OEE Monitoring System for Production Processes Based on Integration of IoT Sensor Data

Szymon ZIAJA[1], Konrad PIĘTKA[2]

[1] MSc Eng.; Research and Teaching Assistant, Department of Economics and Management in Industry, Faculty of Civil Engineering and Resource Management, AGH University of Krakow, Cracow, Poland; email: sziaja@agh.edu.pl,
ORCID: https://orcid.org/0009-0003-3359-8942

[2] MSc Eng.; Research and Teaching Assistant, Department of Economics and Management in Industry, Faculty of Civil Engineering and Resource Management, AGH University of Krakow, Cracow, Poland; email: pietka@agh.edu.pl,
ORCID: https://orcid.org/0000-0002-2090-3683

http://doi.org/10.29227/IM-2025-01-09

Submission date: 01-04-2025 | Review date: 26-05-2025

Abstract

IoT technologies and Industry 4.0 have become integral to modern production processes, enabling real-time monitoring of efficiency indicators and optimizing operational activities and productivity. This article focuses on the implemented system supporting OEE monitoring at the Production and Quality Engineering Laboratory at AGH, with particular emphasis on the OEE module, which is thoroughly described and evaluated for its benefits. The system integrates data from various production devices, providing real-time insights into workstation performance. Additionally, the article discusses key IoT technologies used for production monitoring and the system's architecture, which ensures flexibility and scalability. Furthermore, it demonstrates how the OEE module contributes to enhancing availability, productivity, and quality, reducing downtime, and improving decision-making through early anomaly detection and detailed operational analysis.

Keywords: *OEE, IoT in manufacturing, production process monitoring, production efficiency*

1. INTRODUCTION

The AGH LeanLine 4.0 and 5.0 project is a continuation of the extension with new organisational solutions and technologies of the innovative production line simulation system designed and developed by Paweł Bogacz, Ph.D., Prof. of AGH, together with the AGH Management Student Research Group at the AGH Production Engineering and Quality Laboratory, called LeanLab.

AGH LeanLine is a modern training environment centered around a miniature production line, designed for hands-on learning of lean manufacturing methods. Through realistic simulations of production processes, workshop participants can acquire and hone skills in process management and lean management—learning by doing and by analysing real world production challenges.

This paper presents an advanced OEE monitoring system based on the integration of data from IoT (Internet of Things) sensors, which has been implemented at the AGH Production Engineering and Quality Laboratory as part of the AGH LeanLine project. The aim of this study is to discuss the system's functionalities, with a particular focus on its role in monitoring the efficiency of production processes.

OEE Indicator

One of the key indicators of the operational efficiency of machines, machine assemblies, process lines, or workstations is the OEE (Overall Equipment Effectiveness) indicator. Simply put, the OEE indicator shows the percentage of work completed by machines compared to the theoretical maximum that could be achieved [1]. The foundation for taking actions aimed at optimizing capacity utilization lies in flexibility, process standardization, and appropriate interpretation of the OEE indicator. From a mathematical perspective, this indicator is the product of three components: availability, productivity, and quality, the formulas for which are presented in the table [2]. The global OEE level averages 85%, achieved by leading companies in industries such as automotive and aerospace. The average OEE level is considered to be around 60%, while companies just starting to monitor production efficiency often report an initial indicator value of no more than 40% [3].

IoT technologies in the context of production monitoring

The architecture of the Inernet of Things tools consists of the following elements [4]:

- Devices, which are sensors or transmitters that enable communication, reception of commands and collection and transmission of information;
- IT solutions, which are the receiver of the data collected and transmitted by objects, as well as the place where it is stored and where decisions are made;
- Infrastructure, which enables communication (transmission of data between objects).

The most frequently reported reasons for implementing IoT and Industry 4.0 solutions include: increasing product quality, improving labour productivity, increasing the reliability of performed operations, increasing asset productivity, reducing product manufacturing costs and reducing production losses [4]. The results of these surveys are shown in Figure 1. What is important about its inclusion is that responses with an indication greater than or equal to 35% refer to the OEE indicator, discussed in Chapter 2 of this article. Among the most frequently cited benefits, practitioners report increased

Tab. 1. Components of the OEE Indicator. Source: own elaboration

Tab. 1. Składowe wskaźnika OEE. Źródło: własne

Basic Indicator	Mathematical Formula	Explanation
Availability	$A \quad \frac{t}{t}$	t_r - available time t_t – total time
Productivity	$P \quad \frac{p \quad t}{t}$	p - number of products produced t_c – planned cycle time production time t_r – real time
Quality	$Q \quad \frac{p}{p}$	p_a – number of units of the product meeting quality requirements

Fig. 1. Reasons for implementing IoT solutions. Source: [5]

Rys. 1. Powody wdrażania rozwiązań. Źródło: [5]

productivity as well as improvements in quality and availability (understood as reduced production losses and enhanced reliability of machines and equipment), i.e. the components of the aggregated OEE indicator.

IoT technology in the LeanLab

IoT technologies play an important role in modern manufacturing laboratories and industrial practice, supporting real-time monitoring and improving the efficiency of production processes. Table 2 presents the key components of the IoT architecture implemented at the AGH Laboratory of Production Engineering and Quality, outlining their roles and the specific tools used within the AGH LeanLine project. Within this environment, key IoT architectural elements are implemented to support the monitoring and coordination of production tasks across a simulated line made up of manual workstations. A set of developer IoT modules (M5 Stack) equipped with peripherals is used to collect real-time data related to production cycle times, inter-operational times, workstation availability, failure reports, and basic logistics events. This data is then processed and analyzed through the Explitia Production Portal, which facilitates visualization, reporting, and ongoing evaluation of the OEE indicator. Data transmission and device communication are supported by a dedicated infrastructure based on WiFi 5G and RFID technologies, allowing seamless data flow between system components and users.

Figure 2 presents a diagram illustrating the technical aspect of the implemented solution, including the connections between the M5 Stack modules and sensors, dedicated to a single workstation. This setup is identical for each production station, therefore five identical component connections were prepared. The M5 Stack Stick C microcontroller is the central part of the entire solution. It is an integrated circuit equipped with dedicated software. Its task is to collect data from sensors and transmit it via a communication interface. The communication interface used in this solution is WiFi over a 5G network. Two expanders are connected to the microcontroller, allowing the integration of two buttons and an RFID sensor. One of the buttons is used to report work interruptions at a given station (such as a failure or an unplanned break), while the other reports a shortage of production materials. The RFID readers are used to track the times when products or semi-finished goods enter or leave specific production stations. This is possible thanks to smart stickers with NFC/RFID tags attached to the items. The system operates using a simple MQTT (MQ Telemetry Transport) data transmission protocol, which enables automatic execution of actions by connected IoT devices and seamless data exchange.

OEE monitorinng system

The OEE monitoring system is based on the automatic collection and analysis of data from the production process. Data is collected by sensors placed on the production line, which record, among other things, operator/machine work time, cycle time, inter-operation times, and more. This data is then sent to analytical systems, where it is processed and converted into measurable indicators, including OEE. The results of the analysis are presented in real time on operator dashboards, enabling quick responses to inefficiencies in the processes. Ultimately, the data is used for reporting and decision-making regarding optimization actions, supporting the continuous improvement process in production. On the diagram in Figure 3, the data flow in the OEE monitoring system is presented.

OEE monitoring system in the LeanLab

In April 2024, the Production Portal was launched at the AGH Laboratory of Production Engineering and Quality. The system was developed and is continuously improved by Explitia S.A., in collaboration with the Student Scientific Society of Management, as part of the AGH LeanLine 4.0/5.0 grant project.

The system is based on a modular "plug and play" architecture and includes seven key components:

- APS (Advanced Planning and Scheduling) – a module for production planning and scheduling that enables order management, prioritization, and feasibility assessment.
- Andon OEE – a tool for real-time monitoring of operational efficiency (OEE), including downtime analysis and performance comparisons.
- TRC (Traceability and Recording of Conditions) – a module responsible for recording detailed process

Tab. 2. Components of the IoT Architecture and their application in the AGH Laboratory of Production Engineering and Quality. Source: own elaboration
Tab. 2. Komponenty architektury IoT i ich zastosowanie w Laboratorium Inżynierii Produkcji i Jakości AGH. Źródło: opracowanie własne

IoT Architecture Component	Application	Tools Used in the AGH Production Engineering and Quality Laboratory
Sensors / Detectors	Real-time acquisition and monitoring of production process parameters	IoT M5Stack development modules with peripherals
Information Systems & Software Solutions	Real-time production process management, data analysis, report generation, and visualization	Explitia Production Portal – MES for production management and OEE monitoring
Communication Infrastructure	Ensuring real-time connectivity among IoT devices, systems, and users	Wi-Fi 5G, NFC, RFID – enabling high-speed data transfer and device/operator identification in real time

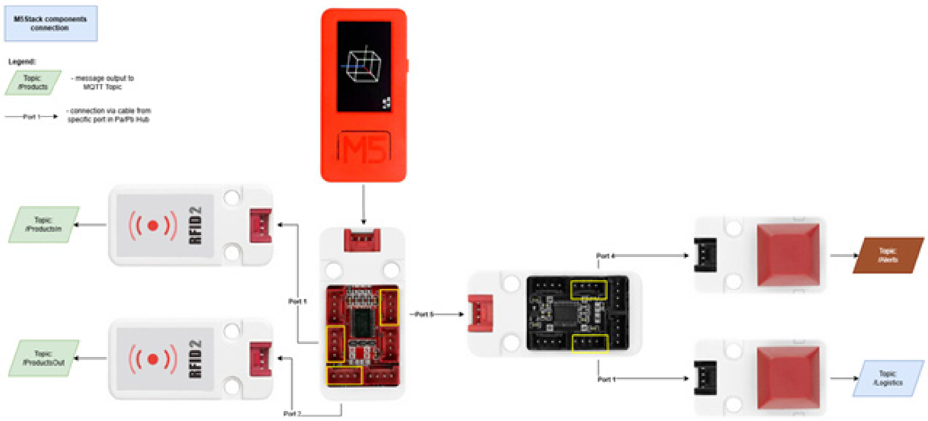

Fig. 2. Connection of M5 Stack components in the system of a single workstation in AGH LeanLine. Source: own elaboration
Rys. 2. Połączenie komponentów M5 Stack w systemie pojedynczego stanowiska w AGH LeanLine. Źródło: opracowanie własne

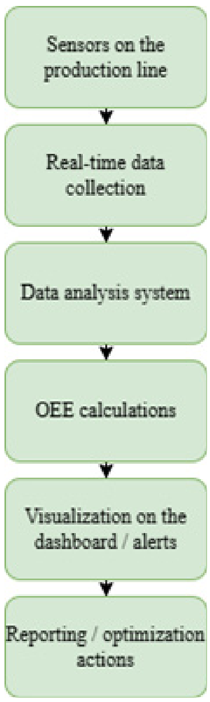

Fig. 3. Data flow in the OEE monitoring system. Source: own elaboration
Rys. 3. Przepływ danych w systemie monitorowania OEE. Źródło: opracowanie własne

data and building the production genealogy.

- Visualization and Simulation Portal – a component enabling the graphical representation of the production line layout, visualization of key indicators, and simulation of operational parameters.
- Operator Panel – a user interface supporting the registration of production events, operator authorization, and system communication.
- Reporting Module (Microsoft Reporting Services) – a system for generating analyses and reports based on Microsoft Reporting Services solutions.
- Logistics Module – responsible for synchronizing production line activities with the logistics department, ensuring the timely delivery of materials in the right quantity and to the correct location.

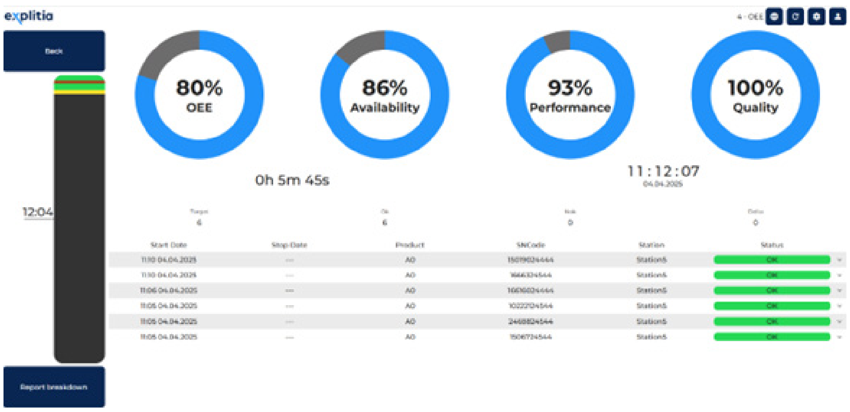

Fig. 4. Visualization of the OEE indicator and its components in real-time during one of the production process simulations in the Production and Quality Engineering Laboratory at AGH

Rys. 4. Wizualizacja wskaźnika OEE i jego składowych w czasie rzeczywistym podczas jednej z symulacji procesu produkcyjnego w Laboratorium Inżynierii Produkcji i Jakości AGH

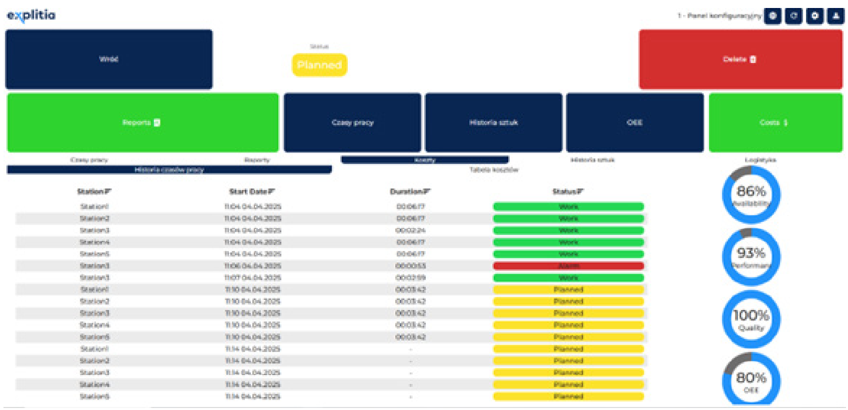

Fig. 5. Main panel during the production process simulation in the Explitia Portal

Rys. 5. Panel główny podczas symulacji procesu produkcyjnego w portalu Explitia

Tab. 3. System functionalities supporting OEE monitoring. Source: own elaboration

Tab. 3. Funkcjonalności systemu wspierające monitorowanie wskaźnika OEE. Źródło: opracowanie własne

Area	Description
System goal	Monitoring and analysis of OEE and its components: availability, performance, and quality, aimed at optimizing production processes.
Technologies used	Data integration from M5Stack devices via MQTT; modular "plug and play" system architecture enabling easy expansion, scalability, and fast deployment.
Modules supporting OEE	- Andon OEE (real-time monitoring and data recording); - TRC (full process traceability); - Visualization and Simulation Portal (data analysis and trend prediction).
Critical OEE functionalities	- Recording and classification of downtime causes; - Machine operational time analysis; - Benchmarking of operators and workstations; - Detection of OEE trends in specified time intervals.
Operational benefits	- Reduced downtime through early anomaly detection; - Improved decision-making based on data; - Increased availability, performance and quality of production.
Visualization and reporting	Dynamic visualization of OEE and its components in real time; historical data analysis; production schedule visualization (Gantt chart); hourly performance analysis.

The Manufacturing Portal System is a modern, modular solution that extends the capabilities of traditional MES systems. Its architecture is based on independent functional modules, allowing users to selectively choose and combine only those elements that match current research or production needs. This approach enables incremental system expansion without interfering with existing components.

Figure 4 illustrates the real-time visualization of the OEE indicator and its components during a production process simulation conducted at the Laboratory of Production and Quality Engineering at AGH.

Figure 5 presents the main panel during another production process simulation. It displays the working times at individual workstations, a real-time summary of the OEE indicator and its components, and the status of workstations at specific time intervals.

The Andon OEE module provides tools to monitor the OEE indicator along with its three components — availability, productivity, and quality — in real time. Data is collected from workstations using M5Stack IoT sensors and the MQTT protocol. The system records downtime, classifies its causes, and enables comparisons of operator productivity and workstation efficiency. All measurements are stored in a central database, allowing for historical analysis and the identification of productivity trends.

Table 3 summarizes the technical implementation of the system's functionalities related to monitoring and improving the OEE indicator, showing the technical solutions assigned to individual system modules.

CONCLUSION

The article presents a system for real-time monitoring of production process efficiency, implemented at the Production and Quality Engineering Laboratory as part of the AGH LeanLine project. The system's architecture is based on developer IoT modules, RFID technology, a 5G network, and a scalable production portal system that enables efficient data management and real-time monitoring of production processes. The article discusses how the integration of various IoT technologies facilitates data collection from production devices and their analysis, contributing to the optimization of operational processes. The key component of the system is the OEE (Overall Equipment Effectiveness) module, which monitors the availability, performance, and quality of production processes, as well as enables anomaly detection for faster response and downtime prevention. Thanks to its flexible architecture, the system has the potential for further expansion with additional functionalities. The author concludes that the described solution can significantly enhance production efficiency through precise data analysis, automated monitoring processes, and improved synchronization and communication between production devices, leading to cost optimization, reduced downtime, and higher production quality.

Literatura – References

1. Lipiak J., Ejsmont K., 2016: Problematyka obliczania wskaźnika OEE dla maszyn fleksograficznych – studium przypadku, [w:] Knosala R. (red.), Innowacje w zarządzaniu i inżynierii produkcji, t. 2, Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole, s. 594.
2. Murdzek M., Richert M., Hubicki R., 2021: Wskaźnik efektywności OEE w systemie produkcji gniazdowej, Nowoczesne metody i narzędzia w inżynierii produkcji i zarządzaniu, Wydawnictwo AGH, Kraków.
3. Koliński A., 2011: Przegląd metod i technik oceny efektywności procesu produkcyjnego, Logistyka, nr 5.
4. Malucha M., 2018: Internet rzeczy – kontekst technologiczny i obszary zastosowania, Studia i Prace WNEIZ US nr 54/2, Szczecin.
5. Przemysłowy Internet Rzeczy. Fabryki przyszłości w dobie rewolucji przemysłowej.https://www.emerson.com/documents/automation/fabrykiprzysz%C5%82o%C5%9Bci-w-dobie-rewolucji-przemys%C5%82owej-iiot-en-5475668.pdf, 25.04.2025

System monitorowania wskaźnika OEE w procesach produkcyjnych oparty na integracji danych z czujników IoT

Technologie IoT oraz Przemysł 4.0 stały się integralną częścią nowoczesnych procesów produkcyjnych, umożliwiając monitorowanie wskaźników efektywności w czasie rzeczywistym oraz optymalizację działań operacyjnych i produktywności. Niniejszy artykuł koncentruje się na wdrożonym systemie wspierającym monitorowanie wskaźnika OEE w Laboratorium Inżynierii Produkcji i Jakości AGH, ze szczególnym uwzględnieniem modułu OEE, który został szczegółowo opisany i oceniony pod kątem jego korzyści. System integruje dane z różnych urządzeń produkcyjnych, dostarczając informacji o wydajności stanowisk w czasie rzeczywistym. Dodatkowo omówiono kluczowe technologie IoT wykorzystywane do monitorowania produkcji oraz architekturę systemu, która zapewnia elastyczność i skalowalność. Ponadto przedstawiono, w jaki sposób moduł OEE przyczynia się do zwiększenia dostępności, produktywności i jakości, ograniczenia przestojów oraz usprawnienia podejmowania decyzji dzięki wczesnemu wykrywaniu nieprawidłowości i szczegółowej analizie operacyjnej.

Słowa kluczowe: *OEE, IoT w produkcji, monitorowanie procesu produkcyjnego, efektywność produkcji*