoring production progress, and ensuring timely completion of orders. This leads to improved productivity, reduced lead times, and better utilization of resources.

- Quality Control: Information systems are used to monitor and control quality throughout the manufacturing process. They enable real-time monitoring of product quality parameters, statistical process control, and automated inspections. This ensures adherence to quality standards, early detection of defects, and timely corrective actions, resulting in higher product quality and customer satisfaction.
- Human Resource Management (Nagendra and Deshpande, 2014): Information systems are utilized for managing employee information, payroll, attendance, and training programs. They help in tracking employee performance, skill development, and workforce planning. Additionally, information systems can be used to facilitate employee self-service portals for accessing Human Resource-related information, applying for leave, and managing benefits.
- Data Analytics and Business Intelligence: Information systems provide data analytics capabilities to analyze operational data, identify trends, and gain insights into process efficiencies, cost optimization, and market trends. Business intelligence tools can be employed to generate reports, dashboards, and visualizations that aid in decision-making at various levels of the organization.
- Environmental and Safety Compliance: Information systems assist in managing environmental and safety compliance in industrial settings. They can track and monitor adherence to regulatory requirements, manage hazardous materials, and ensure the safety of employees and the environment. This includes systems for incident reporting, risk assessments, and compliance audits.
- Maintenance and Asset Management (Love et al., 2016; Graf et al., 2011): Information systems facilitate the management of industrial equipment and assets. They help in tracking equipment maintenance schedules, managing work orders, and monitoring equipment performance. Predictive maintenance techniques can be employed, where data from sensors and machines are analyzed to identify potential failures and schedule maintenance proactively, reducing downtime and optimizing asset utilization.

Information systems play a crucial role in the maintenance and management of industrial equipment and assets. They help in tracking equipment maintenance schedules, managing work orders, and monitoring equipment performance. Predictive maintenance techniques can be employed, where data from sensors and machines are analyzed to identify potential failures and schedule maintenance proactively, reducing downtime and optimizing asset utilization. They provide a centralized repository for maintenance documentation, including equipment manuals, standard operating procedures, maintenance checklists, and troubleshooting guides. This ensures that maintenance personnel have easy access to the required information, reducing downtime and improving the effectiveness of maintenance activities.

Additionally, information systems can capture and store maintenance knowledge and lessons learned, enabling knowledge sharing and continuous improvement. Moreover, information systems can be accessed through mobile devices, allowing human operators to receive work orders, update maintenance records, and access relevant documentation while on the shop floor. Mobile access facilitates real-time collaboration, communication, and data capture, improving efficiency and reducing paperwork.

This study proposes an information system approach to enable a digital checklist, used for the management of equipment maintenance and validation of process status at the beginning of shifts or production changes. We implement the proposed approach in a real-world industrial scenario, which uses currently a paper-based methodology to manage the checklist information. By digitizing the checklists, manual paperwork is eliminated, and the information is readily accessible among employees, teams and departments. Thus, in this study, we aim to address the following research questions:

RQ 1. How are the information processing and the respective ramp-up checklist management affected by the implementation of paperless practices in terms of process performance with emphasis on the efficiency, flexibility and quality aspects?

RQ 2. How does a shift towards a digital checklist impact the concepts of information processing requirements and capability, information flow, and the working processes?

The paper is organized into five more sections. Section 2 provides a technological context and a comprehensive analysis of the state of the art. Section 3 describes in detail the case study to be addressed and the proposed approach. Section 4 describes the experimental methodology and results achieved, while Section 5 further discusses the proposed approach. Finally, Section 6 concludes the paper, stating final remarks about the study performed.

2 RELATED WORK

In the last years, the adoption of paperless strategies in industrial companies has been a hot topic in research (Palade and Møller, 2022; Müller, 2017; Djassemi and Sena, 2006). Digitalization becomes an increasingly important factor for organizations in order to eliminate paper-based processes. One example is regarding the requirement of documentation of the manufacturing production and how is it possible to produce without having the documentation in paper form (Bulut et al., 2020; Mleczko et al., 2013). A digital document-based factory organization can realize potential process improvements that have an impact on efficiency, quality and flexibility.

Ramp-up checklists (Christensen and Rymaszewska, 2016; Biffl et al., 2022) are documents commonly used at the beginning of shifts or during production changes to ensure a smooth transition and optimal performance. These checklists help operators or maintenance personnel go through essential tasks and checks to prepare equipment, processes, and systems for production. They are essential to ensure that equipment, systems, and processes are properly prepared, minimize risks, and ensure a smooth transition into production. They help identify potential issues early on, prevent equipment damage, ensure safety compliance, and maintain product quality. While the specific items on a ramp-up checklist may vary depending on the industry and operational requirements, here are some common elements typically included:

- Equipment Preparation: This includes tasks such as inspecting equipment for any damage or abnormalities, verifying proper calibration of instruments, and ensuring the availability of necessary tools or materials.
- Safety Checks: Operators may be required to perform safety checks to ensure compliance with safety protocols and regulations. This can involve checking safety devices, emergency stop buttons, proper guarding, and verifying the availability and functionality of personal protective equipment (PPE).
- Start-Up Procedures: Operators follow specific procedures for starting up equipment or systems, including powering on machines, initiating control systems, and ensuring proper initialization and sequencing of equipment.
- Parameter Verification: Operators verify and set the operational parameters according to the specific requirements of the production run. This can involve checking and adjusting temperature, pressure, flow rates, speed settings, or other critical parameters.
- Material Verification: Operators verify the availability and quality of raw materials, ensuring that the correct materials are ready for use in the production process. They may also conduct material inspections or perform sample testing if required.
- System Checks: This involves verifying the functionality and readiness of various systems, such as utility systems (water, air, electricity), control systems, communication systems, or any other systems critical to the production process.
- Quality Control Checks: Operators perform checks to ensure that quality control measures are in place. This can involve verifying the calibration of measuring instruments, conducting initial quality checks on products or samples, or confirming that quality standards and procedures are followed.
- Communication and Handover: Operators communicate with the previous shift or relevant personnel to obtain information on any ongoing issues, completed tasks, or specific instructions. They also provide updates or handover information to subsequent shifts or teams (Plocher et al., 2011).
- Documentation: Operators document the completion of tasks, record any observations or abnormalities, and maintain records for future reference or compliance purposes.

In this context, information systems can be utilized effectively for ramp-up checklists used at the beginning of shifts or production changes. By integrating information systems into asset management processes on the shop floor, organizations can enhance maintenance efficiency, reduce costs, improve equipment reliability, and optimize overall asset utilization.

Information systems allow ramp-up checklists to be digitized and stored within the system. The checklists can be designed using customizable templates that align with the specific requirements of the maintenance tasks or production changes. By digitizing the checklists, manual paperwork is eliminated, and the information is readily accessible. On the other hand, information systems can automate the distribution of checklists to the appropriate personnel or teams at the beginning of shifts or when production changes occur. The system can send notifications or reminders to designated individuals, ensuring that the checklists are promptly received and acted upon. This streamlines the checklist distribution process and reduces the chances of missing or delayed checklists.

Real-time updating and tracking are also possible with paperless checklists since operators can update the checklist items in real-time as they perform their tasks. They can mark completed items, record measurements or readings, add comments, or indicate any issues encountered. This real-time updating ensures that the checklist progress is accurately tracked and visible to relevant stakeholders. Moreover, mobile access to the checklists allows operators to access and update the checklists directly on handheld devices. This enhances flexibility and enables real-time collaboration, as supervisors or managers can review checklist progress, provide instructions, or address any concerns remotely.

These digital checklists can also integrate with sensors, data loggers, or equipment monitoring systems to capture relevant data directly from the equipment (Gonçalves et al., 2014). This integration eliminates the need for manual data entry and ensures accuracy. The checklist can be configured to automatically retrieve equipment parameters or readings, providing real-time data for analysis and comparison with expected values (Doltsinis et al., 2020). This level of integration with equipment data enables exception management, where information systems can flag any checklist items that are not completed, fail to meet specified criteria or require attention (Bockelmann et al., 2017). This alerts supervisors or maintenance managers to potential issues or deviations from standard procedures. Exception management enables prompt action and facilitates the resolution of problems before they escalate or impact production.

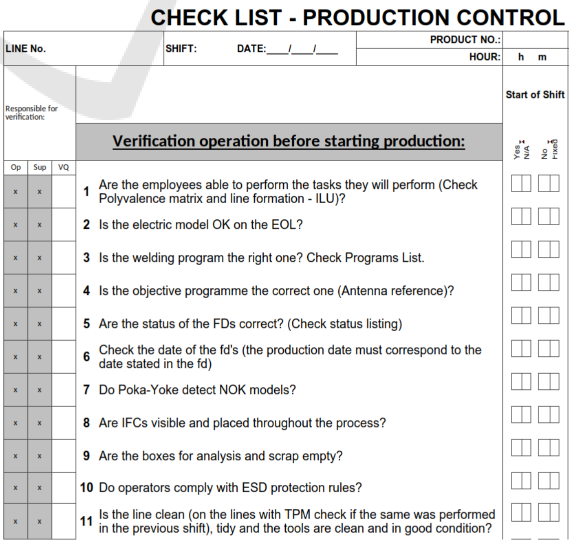
Finally, digital checklists can integrate with workflow management tools, enabling seamless coordination of tasks related to the checklist completion process. For example, if an issue is identified during the checklist, the system can automatically generate work orders or trigger notifications to initiate maintenance actions or escalate the problem to relevant personnel. This is also related to documentation and reporting, where information systems can store completed checklists, maintaining a comprehensive record of maintenance activities or production changes. This historical data can be accessed and reviewed at any time for auditing purposes, performance analysis, or compliance requirements. The system can also generate reports summarizing checklist completion rates, and identified issues, or trends over time, aiding in decision-making and continuous improvement efforts.

3 PROPOSED SOLUTION

An information system is proposed to enable a paperless ramp-up checklist. This helps promote the fluidity of the information flow and facilitates communication between operators and supervisors when managing ramp-up checklists. The proposed digital-format checklist considers a specific use case in the Portuguese industrial company Continental Advance Antenna (CAA) (Continental, 2023).

3.1 Industrial Use Case

CAA has extensive experience in R&D activities related to new functional features in terms of connectivity for antenna systems in motor vehicles. CAA is one of the big players in the automotive sector and one of the most important industrial companies in Portugal, producing 20 million antennas per year. In its shop floor production flow, there is a final production stage where the Printed Circuit Boards (PCBs) are individualized and the final assembly is completed. Typically, each type of antenna produced for specific clients has a dedicated assembly line, which can work in multiple work shifts. A paper-based ramp-up checklist is represented in Fig. 1.


CHECK LIST - PRODUCTION CONTROL

LINE No. SHIFT: DATE:___/___/___ PRODUCT NO.: HOUR: h m

Responsible for verification: Start of Shift

Verification operation before starting production:

Op	Sup	VQ	No.	Item	Yes	N/A	No	Fixed
x	x		1	Are the employees able to perform the tasks they will perform (Check Polyvalence matrix and line formation - ILU)?				
x	x		2	Is the electric model OK on the EOL?				
x	x		3	Is the welding program the right one? Check Programs List.				
x	x		4	Is the objective programme the correct one (Antenna reference)?				
x	x		5	Are the status of the FDs correct? (Check status listing)				
x	x		6	Check the date of the fd's (the production date must correspond to the date stated in the fd)				
x	x		7	Do Poka-Yoke detect NOK models?				
x	x		8	Are IFCs visible and placed throughout the process?				
x	x		9	Are the boxes for analysis and scrap empty?				
x	x		10	Do operators comply with ESD protection rules?				
x	x		11	Is the line clean (on the lines with TPM check if the same was performed in the previous shift), tidy and the tools are clean and in good condition?				

Figure 1: Example of a Paper-based Ramp-up Checklist in CAA.

The ramp-up checklist in CAA is a document that must be compulsorily and carefully completed at the beginning of each shift, at each reference change, and after prolonged maintenance/process intervention or quality problem. This document is intended to verify that all requirements for production are in accordance with the criteria required for the start of production. Currently, this checklist is a document filled in manually by the operators in a paper format making it a time-consuming process and susceptible to human errors. The main checkpoints of this checklist are:

- ILU: This consists of a 3-level system for measuring the qualifications of production operators (I - Basic qualification level; L - Operator who is capable of producing with quality; U
- Operator who is capable of producing with quality and at the pace defined for the assembly line on which it is assessed).
- Electric models: A binary test of the electrical model at the end of the assembly line assessed. The test passes if the result is OK.
- Welding program: In the welding robots, the operator must check if the welding program loaded in the robot is the correct one for the reference antenna being assembled.
- Preventive maintenance: For preventive maintenance purposes, there is an established number of assembled pieces as a threshold. This test assesses if the threshold number of assembled pieces for preventive maintenance was reached.
- Hot melt: The operator must know the injection process and its adjacent equipment in order to check the operating mode of the machine and the state of the injection material.
- Welding: To validate this point, the operator must know the documentation and associated procedure for replacing soldering nozzles, check if nozzle temperature is within limits, check if smoke extractors are working, nitrogen levels, and reservoir of water.
- Screwing: To validate this point, the operator must know the exchange history of the screwdriver and check the torque of semi-automatic screwdrivers.
- Ultrasounds: To validate this operation, the supervisor must check the pressure in the ultrasound nanometer.

3.2 Paperless Checklist

The developed information system is supported in Python programming language and the Flask framework (Lokhande et al., 2015; Grinberg, 2018), which allows CAA's operators and supervisors to manage the ramp-up checklist in a completely digital way. They can visualize and edit the available information in an efficient manner, while being managed and persistently stored in a database. Access to the system is made through a general login, where operators and supervisors have different visualization perspectives.

This type of authentication allows a clear definition of the company's hierarchy and conditioned access to the system, depending on the type of information that each operator is expected to access, and presupposes the completion of the respective fields to the email and password, previously registered in a database associated with the system which ensures security and restricted access to the system. In this way, operators are responsible for verifying the parameters in the checklist, while supervisors intervene in case of issues in the production line that do not allow the production to start.

Regarding operators, the homepage displays the initial parameters of the checklist, that correspond to the pre-start scan of production operations, as represented in Fig. 2. On this page, each date-time field has associated two queues of checkboxes, one queue for the parameter *S* (Verified), and *N* (Unverified). The state of these checkboxes is maintained regardless of the update or page change, providing intuitive functionality for time selection.

When the operator wishes to make an observation, mainly when there are unverified parameters, a separate page is displayed where he is asked to choose the parameter and make the observation. This way, all stakeholders can be notified, in order to resolve the issue and verify successfully the parameter. If the production flow follows its normal course, the operator is also required to check operations after the start of production. Finally, with all the parameters of the checklist validated, the operator is required to validate the checklist. This validation should also be performed by the supervisor responsible in that shift.

The supervisor's homepage includes a listing of all daily checklists, with the respective indication if it has been validated by the respective operator. Each checklist is associated with a specific shift and the operators working in that shift. Moreover, the supervisor can edit the list of operators registered in the system, according to his working shift and workstation within the production line. Finally, supervisors have access to all the parameters registered in the system, having the possibility to edit, delete and add parameters, while editing and creating new checklists as well.

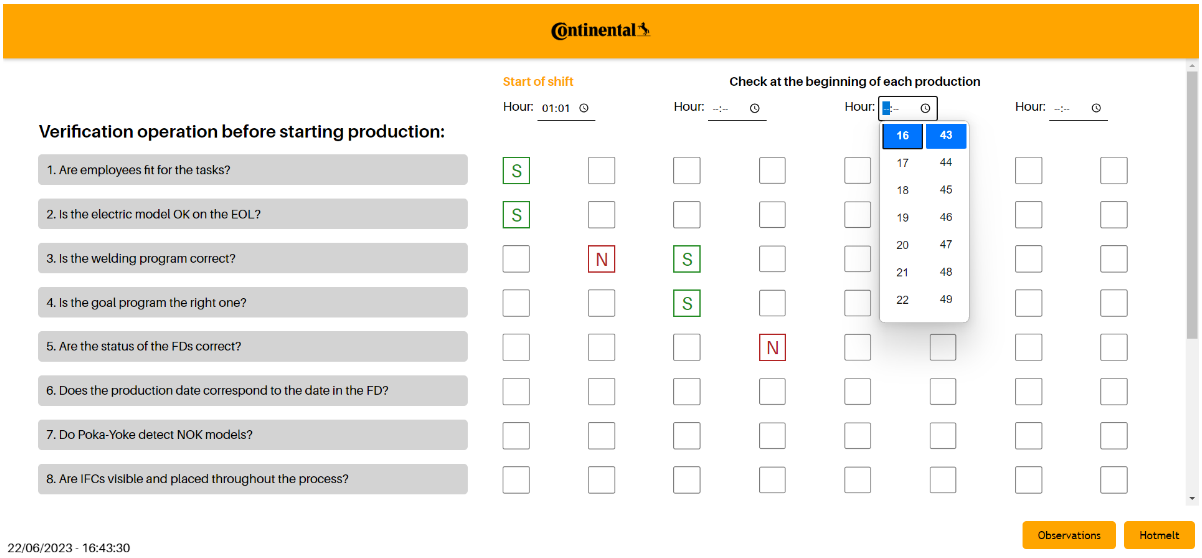


Figure 2: Operator's Checklist View.

3.3 Information Management

As mentioned before, the information system must allow the overall management of users, considering the type of employee (operators and supervisors) and the workplace within the production line. Also, the information system must manage shifts and the daily ramp-up checklists that are associated with specific shifts. Each ramp-up checklist contains multiple parameters to be validated. The system must allow feedback records when there is a problem in a productive process and a parameter is unverified. Both operators and supervisors have access in real-time to this feedback for quick reaction to solve the problem.

Considering the previously identified system requirements, Fig. 3 despites the information model in the format of system entities and their relationship. The system entities are:

- Employee: An employee can be an operator or a supervisor, and is characterized by his name, email and password for registration and login, workplace and production line.
- Work Role: Each employee is associated with a role in the company.
- Work Shift: A work shift is a set amount of time that an employee is expected to work, thus it has a start and end date-time.
- Production Line and Workplace: A production line consists of multiple workstations. Depending on the role of the employee, he can develop his work in a specific workplace within the production line.
- Checklist: The ramp-up checklist is characterized by start and end date times that are related to the beginning and wrap-up of the validation process. Each checklist is associated with a work shift, and specific employees responsible to perform and manage the validation.
- Parameter and Validation: Each checklist consists of multiple parameters to be validated. Moreover, the validation of a parameter is associated with a data-time.

4 EXPERIMENTAL RESULTS

The validation of the proposed solution follows a descriptive approach, considering the specific use case of CAA. To answer the research questions, we gather detailed information on the current processes at the shop floor level for ramp-up checklist management, and how these are affected by implementing paperless practices.

Most of the data to validate the proposed approach was qualitative in nature, and it was collected through interviews, field observations and informal field conversations with different employees from CAA. The data was collected mainly through semi-structured interviews, where a set of questions and topics were prepared in advance. The interviews were conducted with the main stakeholders, i.e., CAA employees who were either involved in planning the implementation of paperless practices or whose current tasks were affected by the proposed approach. The set of questions that were used in the interviews is enclosed next.

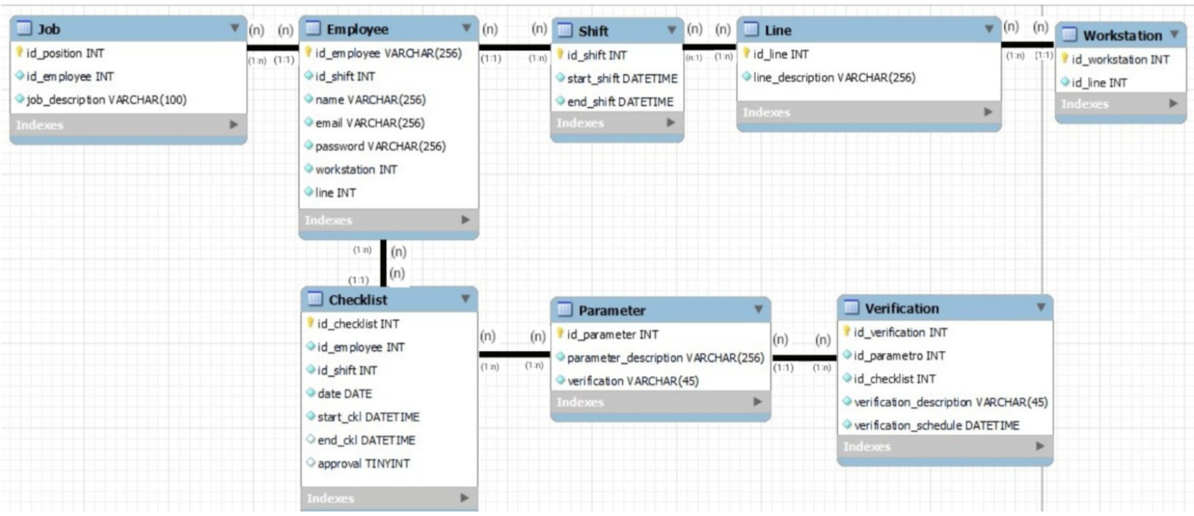


Figure 3: Checklist Relational Model.

Question 1. What is your role in CAA and how are you involved in the paperless checklist?

Question 2. Have you already had experiences regarding a shift towards paperless practices before?

Question 3. What does the collaboration between the different stakeholders look like when managing the ramp-up checklist?

Question 4. What impact does the implementation of a paperless checklist has in terms of information flow and the respective workflow?

Question 5. What are the main challenges for a transition from a paper-based towards a paperless checklist?

Question 6. In what ways does the implementation of a paperless checklist change your working tasks?

4.1 Analysis of Results

Most of the employees interviewed are supervisors of assembly lines, responsible for the continuous improvement of manufacturing processes and project managers. These employees are mainly associated with production, checklist monitoring and editing. They didn't have experience in the past with process digitalization and paperless practices before.

According to the interview feedback, currently, the paper checklist is provided in the assembly line by the supervisor to the operators working in that shift, which will verify all the parameters. Unverified parameters are reported immediately to the supervisor, who has to go on-site to the assembly line and, together with the operators fix the problem. Eventually, depending on the problem verified, other employees from maintenance or other departments must be requested on-site. After the validation of all parameters in the checklist, both operator and supervisor sign the checklist for an archive.

The feedback received regarding the developed information system was predominantly positive. Several positive aspects were observed, such as a remarkable improvement in the storage and organization of checklists, enabling more efficient retrieval of different checklists and parameters, resulting in time savings and increased productivity. Additionally, this system allows for integrating new functionalities, such as filtering various parameters, visualizing shifts and workers across different production lines, and real-time monitoring of digital checklists. Furthermore, it facilitates checklist validation, as in the physical format, these must be delivered to different employees for final approval, thus improving task collaboration among various stakeholders.

The main impacts of a digital checklist are:

- Elimination of paper;
- Supervisor avoids moving around to be on-site;
- Supervisor can consult updated information in real-time;
- Supervisor has easy access to the history of checklists.

However, some challenges were observed, including resistance to change from certain employees who were more accustomed to the traditional method. Transitioning to a digital checklist may require a period of adjustment and training for employees, especially those who are not familiar with technology or have limited computer or mobile device skills. It is essential to address this resistance through effective change management strategies, including clear communication, training programs, and providing ongoing support to employees during the transition period. Moreover, another challenge is the prototyping stage, where both paper and paperless checklist systems will be used for a smoother transition. This stage requires additional management effort.

In addition to the positive aspects mentioned, the developed information system also offers several other advantages. One significant benefit is the reduction of errors and inconsistencies in checklist completion. With the digital system, mandatory fields can be implemented, ensuring that all necessary information is entered correctly. Automated validation checks can be performed to identify any missing or incorrect data, reducing the likelihood of human errors, and improving overall data accuracy. Furthermore, the system provides enhanced data security and confidentiality. Physical checklists can be misplaced, damaged, or accessed by unauthorized individuals, compromising sensitive information. In contrast, a digital system can implement secure access controls, encryption measures, and regular backups to protect data integrity and confidentiality. This adds an extra layer of security to the information and reduces the risk of data breaches.

The system also facilitates remote access and collaboration. With a digital checklist system, authorized personnel can access and work on checklists from anywhere. This enables employees to complete tasks and collaborate on checklists even when they are not physically present at the workplace. Another advantage is the potential for data analysis and reporting. A digital checklist system can generate comprehensive reports and provide valuable insights into productivity, efficiency, and compliance. Analyzing data trends and patterns can help identify areas for improvement, optimize processes, and make informed decisions. The availability of historical data also enables better tracking of performance over time and facilitates auditing and regulatory compliance.

5 DISCUSSION

Considering the qualitative validation and the results found, we have conditions to answer the research questions. Regarding RQ 1., the utilization of the digital checklist allowed for the measurement and analysis of various parameters to assess the extent of its effects. The study's findings suggest that the implementation of the digital checklist positively influenced information processing and ramp-up checklist management. The digital system streamlined the data collection process, enabling real-time monitoring and analysis of key metrics. This increased efficiency was evident in the reduction of data entry errors, quicker access to relevant information through provided filters, and accelerated decision-making in the case of production line errors or overall system optimization.

Moreover, the flexibility of the digital checklist facilitated prompt adjustments to the production processes in response to changing requirements. Regarding quality aspects, the digital checklist exhibited benefits by providing more accurate, consistent, and practical data inputs. This resulted in improved product quality by better tracking process parameters and detecting anomalies at an early stage. As a result, transitioning to a paperless approach enhanced efficiency, flexibility, and process performance quality.

As for RQ 2., this research delved into the broader implications of adopting a digital checklist system within the context of information processing requirements and capabilities, information flow, and the operational workflows of the production line. The introduction of a digital checklist significantly redefined the landscape of information processing requirements and capabilities. By leveraging digital tools, the production line gained the ability to process and analyze data in real-time, enabling rapid identification of trends and deviations. The features introduced led to a more proactive approach to decision-making, as insights based on collected data could be promptly applied. The digital checklist also influenced the information flow within the production lines.

Furthermore, the adoption of a digital checklist prompted a transformation in the working processes. Traditional paper-based tasks were replaced by digital interactions, reducing manual efforts and associated errors. Collaborative efforts were streamlined through digital interfaces, allowing for quicker coordination and problem-solving among team members and supervisors. Consequently, the overall working processes exhibited greater efficiency and adaptability. In conclusion, the shift towards a digital checklist had a profound impact on information processing requirements and capabilities, information flow, and working processes. These changes collectively contributed to an enhanced production environment.

6 CONCLUSIONS

This study proposes a paperless checklist to manage equipment information and monitor production ramp-up in the CAA industrial context. The proposed solution validation focused on a comparison with the current paper-based approach, to assess system advantages and limitations while understanding the impact and challenges of the solution implementation in terms of information flow and employee working tasks.

Overall, despite the challenges, the positive feedback and benefits observed in the developed information system indicate its potential to significantly improve productivity, collaboration, data integrity, and decision-making processes within the organization. It is important to address the challenges through effective change management strategies and provide necessary training and support to employees to ensure a successful transition to the digital checklist system.

On the contrary to supervisors, despite the working tasks of operators not being greatly impacted, in future work, we want to extend the interviews for the operators, since their feedback is missing in this study. Also, from a change management perspective, it is intended to provide the necessary hard and soft skills training for a successful transition.

ACKNOWLEDGEMENTS

This work was supported under the Mobilizing Agenda "A-MOVER - Development of Products & Systems towards an Intelligent and Green Mobility", supported by the PRR-Recovery and Resilience Plan and the European NextGeneration EU Funds.

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