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Predictive maintenance issues and solutions for SMEs – a case study solving a joinery

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A B S T R A C T

Many SMEs are characterised by working with older machines that are not Industry 4.0 compliant and that try to meet the qualitative and quantitative standards that the market expects. The machine maintenance strategy and its implementation significantly impact the company's profitability. The research aims to define maintenance and adjustment processes that are difficult to predict and determine their execution times. In the framework of a case study, we analysed maintenance and adjustment processes in an SME that have a high impact on production quality, but the prediction of which is not solved. During the research, we created a mobile application-based microservice suitable for predicting the due dates of these maintenance tasks using historical data. Based on interviews with employees, they became more confident, motivated and engaged. Overall, it can be declared that mobile application-based microservices may be, based on our experience, an effective tool for improve the production quality of SMEs and extend the production life of less advanced machines. In addition, the reduction in the number of complaints led to cost savings and more predictable production. We also found that the application can be easily adapted to other machines, thus further increasing the digital maturity of the SME.

Introduction

In Hungary, micro, small and medium-sized enterprises (SMEs) play a significant role both economically and in terms of employment. They are vital to the development of economies through job creation(KSH, 2024). Given their importance, understanding the skills present in businesses and the challenges they face is essential. Although SMEs are primarily active in the service sector, their presence in manufacturing is also significant in many respects (KSH, 2024). These companies must learn about and adopt new technologies in order to be able to adapt to dynamically changing environmental conditions, thereby ensuring their long-term competitiveness. At the same time, the Fourth Industrial Revolution presents significant challenges to companies operating in the primary sector. Keeping pace with the continuous transformation of technological systems, organizational processes and management systems is very difficult for a certain corporate sector that typically lacks sufficient capital and human resources. Digital tools and technologies such as (Droec et al., 2019; Horváth & Szabó, 2019) IoT and AI are increasingly automating routine tasks, reducing the need for manual intervention and minimizing human error (Masood & Sonntag, 2020). Digitalization enables more flexible production lines that can be quickly reconfigured to produce different products or meet changing demands. These tools also optimize resource usage, reduce waste, and lower energy consumption, contributing to more sustainable manufacturing practices. In Hungary and across many other regions of Europe, SMEs often suffer from a lack of capital, human resources and knowledge, so they cannot acquire the most modern equipment in production, but often have to cope with their older, existing equipment, still they need to keep up with the increasing quality requirements. In some cases, it is possible to equip machines with IOT devices with retrofit sensors, which are suitable for providing useful data (Adu-Amankwa et al., 2019a; Nagy et al., 2018). To increase the efficiency of the production process, proper maintenance of machines is

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essential for continuous operation and high quality (Nallusamy, 2016). Among various maintenance strategies, it is crucial to select the one that most effectively aligns with the company's goals. By analysing machine data, predictive maintenance can be implemented, which reduces downtime and maintenance costs by anticipating and addressing issues before failures occur (Shagluf et al., 2015). However, certain maintenance tasks remain challenging or impossible to automate due to their complexity. In such cases, predictive maintenance methods can forecast potential problems based on the analysis of real-time and historical data, enabling timely interventions. In this article, we present a microservice integrated into a mobile application as a case study. This microservice is capable of predicting three critical maintenance tasks in advance using available data.

Literary adaptation

Situation of SMEs

The number of SMEs in Hungary is close to 650 000, employing approximately 70% of the workforce (KSH, 2024). Their survival and development is therefore crucial for the Hungarian economy. They operate in an economic environment characterized by both opportunities and challenges. The SME sector has faced many obstacles in recent years, including the COVID-19 pandemic, supply chain disruptions, and the economic impact of Russia's war against Ukraine. Despite these challenges, signs of resilience and adaptation are evident within the sector. Similar to the European Union, local governments encourage SMEs through financing and policy measures to promote innovation, digitalization, and the transition to a green economy (Lóga Máté, 2019; Poór et al., 2024). However, SMEs in Hungary continue to face significant obstacles, particularly in terms of access to funding and skilled labour. This problem is further compounded by the relatively low levels of digital transformation and innovation within many SMEs, hindering their competitiveness on a broader scale (Bánhidi et al., 2023).

Digitalisation

Digitalization in manufacturing offers numerous advantages as it transforms the traditional processes by integrating advanced digital technologies. Digital tools and technologies, such as IoT and AI (Kroll et al., 2018; Morelli et al., 2020) automate routine tasks, reducing the need for manual intervention and minimizing human error. Advanced sensors and data analysis enable real-time monitoring of equipment and production processes, allowing for immediate adjustments to enhance efficiency. Continuous monitoring of production processes ensures that products consistently meet quality standards (Belli et al., 2019) Digitalization also enhances communication and coordination across the supply chain, increases overall efficiency, and supports data-driven decision-making. The adoption of digital technologies enables manufacturers to remain competitive by leveraging the latest innovations and continuously refining their processes (De Vass et al., 2021).

SMEs and Industry 4.0

Many SMEs operate with older machines that do not comply with Industry 4.0 standards, but are still trying to maintain the quality and quantity levels expected by industry (Ludwig et al., 2018). To address these challenges, they often retrofit older machines with digital solutions to extend their lifetime According to Müller et al. (Müller et al., 2018) one effective approach is to equip older machines with sensors and IoT devices, which allows real-time data collection on machine performance, operating conditions and efficiency. Hadjiski explains that installing sensors to monitor critical components, such as vibration and temperature, allows for predictive maintenance, reducing failure risk, minimizing unplanned downtime, and extending the life of the machine (Hadjiski et al., 2014). The data collected through these sensors supports production optimization and efficiency improvements through feedback loops (Adeyeri, 2018; Catenazzo et al., 2018). Studies indicate that digitalizing Industry 3.0 machines is often more cost-effective than acquiring new equipment, while also making them compatible with newer technologies and creating an integrated production environment. This approach enables capitalconstrained SMEs to enhance production capabilities and stay competitive in a fast-evolving market without substantial investment.

Maintenance

Scientific research (Hadjiski et al., 2014; Pejić Bach et al., 2023; Rastogi et al., 2020) and industrial practice have long been concerned with maintenance and maintenance management. Among the various maintenance cases, the four most important are corrective maintenance (CM), preventive maintenance (PM), predictive maintenance (PdM) and cyber-physical maintenance (CPM). CM is maintenance that is reactive to failure and usually has a very significant cost implication PM tries to avoid imminent failure problems by performing scheduled maintenance. PM is seen as a value-adding activity. Although, like CM, PM can cause irrelevant downtime and can affect the LCC (Life Cycle Costing) of the equipment (Kokare et al., 2023). PdM is a proactive process of performance modelling and conditional monitoring. PdM can be identified as an activity to improve productivity, product quality and overall manufacturing efficiency through the systematic monitoring of equipment operating conditions. The rapid development of predictive sciences, with prognosis as a valuable tool, is useful in predicting the MT lifetime and this leads to an effective maintenance strategy. CPM, extending predictive maintenance (PdM), is an intelligent maintenance approach based on the interconnection of the digital and physical worlds. Thanks to the opportunities offered by industrial IoT and big data, CPM enables real-time monitoring of the condition of machines and systems and the prediction of potential failures.

The unpredictability of maintenance processes can pose significant challenges for the maintenance of SMEs (Reis & Gins, 2017), which affect productivity, costs and operational efficiency. Sudden equipment breakdowns can lead to unplanned downtime, halting production and causing delays. Unplanned maintenance often involves emergency repairs that are more expensive than planned maintenance. Unplanned maintenance requires immediate attention, diverting resources from other planned tasks. Reactive maintenance can lead to poor asset management, which reduces equipment lifetime. Newer maintenance strategies can detect or predict most failures. With proper training of human resources, maintenance staff can be trained in the latest maintenance technologies and techniques (Flores et al., 2020; Shamim et al., 2016). In addition, significant efficiency gains can be achieved by involving all stakeholders in the planning and implementation of maintenance. By adopting these principles, SMEs can mitigate the challenges posed by unpredictable maintenance processes, ensuring smoother operations, greater safety and cost savings (Adu-Amankwa et al., 2019b). Points can be identified that cannot be monitored by sensors, maintenance needs cannot be accurately planned in advance (Pech et al., 2021), so a different approach is needed in such cases.

Material and method

At the beginning of the research, we reviewed the relevant literature on digitisation and maintenance practices within the Hungarian SME sector. Subsequently, we examined the maintenance strategies applied by a selected SME in the manufacturing sector. During our investigation, we identified several maintenance and correction processes that were performed on an ad-hoc and unplanned basis. The primary reason for this lack of planning is the inability to predict failures effectively. In addition, feedback is often significantly delayed and in some cases missing altogether. Historical data can provide valuable insights to address such issues. To facilitate the collection of this data, we developed a mobile application. The analysis was carried out using mobile based server-side scripts because 60% of internet applications are accessed via mobile devices, while only 40% are accessed through computers (Zhang et al., 2024). This ratio is gradually shifting further in favour of mobile devices, underlining the need for development efforts to keep pace with this trend. Our analysis is performed daily and maintenance recommendations are generated based on the collected data.

Selected SME and maintenance processes

The enterprise employs 35 people. For more than 30 years they have been involved in furniture manufacturing and trading in the furniture industry. According to preliminary studies, the digital readiness of the enterprise is high in the areas of production, trade and management. They have most explanatory variables of the index measuring digital maturity. They have a website, web shop, email communication, and are also present on social platforms. They also have ERP and CRM systems to support management, sales and production. Their cloud-based collaboration support system helps them work efficiently. They can also issue and receive electronic invoices. They can and usually do hold online meetings both inside and outside the company. IT security is supported by VPN, multi-level authentication and multi-localization data backup, multi-layer firewall, and active information security policy. The machines used in the production steps are CNC machines, which are connected online both with the production preparation and with the company providing support. From recruitment to the production of the finished product, an efficient flow of information is ensured. For all these reasons, the researchers, together with management, concluded that the IT maturity of the company is high.

Planning machine maintenance has always been a pivotal point in the life of companies. After all, in addition to willing to extend the operating time of the machine as much as possible, they would like to spend the least amount on maintaining them. In the case of SMEs, it is typical that the machine usage times are higher than in countries with more developed industries. This business, employ both corrective and preventive maintenance methods. Only two of their machines have suitable sensor systems for predictive maintenance. In this industry, where competition in the market is very significant and the value of allowable tolerances is small, it is only possible to stay on the market with very well-adjusted and maintained devices. Based on customer feedback, we identified critical devices. We found points that constantly need special maintenance (adjustment and cleaning) (Figure 1), but difficult to predict. Since the efficiency of the extraction system, the unwanted displacement of the side beam is influenced by many factors. The cutting width of the cutting wheel also varies very little. The need for these settings, with the exception of the third, cannot be planned in advance in traditional ways. In addition, this is not always a problem for semi-finished raw materials. Inaccuracies mainly occur when cutting lots of small boards or high boards. Another complicating circumstance is that the semi-finished workpieces are used later, by several days or weeks. In addition, of course, the maintenance tasks are not necessarily related to the team who cut the table with the size defect, but it making timely interventions difficult. This complex problem (Figure 1) was solved with the help of data analysis, for which we created a mobile application.

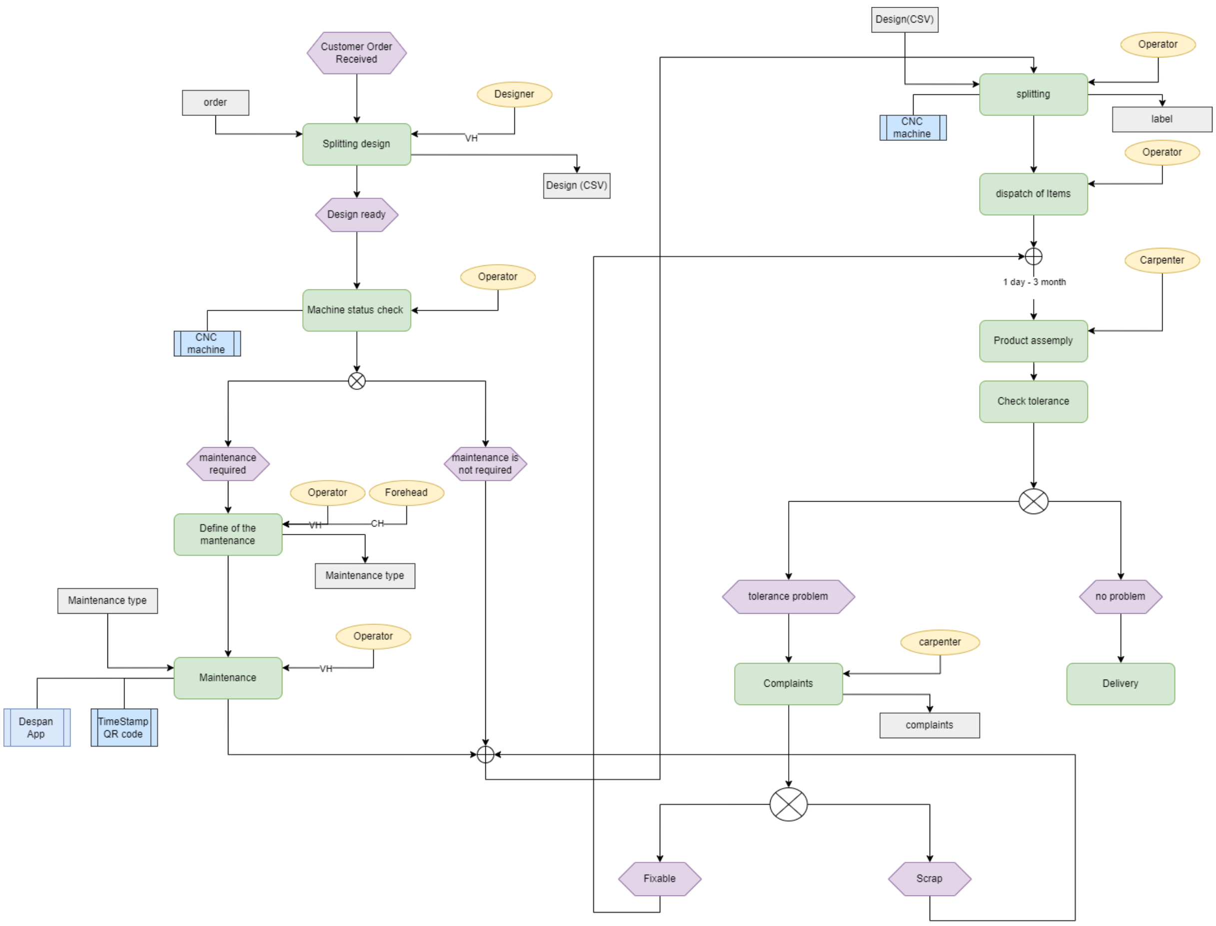

Figure 1 Analysis of the operation of the process

Source: *Self-edited, 2024*

Qualitative Research - Interview

The researchers intend to present the results around qualitative forms of data collection in the framework of a semi-structured interview. The reason for this is that we do not have a perfect database from before the introduction of the application. The already introduced application was examined at the level of machine operators, managers and customers. The interviewees were interviewed based on a threaded guided question, but in a freer form. This method of questioning is one of the most commonly used methods besides group techniques. It focuses heavily on the opinions and expressions of individuals, so any negative experiences that may arise can surface more freely. The respondents received exactly the same questions, but in some cases their order may have been reversed during the discussion. This ensures that respondents are not stressed when answering and can even compare categories. Our goal was to find and explore the differences in perspective that arise from the different perspectives of management, employees and users. As well as differences in the flow of information, or lack thereof, that we would not have obtained with a questionnaire survey.

When designing interviews and questionnaires, possible ethical concerns were carefully considered. Participants were informed about the purpose of the research and confidential issues during the sampling process, and if they had any concerns before the study or during the interview, they were free to withdraw from the research at any time. All names in this article have been replaced with code, and the analysis and final conclusions do not contain any identifiable personal information. CEO code refers to SME manager, foreman to operator1 and operator2 to operators, while cstmr1 and cstmr2 to customers. We interviewed the latter two primarily about their experiences with the impact of the rollout.

Outcomes

The completed mobile application

We developed a mobile application based on the observation that mobile phones are always readily accessible to everyone. Having a dedicated app conveys a sense of innovation, whether it is intended for internal use or for engaging with customers. In our case, the app was designed for internal use, addressing specific limitations of the CNC machines used in production, which only allow for administrator and user accounts. This limitation prevented a personalized connection through the built-in BAR/QR code reader.

The application is utilized by three distinct groups: **machine operators**, **foremen**, and **senior management**. Consequently, it was essential to design the interface to be intuitive, user-friendly, and adaptable to the needs of all user groups, ensuring a seamless experience for each role. The operational processes are illustrated in the flowcharts in Figure 4 below.

Figure 2 Maintenance QR codes

Source: *Self-edited, 2024*

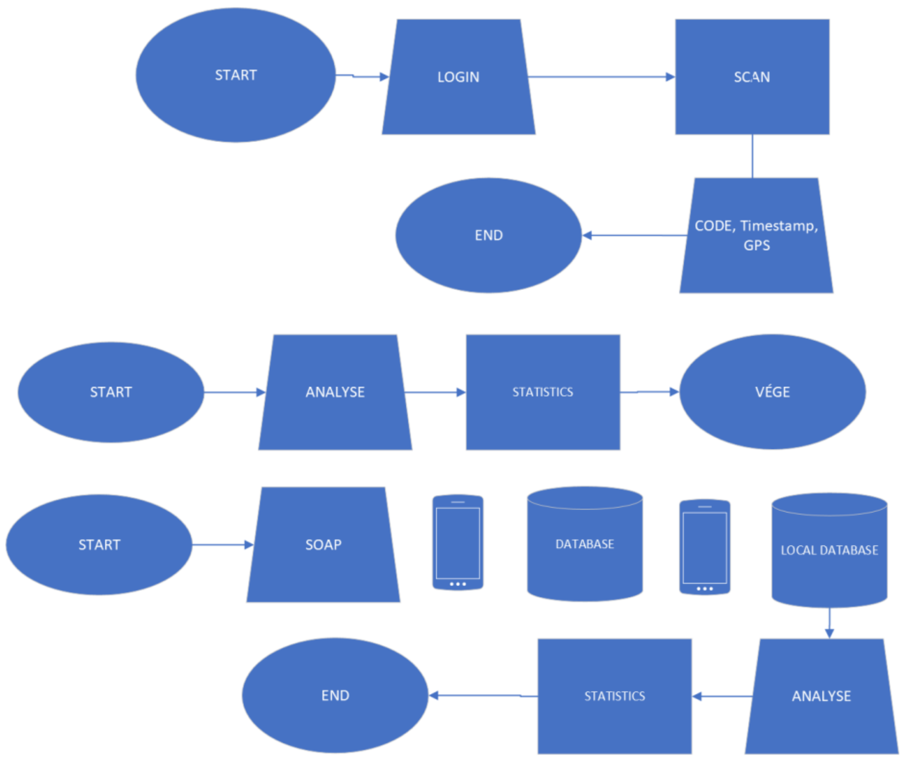

Figure 3 The operational processes

Source: *Self-edited, 2024*

Each employee is required to log in to the application once to gain access. The **operator's role** is to use the application to scan the QR code assigned to the machine immediately after completing the maintenance tasks, such as adjustments or cleaning. Each machine has a unique QR code for every maintenance task, which is affixed to the side of the machine for easy access.

The **foreman's responsibility** is to verify the maintenance operation. After inspection, the foreman must scan the same QR code using their mobile phone, thereby confirming and approving the completed maintenance.

Management receives comprehensive reports on all maintenance activities. These reports can be reviewed directly within the application or received as email summaries.

All data is stored in a server-side database, where it is analyzed daily using the formula illustrated in Figure 3.

$$\sum_{a=0}^{x}(T_a - T_{a-1}) * \sum_{t=0}^{3}\frac{Vh_t * \mu_t}{Vh_t} * \frac{1}{x-1} * C_{comp}$$

x= Number of periods
TA= Setting time
Vh = Cutting length
t = Type of material
μ = Substance factor
Ccomp= Complaint

Before implementing the application, it was challenging to accurately track who performed the three maintenance operations and when. In cases of customer complaints, identifying the responsible party was difficult. If the issue required recutting, it could result in significant additional costs. The application now determines the need for maintenance based on historical data. If a task is overdue by 10% of the scheduled time, an alert is sent to all three groups: operators, foremen, and senior management. If the delay reaches 15%, a follow-up alert is issued, and this process continues until the maintenance is completed. Once the operator performs the maintenance, the foreman must verify and confirm the task. If the verification is not completed within two days, a warning is sent to senior management, which will persist until the check is finalized. Although the foreman was responsible for this process before the application's introduction, interviews revealed that due to consistent heavy workloads, these checks were often neglected. Since the application's implementation, these tasks are consistently completed. This improvement can likely be attributed to the continuous feedback and reports sent to senior management, which create accountability and ensure follow-through. The system is also beneficial for operators, allowing them to monitor the frequency of maintenance for each machine. Moreover, the alerts sent to management foster a more proactive approach among operators, as they understand that maintenance activities are closely monitored and emphasized.

Examination of the usefulness of the program

Before the introduction of the application, operators relied solely on their experience and judgment to determine when to perform maintenance tasks. This often meant that maintenance was only carried out reactively—for instance, during sheet cutting, if it was discovered that the cut size had fallen outside the acceptable tolerance range. By this point, the issue may have already persisted for several days, potentially affecting production quality and efficiency.

The implementation of the application has resulted in more frequent maintenance activities. These tasks are now systematically monitored and verified, with alerts sent to the foreman to ensure follow-through. The continuous flow of data, which extends to the management level, has also fostered a greater sense of responsibility and diligence among both operators and foremen.

The thematic structure of the interviews conducted is outlined below. Table 1 presents a summary of the interviewees' IT preparedness, work experience, software knowledge, and their assessment of the administrative burden associated with their respective roles or tasks.

Table 1 IT knowledge assessment and application assessment

Question area	CEO	Foreman	Operator1	Operator2	Cstmr1	Cstmr2
Assessment of IT knowledge (1-5)	4	2	1	1	NR	NR
Experience in the company/gel	32	20	4	2	NR	NR
ERP usage	Yes	No	No	No	NR	NR
Office software knowledge	High	Medium	Low	Low	NR	NR
Administrative burden	High	High	Neutral	Neutral	NR	NR
Perception of innovativeness	Positive	Positive	Positive	Positive	Positive	Positive
Application assessment	Positive	Positive	Positive	Positive	Positive	Positive

Source: Self-edited, 2024

It can be observed from the table above that IT knowledge within the company is perceived as being strong only at the management level. Other employees possess only the basic IT skills necessary for their work. The manager, who has been with the company for nearly thirty years, and one of the administrative staff, who has eighteen years of experience, have considerable IT knowledge. Meanwhile, the Gen Z employee, who has been with the company for two years, has a different perspective. The company's partners have also worked with the company for several years.

Regarding the use of ERP systems, nearly all respondents engage with some type of software daily. Their proficiency with office software is generally considered above average, with the exception of an external partner company. When evaluating their administrative workload, the manager, the senior administrative colleague, and one partner company were neutral. This neutrality stemmed from the lack of a benchmark to compare their workload to that of other companies, which was revealed by further questioning.

The younger colleague, however, expressed a distinctly negative view of their administrative burden, describing it as monotonous and boring. As he put it, "I don't like working after others, especially when it's unnecessary and could be done more simply." A similar negative response came from the employee of the second company, who attributed his dissatisfaction to the mistakes he forgets to report. Despite these critiques, they believe the company is innovative, a belief confirmed by the introduction of the mobile application.

Finally, the overall perception of the application was positive, except for one individual, a Gen X employee. His reason for this negative perception was that he no longer enjoys replacing old, proven systems with new ones. As he put it, "Personal relationships are more important to me."

The following section explores the sense of usefulness of the application, with the detailed results presented in the next table.

1. Table What is the general perception of the application in terms of usefulness?

CEO	*"I am up to date with the CNC machine with very little time"*
Foreman	*"The phone warns me until I check maintenance so I don't forget" "Re-cutting and reducing repairs allow you to avoid constantly interrupting your normal session."*
Operator1	*"Everyone's work is finally being followed, and it's not just one person doing maintenance."*
Operator2	*"It's easy to handle. It gives you extra work, but if there are fewer complaints, it's worth it."*
Cstmr1	*"If the app reduces the amount of inaccurate raw materials, it saves us a lot of man-hours."*
Cstmr2	*"All companies are struggling with this problem. That's why I left here and came back. I hope they can maintain this quality in the long run."*

Source: Self-edited, 2024

In terms of utility, it can be said that, overall, the application is considered useful by all participants. In their repeated feedback, they highlighted its innovative nature, time-saving benefits, and the reduction in complaints. The operators noted that a recurring problem, which had persisted for several years, was finally solved. The foreman emphasized the increase in predictability during production. Perhaps the most significant feedback came from customers (carpenters), who appreciated the reduction in unnecessary overtime. With such a development, we not only enhance internal motivation and commitment among employees but also strengthen our image and brand in the eyes of external partners by offering 21st-century solutions.

Conclusions, proposals

The application was tested in a production environment, making its use mandatory for employees. Based on our observations, we are now investigating the possibility of successfully extending its implementation to other CNC machines. The application has created a complete vertical data flow, which did not exist previously. Analysis of the data generated by the application shows that the use of feedback systems increases employees' confidence in their work. During the interviews, we focused on understanding the sense of usefulness and challenges from each participant's perspective. We found that all testers and customers at the company, even those who did not directly use the application but were aware of its impact, were also satisfied with the implementation. All three levels of the company—management, foremen, and operators—identified positive aspects of the application.

Confirmation is vital for every employee, and the app provides feedback that assures them they are performing their tasks correctly. An indirect benefit is that, with its own mobile application, the company strengthens its brand image as an innovative employer. Based on the results and user feedback it is clear that with relatively little effort, the operating time of the company's non-Industry 4.0-compliant machines and the quality of products manufactured using these machines can be significantly improved.

Personalized mobile applications can enhance the degree of digitalization in micro-enterprises and improve their chances of survival.

Among the limitations of this research, it is important to note that these results apply specifically to the SME in question, considering its work culture. However, the findings offer valuable insights for the sector as a whole. Another limitation is that the selection of SMEs for this study was influenced by their willingness to cooperate once the parameters were defined. One of our suggestions for future research is to compare similar developments across SMEs with different profiles. Overall, it can be concluded that the unique mobile application used by the selected SME has had both direct and indirect positive effects on the company and its employees.

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