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Digital Standardization of Lean Manufacturing Tools According to Industry 4.0 Concept

Daniel Medyński [1], Piotr Bonarski [1,2], Piotr Motyka [1], Adam Wysoczański [1,2,3], Renata Gnitecka [1,4], Krzysztof Kolbusz [1], Magdalena Dąbrowska [1], Anna Burduk [5], Zdzisław Pawelec [1] and José Machado [6,*]

1 Department of Production Engineering and Logistics, Faculty of Technical and Economic Sciences, Witelon Collegium State University, Sejmowa 5A, 59-220 Legnica, Poland; daniel.medynski@collegiumwitelona.pl (D.M.); piotr.bonarski@collegiumwitelona.pl (P.B.); piotr.motyka@collegiumwitelona.pl (P.M.); a.wysoczanski@tn-i.com (A.W.); renata.gnitecka@collegiumwitelona.pl (R.G.); krzysztof.kolbusz@collegiumwitelona.pl (K.K.); magdalena.dabrowska@collegiumwitelona.pl (M.D.); zdzislaw.pawelec@studenci.collegiumwitelona.pl (Z.P.)
2 Technonicol-Insulation (Currently Boerner Insulation), Wyzwolenia 55, Wykroty, 59-730 Nowogrodziec, Poland
3 Industrial Support, Sejmowa 5A, 59-220 Legnica, Poland
4 Institute of Technology and Innovation, Witelon Collegium State University, Sejmowa 5A, 59-220 Legnica, Poland
5 Department of Laser Technologies, Automatization and Product Organization, Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wroclaw, Poland; anna.burduk@pwr.edu.pl
6 MEtRICs Research Centre, School of Engineering, University of Minho, Campus of Azurém, 4800-058 Guimarães, Portugal
* Correspondence: jmachado@dem.uminho.pt

Abstract: Standardization is a key element in the effective use of lean manufacturing methodologies and tools for achieving process sustainability. Their combination is conducive to eliminating waste and improving the efficiency of production processes and guarantees the company that employees use the most efficient tools and do not waste time on unnecessary activities. These activities can be further improved by using digital solutions, in accordance with the concept of Industry 4.0. Therefore, the authors have developed the e-Lean system, whose task is to digitize selected lean manufacturing tools. The subject of this work is analysis of the functionality and effectiveness of the essential part of the e-Lean system in the form of specialized TPM (Total Productive Maintenance) software as an application. During implementation in a construction production company, the TPM application was tested by lean manufacturing and maintenance specialists. The research consisted of assessing the functionality and efficiency of processes in relation to conventional TPM solutions. Additional functionalities of the e-Lean system have been confirmed, such as systemic approval of machinery inspection, which requires passing all necessary steps at individual inspection points, direct access for supervisors to the results of inspection activities and their status, direct and easy access to photographic documentation of machines added during inspection both in optimization of working time and its course (e.g., the optimal number of steps taken by the employee during the inspection), as well as an efficient system of motivating employees (collecting points). The improvement in the effectiveness of processes was determined by measuring the control times for three control points (polymerization furnace, packing area, and defibering machines). The average control time was reduced from 16,200 to 13,923 s. Thus, thanks to the use of the application, it was found that the efficiency of using the TPM tool was increased by approx. 15% compared to previously used non-digital solutions.

Keywords: lean manufacturing tools; lean manufacturing methodologies; digital standardization; industry 4.0

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1. Introduction

Lean manufacturing as a philosophy and methodology is used to manage and optimize production processes. It puts emphasis on eliminating waste, improving production efficiency and effectiveness, and increasing product quality and customer satisfaction. The concept originated in Japan in the 1950s and is also known as the Toyota Production System (TPS) because it was developed by Toyota. The main principles of lean manufacturing are as follows [1–5]:

- Identify value from the customer's perspective: determine what customers value and what they are willing to pay for.
- Map the value stream: map the steps involved in producing a product or service and identify areas where waste can be eliminated.
- Create flow: create a continuous flow of work through the system, reducing lead times and work in progress.
- Establish pull: only produce what is needed when it is needed based on customer demand.
- Seek perfection: continuously improve the system by eliminating waste and improving efficiency.

Below are the most commonly used lean manufacturing tools that help achieve the assumed goals [6–10]:

- 5S (used to create an optimal workplace, and its name is an acronym of five Japanese words:
    1. Seiri (selection)—we separate all materials (instructions, tools) from each other at the workplace and remove unnecessary things.
    2. Seiton (organization)—we designate and mark tools and their parts.
    3. Seiso (cleaning)—removing dirt, laying, cleaning, and renewing the workplace.
    4. Seiketsu (standardization)—constantly keeping the workplace in order so it remains clean and tidy (here we smoothly move on to the next tool).
    5. Shitsuke (self-discipline)—habits and habits necessary to comply with the implemented improvement solutions.
- Kaizen: means continuous improvement and consists of the continuous introduction of changes and improvements with the help of small steps.
- Kanban: allows you to control production by events occurring directly in production.
- TPM, i.e., Total Productive Maintenance: this Comprehensive Productivity Maintenance enables the activation of all employees and machines to maximize the total efficiency of production resources.
- SMED, i.e., Single Minute Exchange of Die: literally translated as a one-minute exchange of a mold or tool that sets the goal of reducing changeover time to 10 min or less.
- VSA, or Value Stream Analysis: value stream mapping, as the main lean tool, enables visualization of information flow and the manufacturing process for selected products.
- Six Sigma: used to reduce costs and improve quality through the use of statistical tools.
- Poka-yoke: used to prevent errors from appearing through technical solutions, etc.

One of the key principles of lean manufacturing, allowing for the efficient implementation of lean tools, is the standardization of production processes, which consists of setting standards of conduct that allow for the expected results to be achieved in a repeatable and effective manner. The standardization of production processes comprises the creation of unambiguous, defined procedures that are used at every stage of production. Within lean manufacturing, the standardization process is often used, involving the use of tools such as Standard Work and Standard Operating Procedures (SOPs). Standard Work is the description of an ideal production process including the time needed to complete individual tasks by employees, while SOPs are detailed instructions for the production process [8–11]. The standardization of production processes is therefore aimed at increasing the efficiency of processes, reducing errors and deviations, and unifying the final results.

In the context of lean manufacturing, standardization is extremely important for the smooth functioning of the tools used in the lean manufacturing methodology and plays an important role in eliminating waste and improving efficiency. By standardizing processes, companies can ensure that workers are following the most efficient methods and are not wasting time on unnecessary activities. Standardization also makes it easier to identify and eliminate sources of waste and to track performance metrics over time.

The common goal of lean manufacturing and the standardization of manufacturing processes is to improve production efficiency, with standardization focusing on ensuring repeatability of results and lean manufacturing focusing on continuous process improvement to ensure process efficiency and improve product quality. Thus, lean manufacturing and standardization of production processes are two interrelated approaches to improving production efficiency. These activities can be improved by using digital solutions, in accordance with the concept of Industry 4.0 [11–21].

Therefore, this work analyzes the functionality of the e-Lean system in terms of TPM, which is the result of cooperation between Witelon Collegium State University, Industrial Support, and Technonicol Insulation, where the system was implemented.

2. Methodology

One of the key lean manufacturing tools closely related to the standardization of production processes is TPM. This tool allows you to achieve maximum efficiency with production equipment by involving many employees in the maintenance process [22,23]. In addition, it enables efficient and ongoing diagnostics of machines and production equipment, which requires monitoring of a number of parameters; it is very important from the point of view of the operation of machine and equipment elements and the continuity of production processes. The primary goal of TPM is to reduce equipment downtime, minimize defects, and improve overall equipment effectiveness (OEE) by involving all employees in the maintenance process [24–26]. This involves empowering operators to take responsibility for the maintenance and improvement of their equipment and providing them with the skills and knowledge necessary to do so. TPM also involves a focus on continuous improvement, with the aim of eliminating losses and improving productivity over time. The key elements of TPM include the following [27–32]:

- Autonomous maintenance: operators are trained to perform routine maintenance tasks, such as cleaning, inspection, and lubrication, with the aim of preventing equipment breakdowns and reducing the need for external maintenance support.
- Planned maintenance: maintenance activities are planned and scheduled in advance, with the aim of minimizing downtime and optimizing maintenance resources.
- Quality maintenance: the focus is on eliminating defects and preventing their recurrence, with the aim of improving product quality and reducing waste.
- Training and development: employees are trained and developed to perform their jobs effectively and to continuously improve their skills and knowledge.
- Equipment improvement: the aim is to continually improve equipment reliability, maintainability, and operability, with the goal of increasing productivity and reducing costs.

Overall, TPM is a comprehensive approach to maintenance and productivity improvement that involves everyone in the organization, from top management to the shop floor. By fostering a culture of continuous improvement and empowering employees to take ownership of their equipment, TPM can lead to significant improvements in equipment reliability, productivity, and quality [28,33].

In order to improve the TPM tool, specialized software was developed to improve the maintenance of machine parks in continuous production readiness. It was assumed that the e-Lean system would be installed on the company's server and would cooperate with the license server. System users with different levels of access to data, depending on the assigned role, will be able to communicate with the enterprise server via a mobile application. The method of binding the key elements of the system installed on the license server is shown in Figure 1.

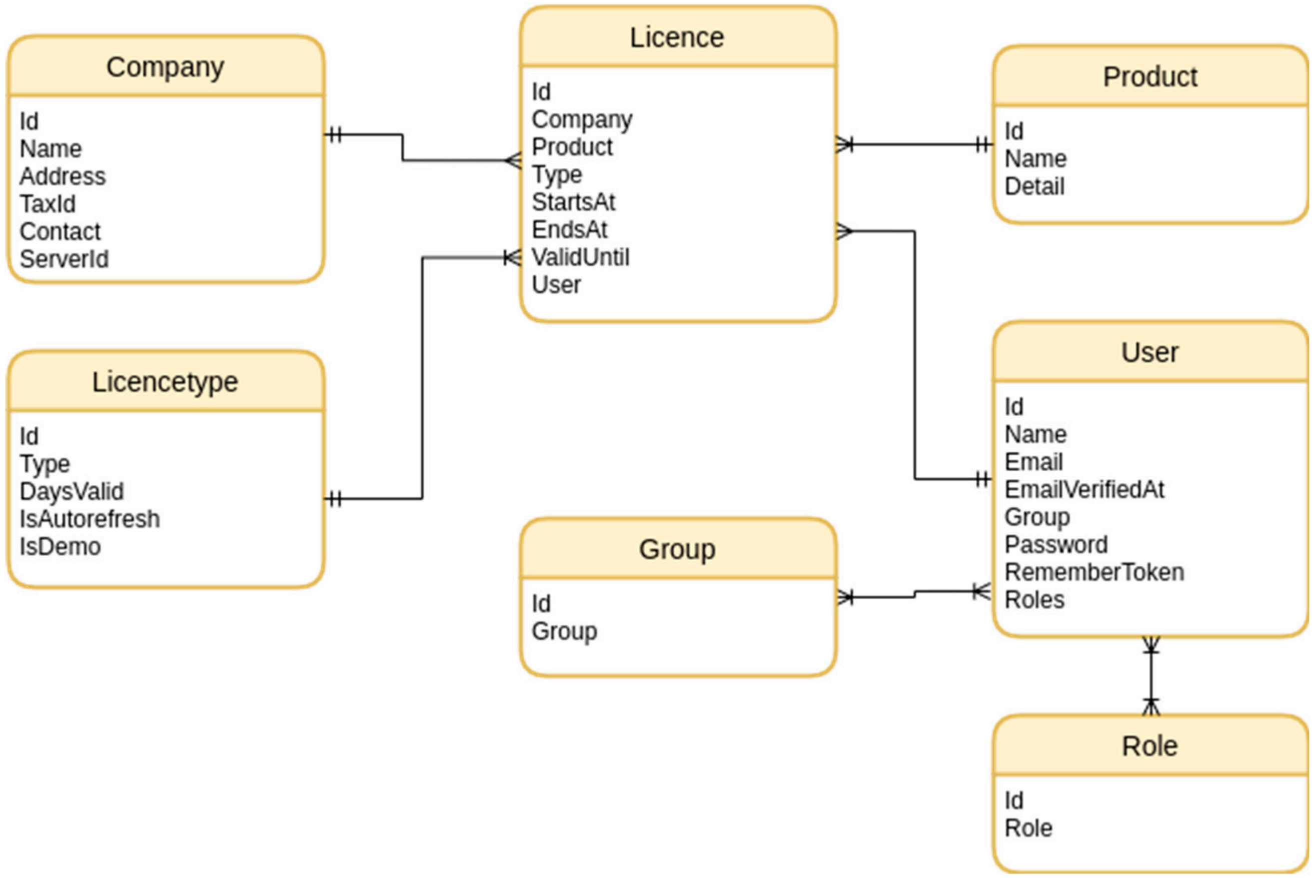

Figure 1. The main elements of the e-Lean system on the license server.

In turn, the main elements of the system and the method for data connections in the system installed on the server in the enterprise are shown in Figure 2.

The method of implementing the system consists of three steps: installation, configuration, and definition of machines and devices. On the other hand, the use of the system in the enterprise includes three stages: TPM control, acceptance of the control results or their rejection, and reporting, which is presented in the diagram in Figure 3.

The main functionalities of the system from the user's point of view include managing users and roles; defining machines, control points, and control methods; generating TPM control actions; performing TPM checks; simple and detailed reporting; automatic sending of control reports to selected groups; the creation of user statistics; assessment of the machine's condition; creation of general instructions and controls; and external training and awards. Depending on the license package, the company can adapt the functionality of the system to its needs.

In addition, the system enables data analysis and the forecasting of possible failures based on the analysis of trends in the technical parameters of machines. The use of trend models makes it possible to detect changes in the characteristics of the machine's operation, which may indicate an impending failure. Thus, it aims to anticipate future failures so that preventive actions can be planned and unplanned machine downtime minimized.

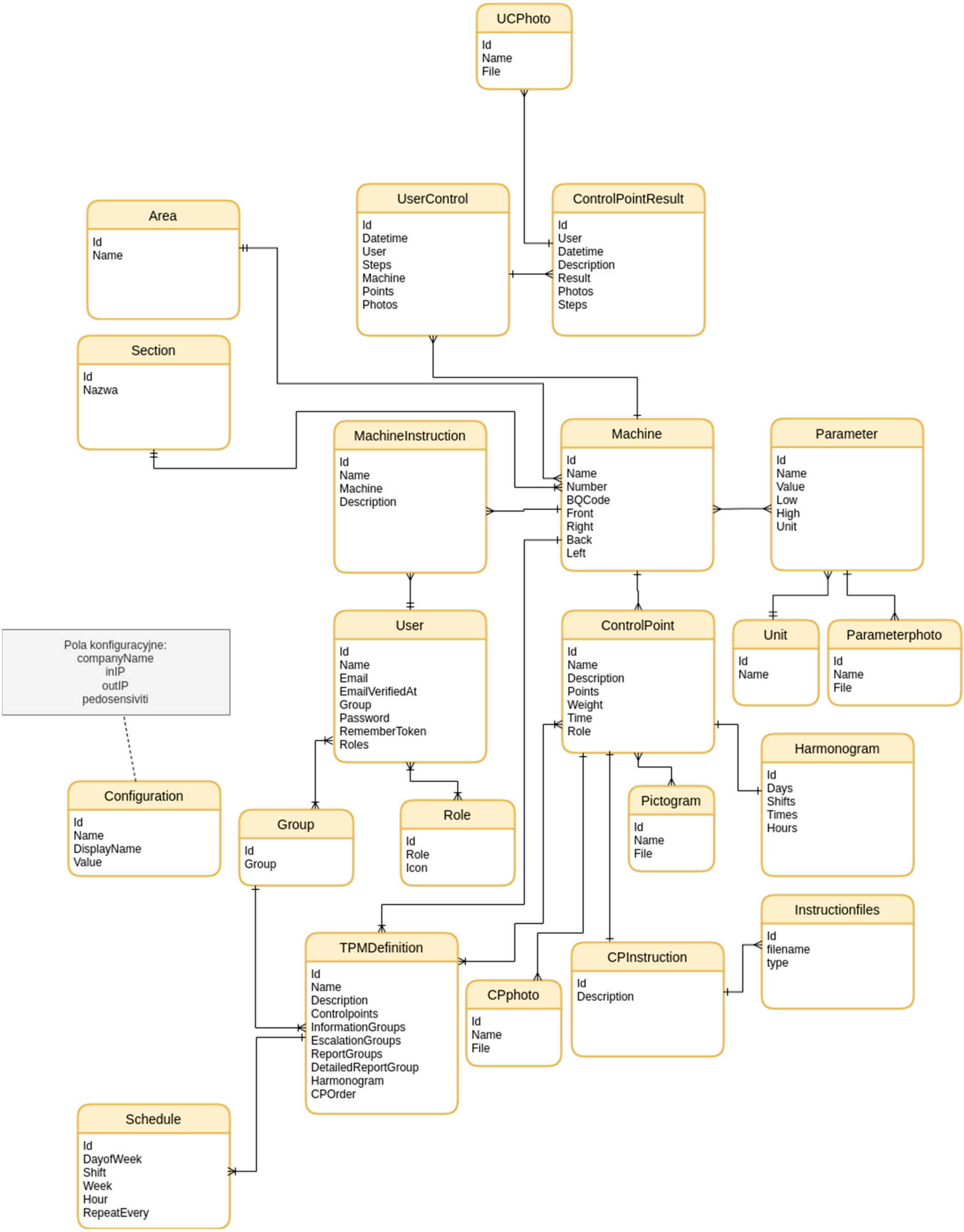

Figure 2. The main elements of the e-Lean system and data binding.

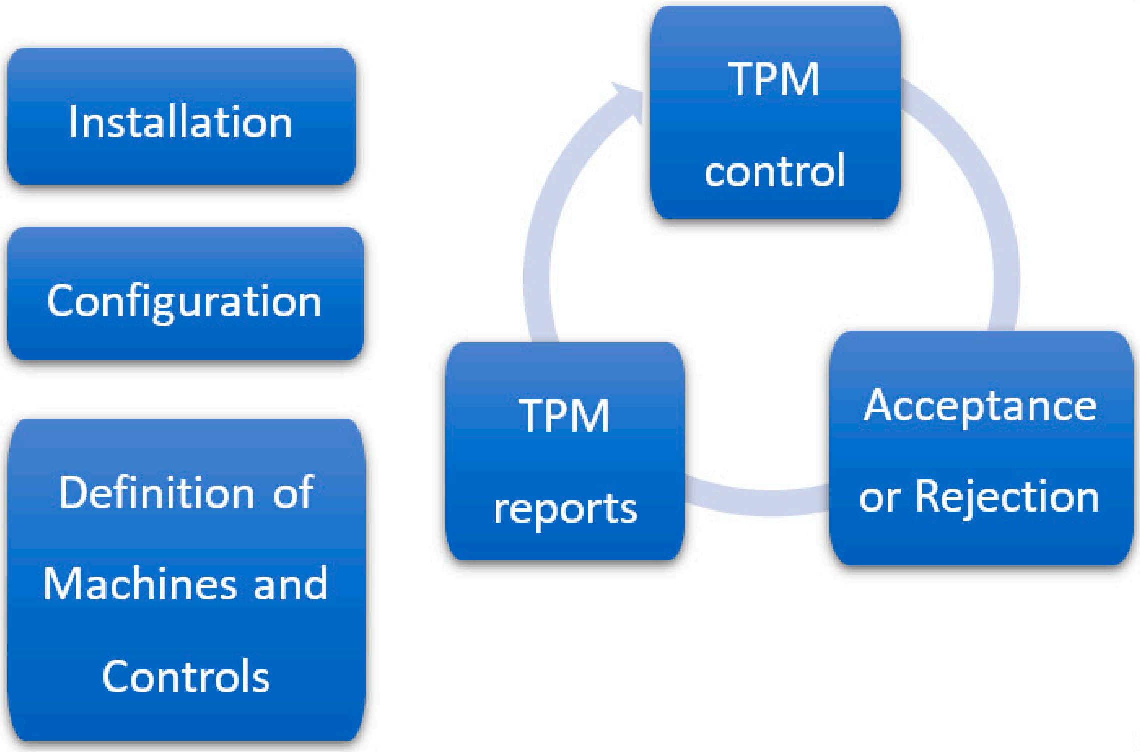

Figure 3. Principle of operation of the e-Lean system.

3. Results and Discussion

In industrial practice, TPM solutions are most often implemented through the use of paper documentation or digital forms, to which access is limited. The task of the tested application is not only to facilitate access from the office to the online inspection database, without the need to check all inspection books, but also to enter additional data, e.g., in the form of photographic documentation. Thanks to this, it is possible to monitor the status of technical inspections of machines and production equipment throughout the enterprise from one place to a greater extent than before.

The TPM application as an element of the advanced e-Lean system, which can be implemented in manufacturing enterprises without restrictions, applies to the machine park and users with different levels of access to data. Implementation of the e-Lean system consists of adding relevant data to the system from the point of view of maintaining the machine park in production readiness regarding, for example, machines and devices for which any control points can be defined and users who can be given appropriate roles in the system in accordance with their competences and level of access to data adequate for their function in the company and others. The application installed on the server can be accessed from stationary and mobile devices (PCs, smartphones, tablets) located in offices, as well as from the mobile devices of production employees. Figure 4 shows a screenshot of the computer screen showing the license information for the system.

There is a system toolbar (Figure 4, item 1) that includes the functionality of the system. Below, you can see data regarding the server's ID and license activity status (Figure 4, item 2), as well as server settings (Figure 4, item 3) such as server address (Figure 4, item 4), account login from which notifications are sent (Figure 4, item 5), server port (Figure 4, item 6), the encryption used for communication with the server (Figure 4, item 7), and the e-mail address to be used when sending notifications (Figure 4, item 8).

Figure 5 through Figure 6 show the functionality of the TPM application regarding its users and their characteristics.

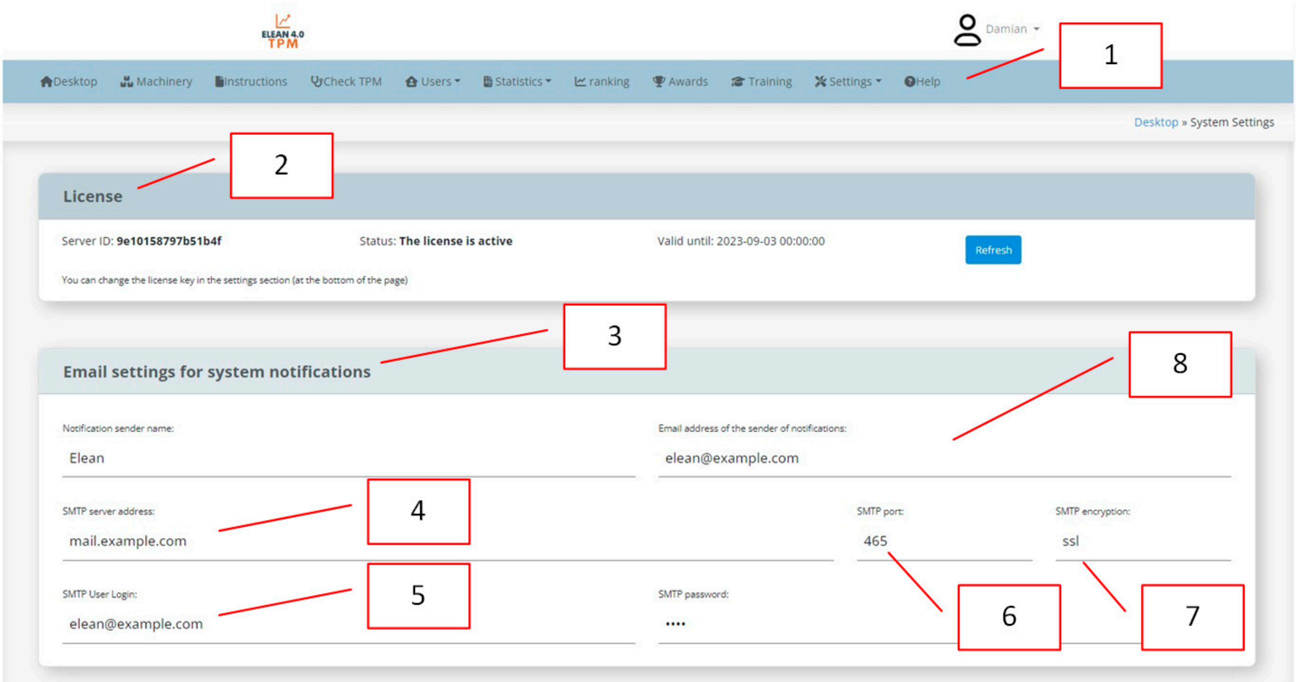

Figure 4. A screenshot of the TPM application showing the system's license data.

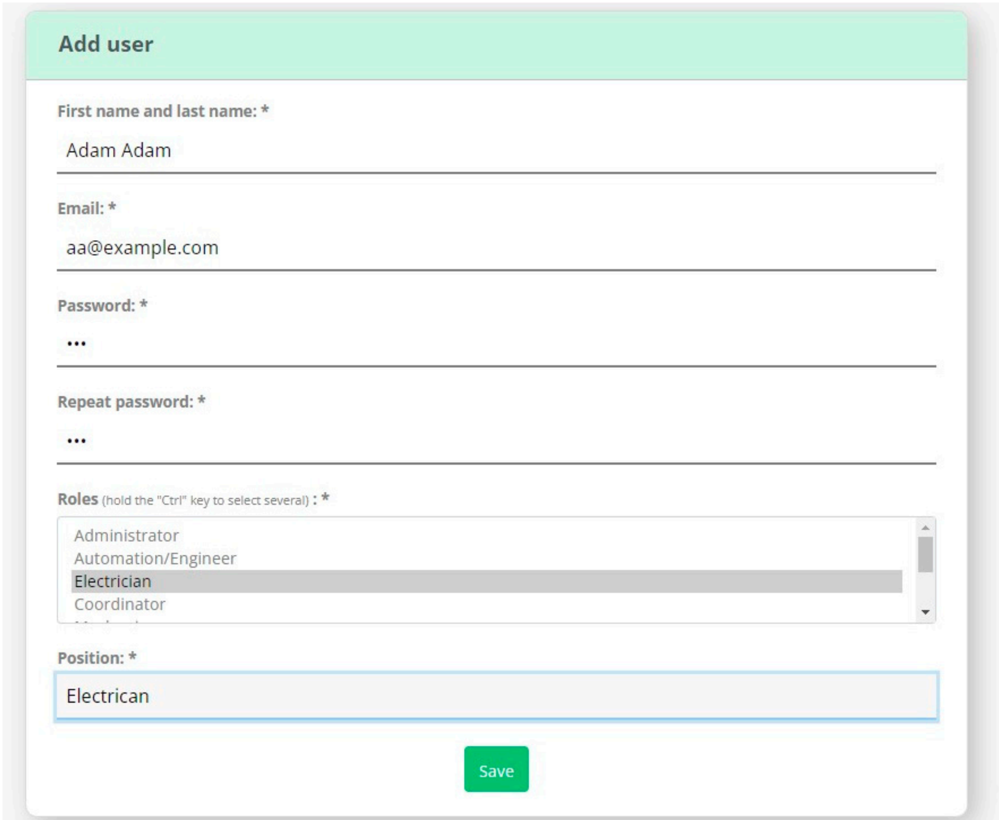

Figure 5. Screenshot of the TPM application from a mobile device showing a user being added.

Figure 5 shows a screenshot from a mobile device (this time) in the form of a tab that allows you to add new users by entering data such as name, e-mail, password, and the role assigned in the system, as well as the position in the company.

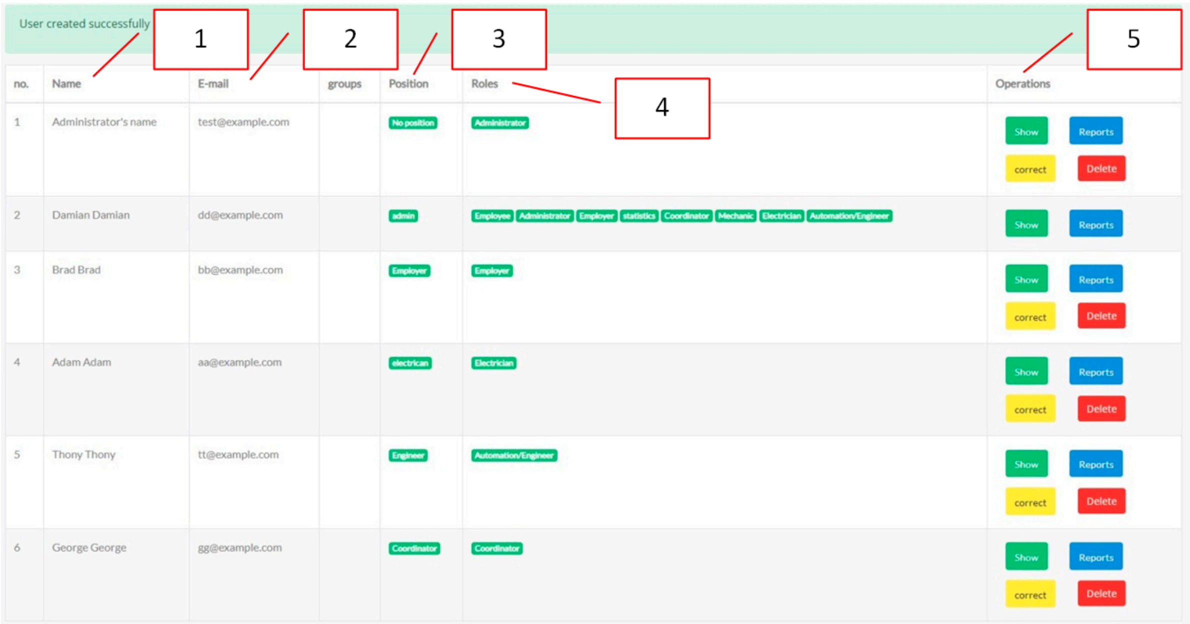

Figure 6. Screenshot of the TPM application showing a list of users with their characteristics.

The screenshot in Figure 6 shows the list of registered users, which, in addition to the username (Figure 6, item 1), includes e-mail addresses (Figure 6, item 2), position (Figure 6, item 3), and assigned role in the system (Figure 6, item 4). In addition, there are function fields on the right side labelled as Operations (Figure 6, item 5), which, after clicking, allow you to view details about individual users, e.g., in terms of reports.

The TPM application primarily contains functionality related to the maintenance of machinery and production equipment, which helps to improve production efficiency. The characteristics of the machinery and equipment must be entered into the system, and the control points must then be defined (Figure 7) and pre-defined checks systematically carried out according to the plan (Figure 8).

Figure 7 presents screenshots of application tabs showing defined checkpoints with their characteristics, e.g., ID, name of the checkpoint, number of places to be verified, weight, execution time, and the role of the employee in the system (Figure 7, item 1), as well as a description concerning the performance of control activities (Figure 7, item 2). It is also possible to place photographic documentation here (Figure 7, item 3), assign pictograms as information indicators (Figure 7, item 4), and place instructions on how to proceed, e.g., in a PDF, MP3 or AVI file (Figure 7, item 5).

The system allows you to schedule TPM checks (pressure gauge, oil level, etc.) at the right time. Figure 8 shows the functionality of the system in terms of scheduling inspections for a control point, which in this case is titled Tool holder control. Here, you can see the control schedule based on a specific day of the week (Figure 8, item 1), as well as based on a specific date (Figure 8, item 2).

Figure 9 shows a screenshot of the TPM application showing a list of sample checkpoints. These are the checkpoints defined in the TPM check (Figure 9, item 1). Below, they are listed respectively as tool holder control and machine power control (Figure 9, item 2). Subsequently, the number of points to be assigned for the performance of the control activity, their weight, and the time allocated to a given control point are visible (Figure 9, item 3–5). There are also specialists assigned to a given checkpoint in terms of their role (Figure 9, item 6) and there is also a place for a description of the operation (Figure 9, item 7). Next, icons are displayed as information indicators for the checkpoint (Figure 9, item 8), instructions for download (Figure 9, item 9), and option buttons for details, icons, QR codes, corrections, and checkpoint removal (Figure 9, item 10).

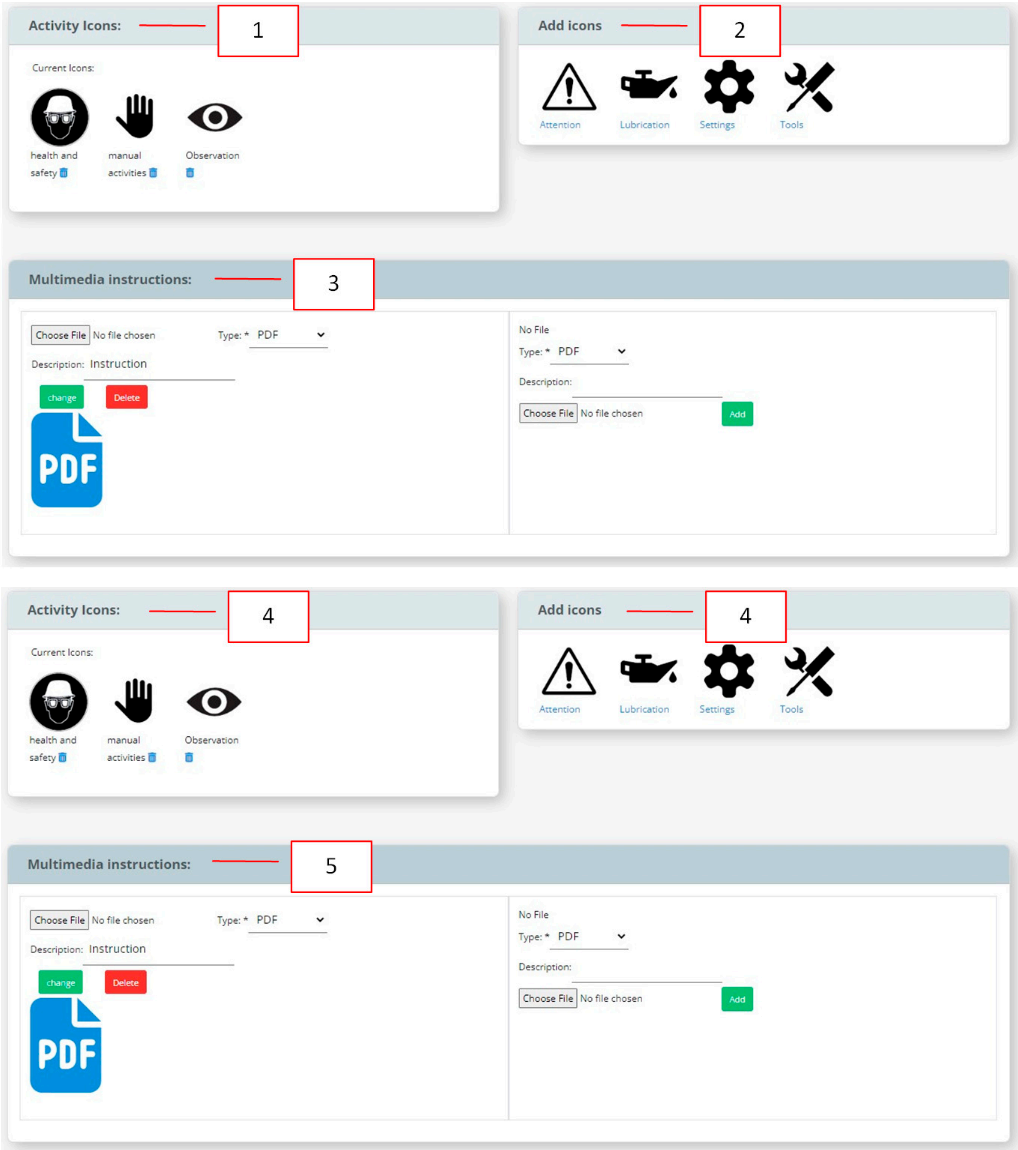

Figure 7. Screenshot of the TPM application defining checkpoints.

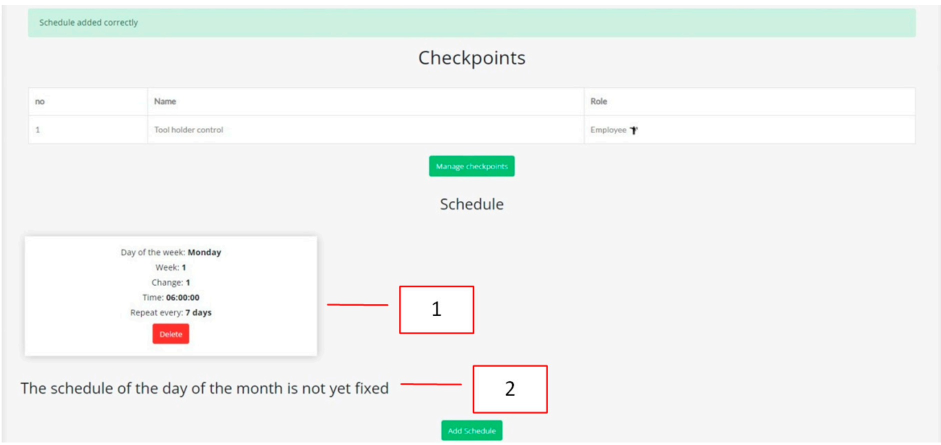

Figure 8. A screenshot of the TPM application showing the scheduling of checks to be performed for a checkpoint.

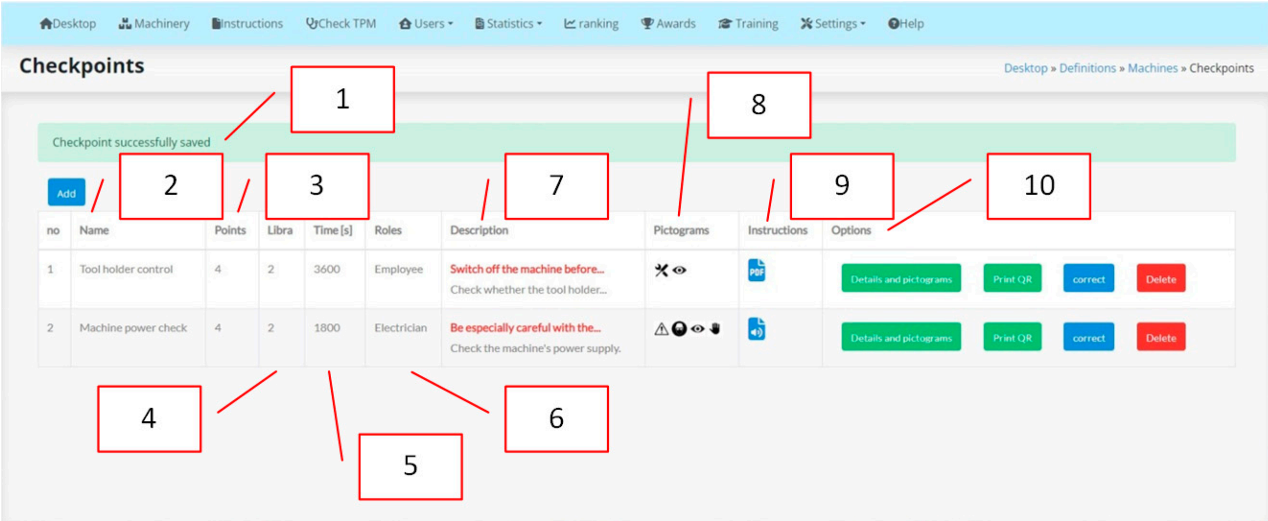

Figure 9. Screenshot of the TPM application showing an example list of checkpoints stored in the system.

In turn, the list of scheduled inspection orders is shown in Figure 10, including inspections to be assigned (Figure 10, item 1), those assigned (Figure 10, item 2), and other (Figure 10, item 3), e.g., completed and waiting for confirmation or cancelled.

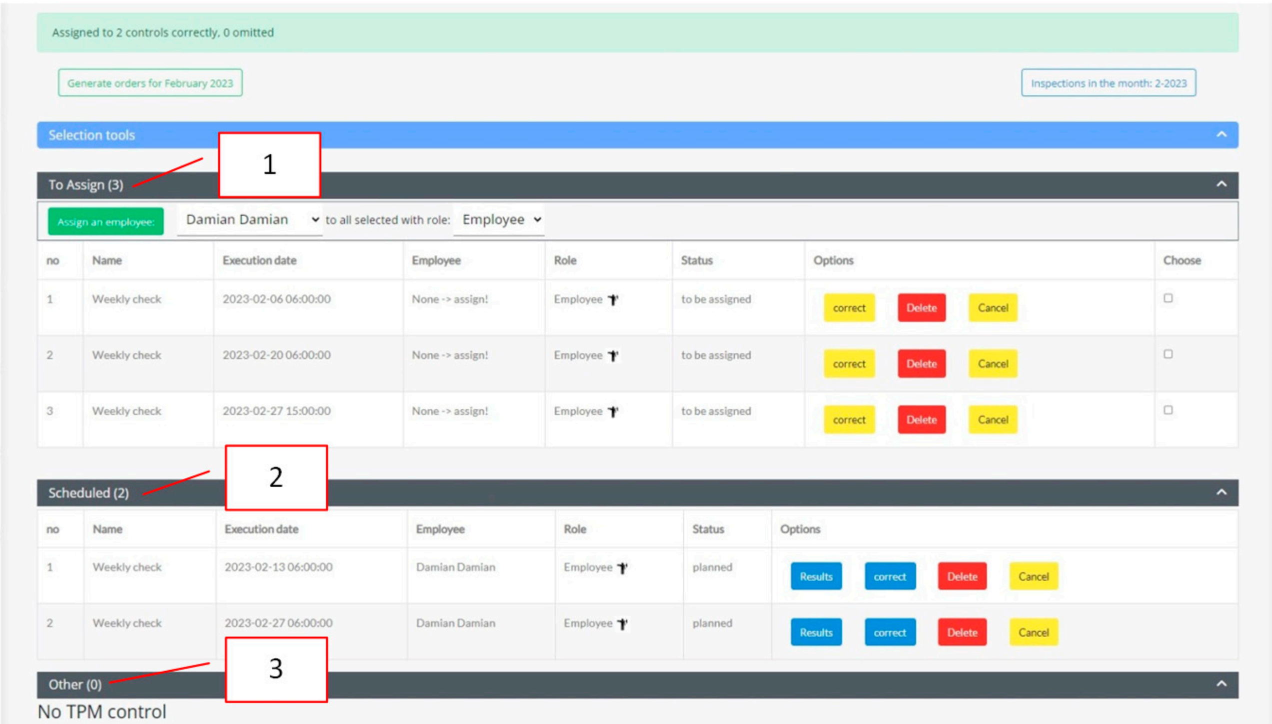

Figure 10. Screenshot of the TPM application showing an example list of scheduled checkpoints.

As already mentioned, the TPM application can be installed on company mobile devices of production employees and maintenance services. The operator or technician performing the machine inspection scans the QR code on the machine. After scanning the code, full instructions on what to do appear. Next, the controller scans the QR codes of individual checkpoints and assesses the compliance of the actual state with the instructions. In addition, they can enter comments into the system. Only after verification is it possible to proceed to the next steps. Thanks to this, the employer can be sure that all points defined in the inspection plan have been checked. This solution eliminates the need to archive paper inspection plans, helping to maintain the technical efficiency of production machines and devices and supervise ongoing activities.

The screenshot in Figure 11 shows an exemplary description of the control for a CNC 63,770 machine tool. The panel contains basic data about the machine (Figure 11, item 1). There are also photos of the machine taken from the front, rear, left, and right sides (Figure 11, item 2). In addition, the panel contains important optional data (Figure 11, item 3), such as parameters (production machine), checkpoints and instructions, definitions (specifying when and how to control, what to control, and by whom), and orders (the definition also includes the generation of orders).

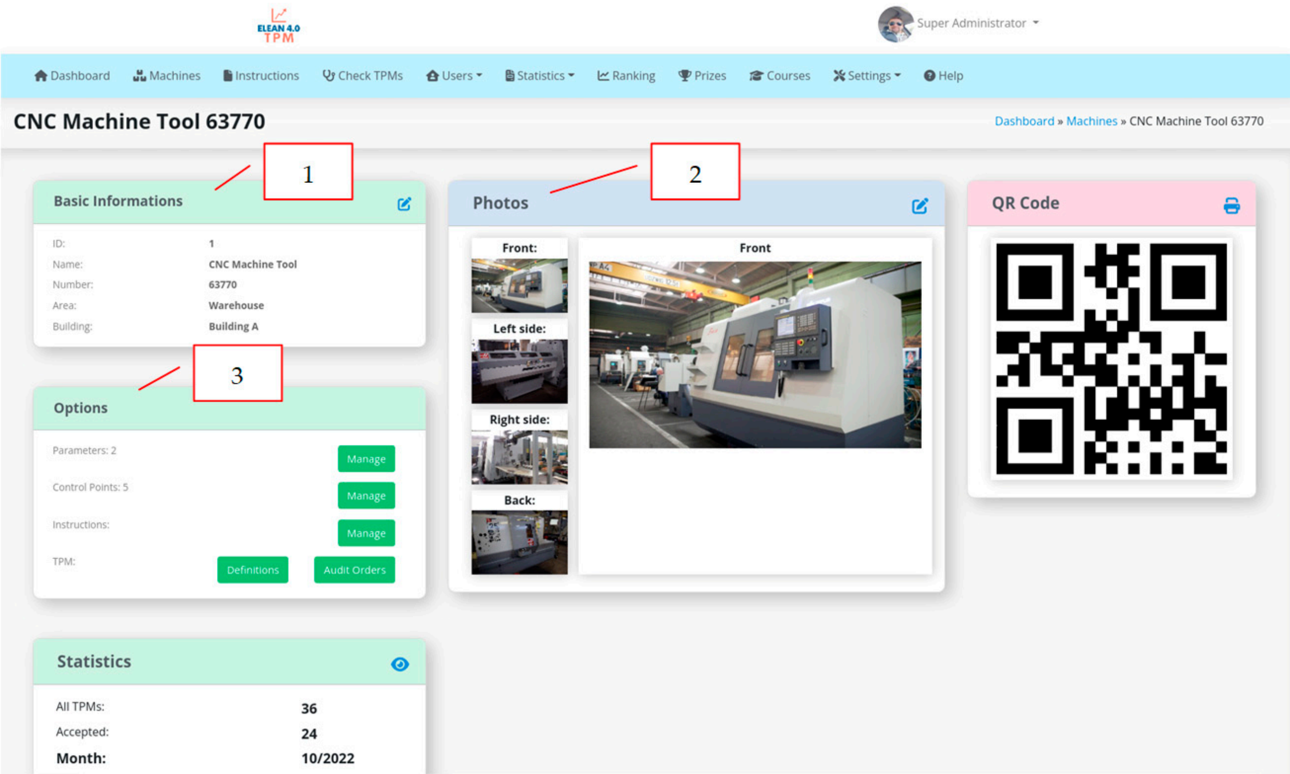

Figure 11. Screenshot showing selected functionality of the e-Lean application—CNC Machine Tool 63,770 overview.

The e-Lean application, used to carry out TPM checks, has the functionality to search for reports in a given period of time for all working machines (Figure 12, item 1), as well as reports for individual working machines (Figure 12, item 2). In addition to the control result expressed as a percentage of the ratio of correct points to all (positive result above 50%), the report result is presented numerically for individual control points (CP). The first numerical value, 3, represents the number of points to check. The numerical values of 2 and 1 mean compatible points and non-consistent points, respectively (Figure 12, item 3). In addition, the e-Lean application indicates the employee who performs the control activity (Figure 12, item 4) and defines the status of the control result, its confirmation, and comments in the event of rejection (Figure 12, item 5).

Another screenshot of the e-Lean application shows a list of machines in individual areas of the enterprise (Figure 13, item 1). In this part of the application there is a panel for managing production machines (Figure 13, item 2), and it is possible to correct information about machines by editing (Figure 13, item 3) or deleting machines (Figure 13, item 4), as well as view statistical data (Figure 13, item 5) and TPM control reports for individual machines (Figure 13, item 6).

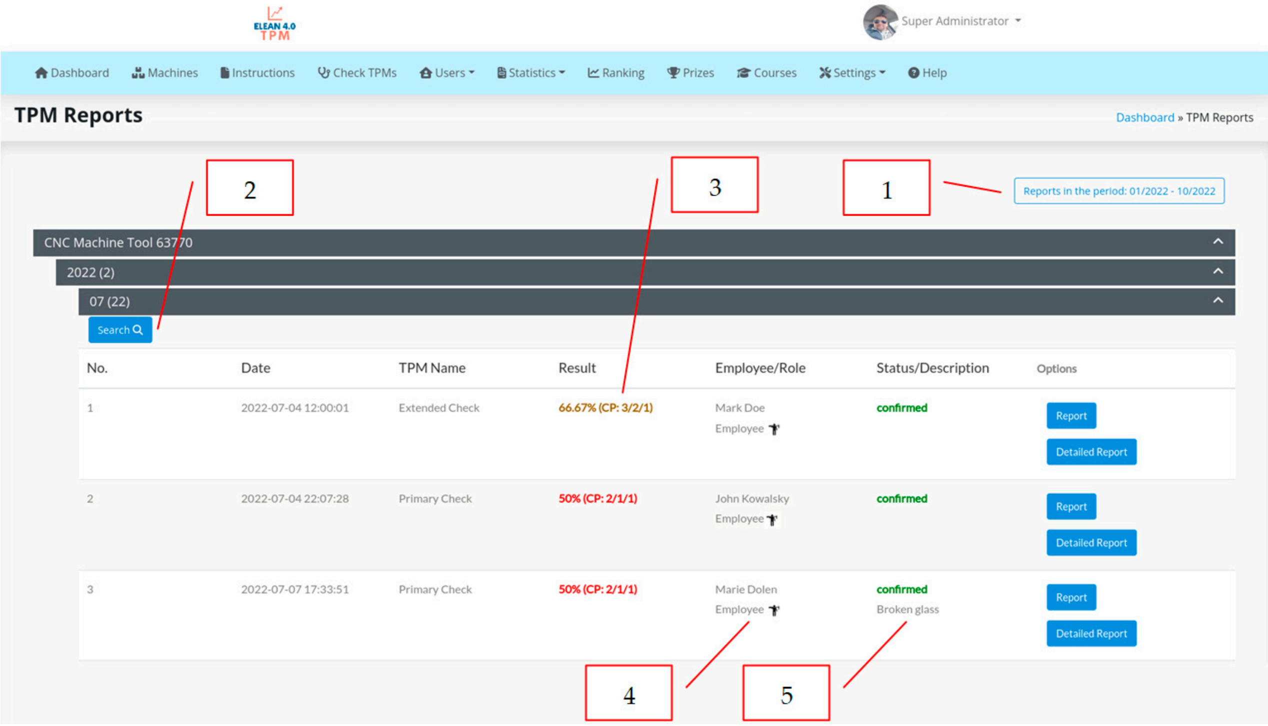

Figure 12. Screenshot of TPM reports in e-Lean.

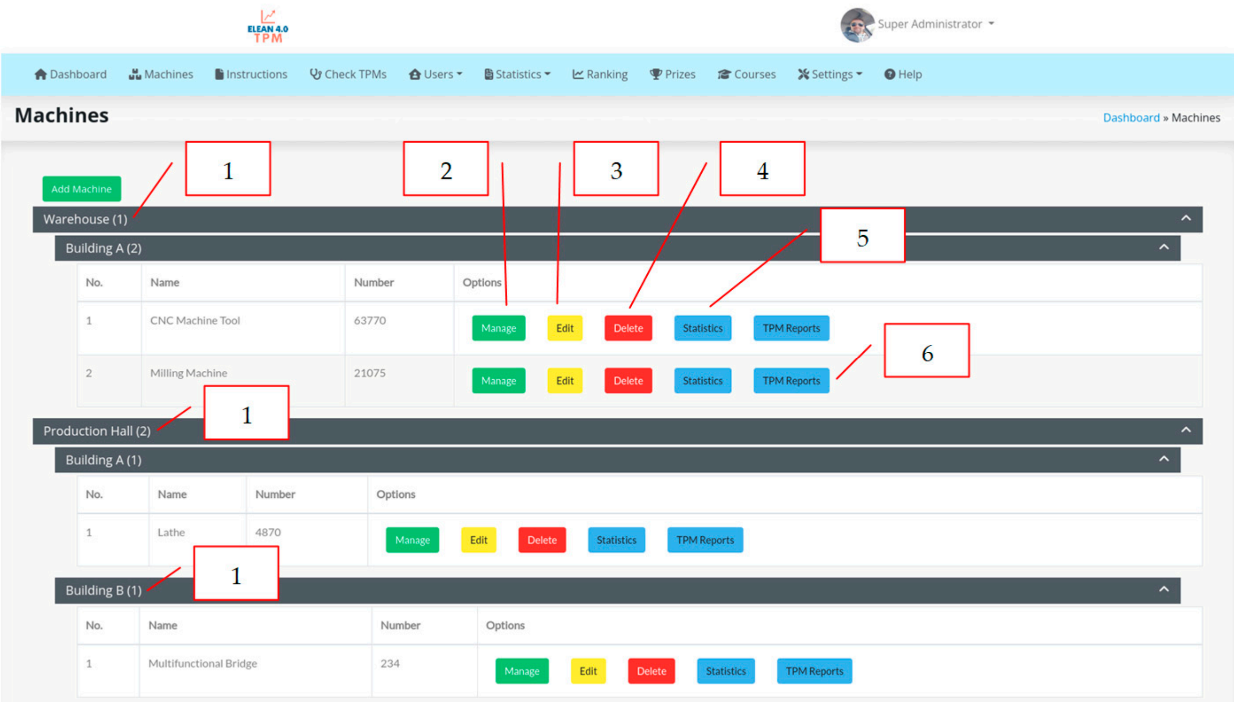

Figure 13. Screenshot of the e-Lean application showing an overview of the company's machines.

In addition, the application can be used as a motivator that encourages employees to perform review activities because it contains a bonus system that grants a specific pool of points for each activity, which the employer can include in the bonus process.

The TPM application was tested at Technonicol Insulation. After that, the first update to the application was carried out and preparation for implementation in automotive plants was undertaken. The results of the implementation turned out to be very promising.

Table 1 shows the averaged results from at least three measurements obtained during a TPM inspection carried out on a production line in a construction company. The average control time consisting of carrying out three control points (polymerization furnace, packing area, and defibering machines) was reduced from 16,200 to 13,923 s. Thus, thanks to the use of the application, the effectiveness of the TPM tool was increased by approx. 15% compared to previously used non-digital solutions.

Table 1. The results of TPM inspections carried out for a production line in a construction company using conventional and digital solutions.

Checkpoints	TPM Control							
	Conventional				E-Lean			
	Time [s]	Added Value	Yes	No	Time [s]	Added Value	Yes	No
1st checkpoint—polymerization furnace	900	System approval of the control requires all checkpoints to be passed	—	x	873	System approval of the control requires all checkpoints to be passed	x	—
		Direct access by superiors to control activities and their statutes	—	x		Direct access by superiors to control activities and their statutes	x	—
		Control photos of machines placed in the system, with easy access	—	x		Control photos of machines placed in the system, with easy access	x	—
		Optimization of work (optimal number of steps taken by the employee during the inspection and time)	—	x		Optimization of work (optimal number of steps taken by the employee during the inspection and time)	x	—
		Efficient employee motivation system (collection of points)	—	x		Efficient employee motivation system (collection of points)	x	—
2nd checkpoint—packing area	900	System approval of the control requires all checkpoints to be passed	—	x	810	System approval of the control requires all checkpoints to be passed	x	—
		Direct access by superiors to control activities and their statutes	—	x		Direct access by superiors to control activities and their statutes	x	—
		Control photos of machines placed in the system, with easy access	—	x		Control photos of machines placed in the system, with easy access	x	—
		Optimization of work (optimal number of steps taken by the employee during the inspection and time)	—	x		Optimization of work (optimal number of steps taken by the employee during the inspection and time)	x	—
		Efficient employee motivation system (collection of points)	—	x		Efficient employee motivation system (collection of points)	x	—

Table 1. *Cont.*

Checkpoints	TPM Control							
	Conventional				E-Lean			
	Time [s]	Added Value	Yes	No	Time [s]	Added Value	Yes	No
3rd checkpoint—defibering machines	14,400	System approval of the control requires all checkpoints to be passed	—	x	12,240	System approval of the control requires all checkpoints to be passed	x	—
		Direct access by superiors to control activities and their statutes	—	x		Direct access by superiors to control activities and their statutes	x	—
		Control photos of machines placed in the system, with easy access	—	x		Control photos of machines placed in the system, with easy access	x	—
		Optimization of work (optimal number of steps taken by the employee during the inspection and time)	—	x		Optimization of work (optimal number of steps taken by the employee during the inspection and time)	x	—
		Efficient employee motivation system (collection of points)	—	x		Efficient employee motivation system (collection of points)	x	—
Total	**16,200**				**13,923**			

In addition to the functionalities presented in Chapter 2 and 3, the e-Lean system has additional functionalities that are added values and show the advantage of the e-Lean TPM system over conventional TPM. This is reflected in the results in Table 1.

The next research step will be to analyze the possibility of implementing the application at the stage of designing the production process in such a way that the machine or device comes to the customer with the software. The software, based on the technical and operational documentation, will have a defined inspection schedule prepared by the machine manufacturer.

4. Conclusions

The digitization of TPM resulted in a significant increase in the functionality of the tool and an improvement of 15% in its effectiveness based on the time of inspections carried out. Reducing the time of inspections, however, is not the main aspect that causes interest in lean digitization.

The most important element is the real possibility of monitoring the performed tasks, consequently resulting in an increase in the effectiveness of the inspections (TPM) carried out in this case and in turn allowing for the early detection of irregularities and the possibility of planning preventive activities, thus eliminating the potential occurrence of failures during production.

With conventional methods, it is not possible to reliably verify the performed work, while digital methods force the user to go to specific places to enter the appropriate results into the system to go to the next step and finally complete the activities related to daily operator inspections (autonomous maintenance). Machine inspections become real, and we have the ability to monitor them and evaluate their effectiveness based on reliable data.

The used methodology and respective tools that allowed the mentioned results to be achieved can be extrapolated for similar cases in industry. This approach, as it is presented, is simple in terms of understanding and practical application for engineers in their respective companies.

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