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Article

Automated system for OEE management in the industrial sector

Diego Gomez[1,*], **Sofia Pantoja**[1], **Enoc Acosta**[1], **David Arrieta**[1] **and Sebastian Gutierrez**[1]

[1] Department of Electrical and Electronics Engineering, Universidad del Norte, Barranquilla, Colombia.
[*] Correspondence: dgomez@uninorte.edu.co

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Abstract: In today's fast-paced manufacturing environment, the need to monitor production processes is becoming increasingly urgent. As companies strive to remain competitive in the Industry 4.0 era, they seek innovative solutions to enhance efficiency. This project addresses that need by providing a solution to capture OEE (Overall Equipment Effectiveness) measurements from machines in the drum-filling industry, specifically targeting semi-automatic equipment. The primary objective is to streamline decision-making and improve data management performance. In collaboration with Alianza Team S.A., this article outlines the detailed design and development process of a web platform called AutOEE, which integrates the Snap7 communication technology. Additionally, the article presents technical experiments, including tests conducted using a PLC provided by ELEIA to simulate real production environments. These tests verified system stability, web interface responsiveness, and accurate data extraction, with reconnection features to recover from connectivity loss. The platform also supports real-time and historical OEE data visualization, with customizable views for specific days and shifts. User feedback, gathered through a web interface test with randomized data, was overwhelmingly positive (98%), praising ease of use, relevance, and load times. However, suggestions for improvement included simplifying access to historical data, adding PDF report generation, improving security, and enhancing error reporting. These insights will guide future platform updates.

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1. Introduction

Alianza Team, a leading food manufacturing company, strives to continuously improve efficiency and innovation in its production processes. To maintain its competitive edge, the company aims to optimize equipment performance, reduce downtime, and maximize production, with particular focus on its oil drum filling line. Even minor inefficiencies in this line can accumulate into significant losses over time.

A crucial tool in this optimization effort is Overall Equipment Effectiveness (OEE), a widely used metric that provides actionable insights into equipment performance by identifying hidden capacity, reducing

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overtime, reducing production times, and lowering capital expenditures [1]. OEE is recognized around the world and applied in various industries, including similar systems such as automated bottle filling machines [2, 3]. As a widely accepted benchmark for evaluating manufacturing performance, OEE plays a pivotal role in the Total Productive Maintenance (TPM), Lean Manufacturing, and Six Sigma frameworks [4, 5]. Recent studies have proposed integrated methodologies combining facility condition assessment (FCA) with lean manufacturing principles to enhance decision-making in industrial facility management. For instance, Guillén et al. [6] developed a framework that successfully improved productivity and reduced quality issues in a chemical production plant. Its application enables industries to uncover hidden capacity, minimize downtime, and improve operational efficiency on production lines [1]. This holistic approach to equipment monitoring is crucial to identify bottlenecks and drive continuous improvement initiatives that directly impact productivity and profitability. Despite its recognized importance, many companies, especially in developing economies, still rely on manual or semi-manual methods to calculate OEE, leading to inaccuracies, delayed decision making, and missed opportunities for improvement [7]. This disconnect between best practices and actual implementation reflects a significant gap in current industrial practice, where the full potential of OEE remains unexplored. Bridging this gap through automation and real-time analytics is essential to meet the demands of modern, data-driven manufacturing environments. Such advancements not only improve accuracy and responsiveness but also empower managers and operators with actionable insights to optimize equipment performance and reduce waste [8].

Currently, Alianza Team calculates OEE manually—a process that is labor-intensive and prone to human error. This project seeks to address these challenges by focusing on the semi-automated oil drum filling machine, where an operator positions and initiates the filling process. By enhancing OEE monitoring, the company can gain deeper insights, reduce waste, and ultimately improve productivity. The proposed solution is an automated system that collects, stores, and visualizes real-time data, making it easier to analyze trends and make informed decisions. The main objective is to develop an automated system that captures real-time production data, calculates OEE instantly, and presents it in a user-friendly format. This requires identifying, analyzing, and defining critical data points essential for accurate OEE calculation, leading to the creation and deployment of a comprehensive OEE management system. The prototype's usability was validated through an internal survey conducted at Alianza Team, providing real-time monitoring and historical data access through a secure web platform. Tailored user interfaces enhance the experience for various roles within the company, ensuring Alianza Team has everything needed to leverage the system for sustained production efficiency improvements.

The AutOEE project is a response to the industry's growing demand for optimization and efficiency, particularly in monitoring and enhancing production line performance. OEE has become a standard metric in industrial performance evaluation, measuring availability, performance, and quality. Recent research, such as that by Ng Corrales and colleagues, provides a comprehensive review of methods for calculating and applying OEE, offering companies tools to identify improvement opportunities and maximize productivity [9]. Originating from Seiichi Nakajima's Total Productive Maintenance (TPM), OEE remains central to reducing downtime and optimizing machine performance [10]. It is also key within Lean and Six Sigma frameworks; for example, Six Sigma increased OEE from 70% to 80% in a semiconductor case study and improved OEE by 21.6% in the paper industry, demonstrating these methodologies' positive impact on equipment performance [11].

Recent advancements in data-driven methodologies, such as performance analytics and predictive maintenance, are helping companies pinpoint areas for improvement with precision[12][13]. AutOEE embraces this shift toward data integration by replacing manual processes with automated systems that streamline data collection and analysis, driving efficiency gains [14]. Enabled by communication protocols like Snap7, developed by Davide Nardella, AutOEE facilitates seamless interactions between industrial devices, reducing losses and enhancing flexibility [15]. By supporting both TCP/IP and S7 protocols, Snap7 ensures that S7 PLCs can communicate across various devices, enabling command-oriented data access in real-time. Integrated with IoT and AI within smart manufacturing systems, AutOEE enables real-time OEE monitoring. Active collaboration with the client—a core element of the AutOEE development methodology—further reflects best practices in custom software projects [16].

Additionally, when evaluating OEE software options, both open-source and commercial platforms present distinct advantages depending on the operational context and scalability requirements. Commercial systems such as FactoryTalk or SIMATIC offer mature, feature-rich environments with strong vendor support and full integration into proprietary ecosystems. These solutions typically demand high upfront costs, recurring licensing fees, and often lock users into specific hardware or software stacks, limiting flexibility and long-term adaptability [17,18], thereby widening the gap between SMEs and large enterprises. Recent studies have highlighted that small and medium-sized enterprises (SMEs) often lack mature digital transformation strategies and tools, limiting their ability to adopt integrated OEE monitoring systems [19]. In contrast, open-source platforms like OpenOEE promote greater flexibility, transparency, and cost-efficiency, making them especially attractive for small and medium-sized enterprises with limited budgets or unique operational needs [20, 21]. These systems allow users to customize and extend functionality without relying on vendor constraints, facilitating innovation and rapid iteration in dynamic manufacturing environments.

AutOEE adopts and extends this open-source philosophy by delivering a modular, vendor-neutral architecture that can be adapted to diverse industrial contexts. This approach not only reduces costs but also empowers manufacturers to maintain full control over their digital infrastructure, ensuring that the system can evolve alongside changing business needs. By prioritizing openness, scalability, and extensibility, AutOEE positions itself as a future-proof alternative to rigid commercial platforms. Furthermore, the project's emphasis on continuous client collaboration and iterative refinement exemplifies industry best practices in the development of customized industrial software solutions [22].

The S7 protocol has the advantage of being command-oriented, allowing access to specific data blocks within a PLC's memory. Based on ISO TCP, the encapsulation of these protocols is shown in Figure 1.

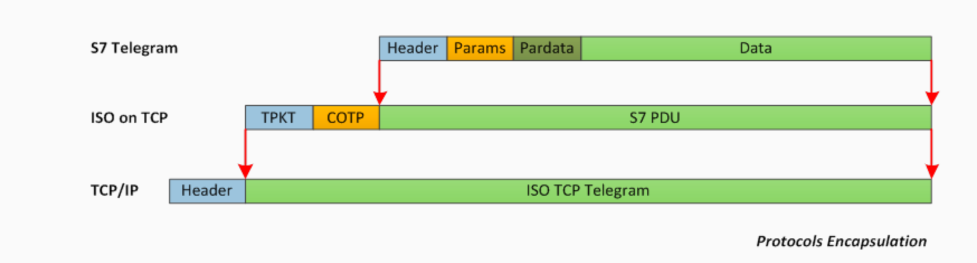


Figure 1. Protocol Encapsulation.

Snap7 operates around three primary objects: the client, the server, and the partner. As seen in Figure 2, the web platform development focuses on the client object. The client can read or write data to the PLC's memory and even alter its functioning. When using this object, the PLC acts as a server, responding to the client's requests.

One of Snap7's key advantages is its non-intrusive nature. Using Snap7 does not require altering the server (PLC); it only requires port access, and the communication service is managed by the communication processor's firmware, as shown in Figure 3.

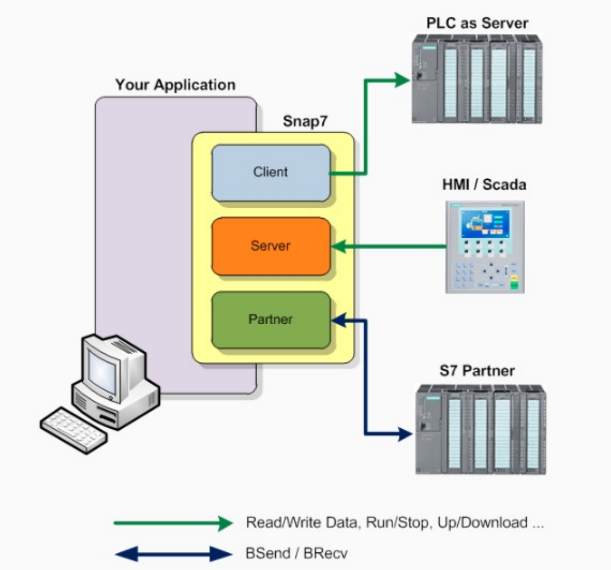


Figure 2. Snap7 Objects.

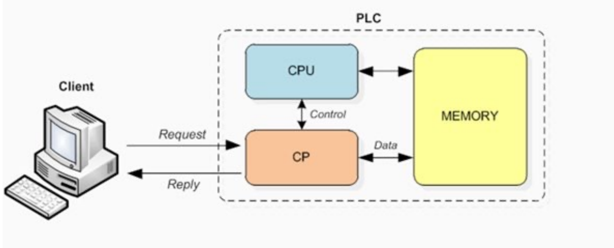


Figure 3. Snap7 Client and Server.

2. Methods and Materials

Snap7 is compatible with multiple languages, including C/C++, .NET/Mono, Pascal, LabVIEW, Python, and Node.js [15]. Furthermore, adopting non-relational databases like MongoDB supports the growing need to handle vast data volumes with flexibility, allowing for efficient real-time analysis [23]. Agile development methodologies have been key in building this system, with close collaboration ensuring solutions meet the unique requirements of each production process [24]. Research shows that real-time data visualization enhances resource organization and minimizes losses [25], making interactive graphical interfaces valuable for experienced and new users alike. Systems like AutOEE are further amplified by storing historical data, enabling performance evaluations over time and driving positive impact across industries [26].

The integration choices with the PLC, particularly the use of Snap7 technology to access memory without modifying the original PLC program, ensure system scalability. This non-intrusive approach enables seamless communication with the PLC, allowing developers to retrieve and monitor key process variables without halting or altering established automation logic. As a result, new data points and functionalities can be added incrementally—such as additional sensors, KPIs, or operational alerts—without interrupting ongoing production activities. This flexibility is particularly valuable in dynamic manufacturing environments where adaptability and continuous improvement are essential. Moreover, by employing a Node.js server environment capable of handling asynchronous operations, the system can efficiently process multiple real-time data requests, supporting an increase in connected devices or data complexity without compromising performance or stability. Thus, the designed integration not only addresses current operational requirements but also establishes a future-ready platform capable of evolving alongside industrial needs, supporting long-term digital transformation strategies and sustainable growth. [27,28].

2.1. Regulatory Framework

This project adheres to legal and technical standards to ensure compliance and security. A primary regulatory guideline is Law 1273 of 2009, which prevents unauthorized data transfer through computer manipulation [29]. Additionally, relevant technical standards for component quality, machine safety, and platform integrity were applied to meet the project's requirements.

2.2. Project Constraints

The project was shaped by several important constraints that influenced its design and implementation. Firstly, the client's specific requirements played a crucial role in defining the project's scope. As the solution was tailored specifically for Alianza Team, the development had to adhere strictly to their operational and technical needs. Additionally, the project's deployment was limited to Alianza Team's local server, preventing the use of cloud-based solutions and thereby increasing the potential for hardware-related issues and downtime. This limitation also restricted scalability, as the project could only function within the confines of the existing infrastructure. Furthermore, the team's composition and project timeline introduced additional constraints. With only three engineers working on the project and a fixed timeline, the scope was focused on developing a solution for a single machine to ensure feasibility and timely delivery. These constraints, while challenging, were instrumental in defining the project's boundaries and guiding its development to meet both the client's needs and the available resources.

2.3. Development Methodology

The development process followed a structured four-stage methodology to ensure a comprehensive approach to technical development and client collaboration.

The four stages are detailed as follows:

- **Preparation Stage:** Familiarization with the PLC S7-300 and conveyor belt systems.
- **Client Collaboration:** Meetings to align project objectives and define operational needs.
- **Data Extraction Planning:** Designing data capture methods to ensure real-time accuracy.
- **Prototype Development:** Creating a functional platform tailored to Alianza Team's requirements.

2.3.1. Preparation Stage

The initial phase focused on gaining familiarity with the key components of the system. The team worked directly with the laboratory's PLC S7-300 and the conveyor belt system, programming using Ladder logic and TIA Portal. This phase was crucial for understanding the machine's existing functionality, the specifics of data control and automation, and the technical capabilities of the PLC system. This hands-on experience provided the foundation for subsequent stages, enabling the team to identify the most suitable methods for interfacing with the machine and extracting critical production data.

2.3.2. Client Collaboration

During this stage, the team engaged in collaborative meetings with Alianza Team to understand their specific operational needs and challenges. The team analyzed the current setup of the machine, established a clear understanding of the required outputs, and discussed potential infrastructure changes. This phase was essential for aligning the project with the client's vision and ensuring that the solution was tailored to meet their operational goals. These discussions also served to define key parameters such as the types of data to be extracted and how they would be used to assess production performance.

2.3.3. Data Extraction Planning

With a clear understanding of the client's needs and the machine's setup, the next phase involved detailed planning for the data extraction process. The team carefully designed an approach that would efficiently capture production-related data from the PLC, ensuring minimal impact on the ongoing production process. The planning considered the best methods for real-time data capture, processing, and storage, ensuring accuracy and consistency in the data collection. The design took into account factors such as the frequency of data retrieval, the system's processing capacity, and the required level of granularity in the data.

2.3.4. Prototype Development

The final stage focused on the development of a functional web prototype, incorporating a database, server program, and a user interface tailored to Alianza Team's requirements. The prototype was designed to display key production metrics, such as Overall Equipment Effectiveness (OEE), and provide access to historical data for detailed analysis. The team used iterative development methods, testing the prototype through simulations with ELEIA to refine functionality and usability. After addressing any issues identified during the testing phase, the prototype was deployed on Alianza Team's local server. The final step involved collecting feedback from users through a survey, which provided insights for further refinements and improvements to the system.

2.4. Engineering Design

The engineering design process began with a thorough analysis of Alianza Team's requirements, which led to the definition of key design elements aimed at addressing the company's needs while ensuring smooth integration into existing workflows:

- **Memory-Only PLC Access**: Data was extracted from the PLC without altering its existing programming, ensuring minimal disruption.
- **Visual Style**: The web interface was aligned with Alianza Team's existing visual framework to ensure ease of adoption by users.
- **Turn-Based OEE Calculations**: The system was designed to calculate OEE metrics for each work shift.
- **Data Histories**: The platform generates reports by date and shift, capturing reasons and durations for unplanned machine stops.
- **User Interfaces**: Four tailored user interfaces—operator, production, maintenance, and management—were developed to meet the specific needs of each team, without disrupting their daily tasks.

To meet the requirement of extracting memory from the PLC, Snap7 technology was selected. This client-server technology facilitates communication between the server and the PLC, enabling requests to specific data blocks within the PLC. The team utilized a Snap7 wrapper in the form of a library within the Node.js runtime environment. Although other programming languages also supported Snap7, Node.js was chosen for its ability to handle asynchronous functions efficiently and its extensive documentation, which made the integration process smoother.

Although Snap7 allowed for memory access without modifying the PLC's ladder logic, some minor alterations were inevitable. However, these changes were far less disruptive compared to other options, such as establishing a UDP connection with the server or hosting a web server directly on the PLC. The primary goal was to minimize impact on the company's workflow and ensure the platform was easy for employees to adopt.

For the visual design of the web platform, the team drew inspiration from previous work within the company (as seen in Figure 8) but enhanced it by incorporating layout blocks that improve content organization and space utilization. Rather than using complex frameworks, the team opted for plain JavaScript to maintain full control over the design, ensuring the platform was both functional and easy to maintain.

To meet the requirement of calculating OEE on a shift basis, the team leveraged Node.js's extensive library, which enabled the definition of routines triggered at specific times throughout the day. This streamlined the process of calculating OEE per shift, allowing the system to accommodate different work schedules and production times efficiently.

A non-relational database was implemented to meet the need for storing and accessing historical data. The team chose MongoDB due to its simplicity and flexibility. Given that the project involved only a small number of collections with minimal relationships, MongoDB was the ideal solution. Furthermore, the team's familiarity with MongoDB made it a natural choice [23].

The platform features four distinct user interfaces tailored to different roles within the company:

- **Operator Interface:** Provides basic functionality, with operators unable to access historical OEE data.
- **Production Interface:** Used for entering defective units into the system.
- **Maintenance Interface:** Focuses on tracking downtime and productive time.
- **Management Interface:** Simple and streamlined, designed to provide essential information for decision-making.

Each interface was designed to present relevant functionality based on the user's role, ensuring that the platform was intuitive and aligned with daily tasks. To avoid disrupting workflows, the platform does not require a login system, allowing users to quickly access the system and get to work without additional steps.

Overall, the design process ensured that the platform would meet Alianza Team's functional needs, improve efficiency, and seamlessly integrate with existing workflows.

2.5. System Design

Before proceeding with the system design, it was essential to define the OEE specifications at Alianza Team. The following points were clarified during this phase:

- Any downtime greater than five minutes was considered an unplanned stop.
- The nominal production speed was set at 2 containers per minute.
- Work shift schedules were defined as three shifts of 8 hours each per day.
- Due to the process workflow, the quantity of rejected items is only known days after they are filled. Therefore, it was decided that the user would be responsible for entering this data, and real-time quality metrics were disabled.

The system's operation can be divided into four continuous stages: **Extraction, Calculation, Storage, and Visualization**. Figure 4 illustrates the overall structure of the system and the interactions between each stage.

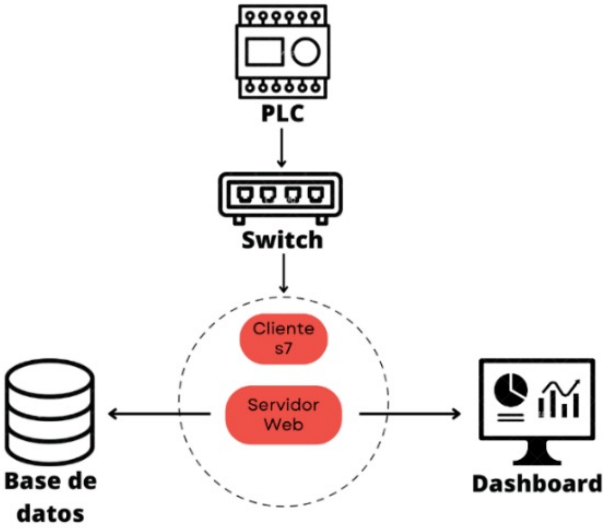


Figure 4. Block Diagram.

2.5.1. Extraction Stage

In this initial stage, the system uses Snap7 technology to read data directly from the PLC. This data includes variables that are either already present in the PLC's existing programming or have been modified with counters and timers to capture essential machine states, downtime periods, and other key metrics. These variables are crucial for determining Overall Equipment Effectiveness (OEE) by tracking real-time production conditions without modifying the core PLC programming.

Data extraction from the PLC takes place every five seconds, ensuring timely updates. Some of the extracted data is also immediately stored in the database to facilitate future calculations and reporting, creating a record of machine performance over time. By logging key variables this frequently, the system can deliver an accurate and responsive view of machine status and efficiency.

2.5.2. OEE Calculation

The OEE calculation is based on machine state conditions, which are determined by the status data extracted from the PLC. The system categorizes machine states into three key conditions—"Run," "Stand-By," and "Stop"—each affecting OEE components in a distinct way:

- **Run State:** When the machine is in "Run," the system interprets this as productive operation. In this state, machine availability is not impacted, as the machine is actively producing. However, any reduction in the operator's speed while in "Run" directly influences the performance aspect of OEE.
- **Stand-By State:** The "Stand-By" state represents scheduled stops, such as planned breaks or maintenance. Since these stops are anticipated, they do not affect any component of the OEE calculation.
- **Stop State:** When the machine enters "Stop" state, this signals an unplanned interruption. The system marks these downtimes as unplanned and counts them against the availability metric, lowering the availability score. In this state, the system also records the duration of downtime and assigns a specific stop code, which allows for further analysis of common interruption causes.

The formulas used to calculate OEE components—Availability, Performance, and Quality—are designed to measure productivity in the context of these states. The formulas are as follows:

- **Availability (D)**, measures the proportion of time the machine is available for production:

$$D = \frac{(8hrs - \text{Scheduled Downtime}) - \text{Unplanned Downtime}}{8hrs} \times 100\%.$$

- **Performance (R)**, reflects the production speed relative to the nominal speed of 30 units per second:

$$R = \frac{\text{30 units per second} \times \text{Units per shift}}{\text{Available time}}.$$

- **Quality (C)**, represents the proportion of produced units that meet quality standards:

$$C = \frac{\text{Produced units per shift} - \text{Defective units}}{\text{Produced units per shift}} \times 100\%.$$

These calculations allow the system to deliver a real-time and historical view of OEE, aligned with operational needs and machine states, providing valuable insights into production efficiency and areas for improvement. Figure 5 illustrates how the data is extracted from the PLC and the subsequent OEE calculation process, based on the formulas provided.

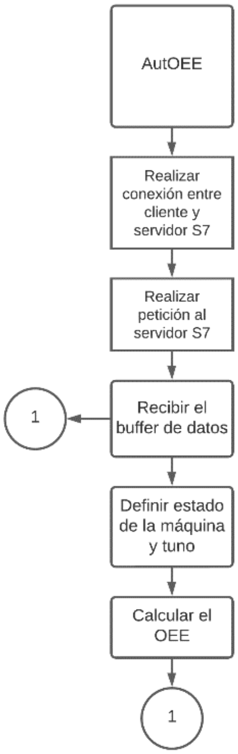


Figure 5. Data Extraction and Calculation.

2.5.3. Visualization Stage

The client-side application is designed to continuously update the machine's status and OEE (Overall Equipment Effectiveness) values by requesting data from the server every five seconds. This frequent polling ensures that the interface reflects real-time data, allowing users to monitor the performance of the machine and identify any issues promptly.

The user interface is also designed to enable the generation of detailed reports based on specified date ranges. Report generation is handled via database queries based on a date range. The quality parameter is applied for each shift and day, using the stored machine data and user-entered values. These reports provide insights into the performance of the machine, including efficiency and defect data. The system calculates quality metrics, including OEE, for each shift, using stored production data and defect counts. By utilizing this shift-based calculation, the platform ensures that users can evaluate performance in a time-sensitive manner, reflecting the unique conditions of each work shift.

Figure 6 illustrates the flow of data between the client-side application and the server, highlighting how the client makes requests every five seconds to retrieve updated machine status and performance data.

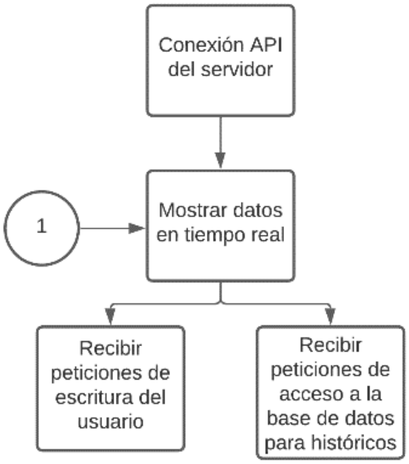


Figure 6. Visualization Block Diagram.

2.5.4. Database Connection Stage

In the final stage of the project, the system was fully integrated with the database to log and store data systematically. A critical part of the system's design was ensuring that the data flow was streamlined and that the system could handle large amounts of real-time and historical data efficiently. OEE data, along with user-entered defect counts, are stored in separate collections within the database to simplify access and reporting.

The database is structured to allow easy retrieval of historical performance data. Users can generate reports that provide insights into past production performance, including reasons for machine downtime, durations of unplanned stops, and other key metrics. This functionality is essential for ongoing performance evaluation and process improvement.

To illustrate the complete integration of the system, Figure 7 depicts the overall data flow from the client application to the server, the interactions with the database, and the process of logging OEE data and

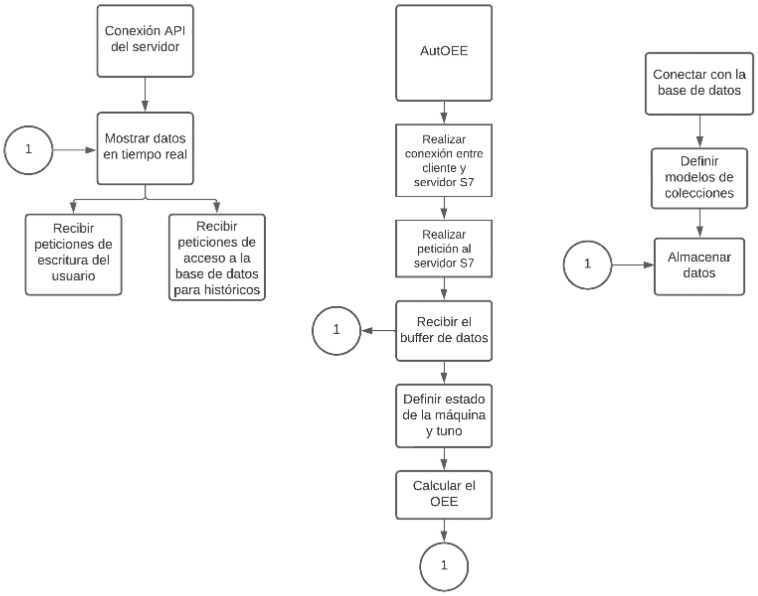


Figure 7. AutOEE Block Diagram.

defect information. It also shows how the system's components work together to provide real-time and historical performance insights, highlighting the seamless integration of the various parts of the system.

3. Experimental Test and Results

The testing phase was conducted in collaboration with ELEIA, an integrator company that provided access to a PLC in a controlled environment. This PLC closely simulated the filling machine on Alianza Team's production line, making it an ideal setting for validating the algorithm's functionality without impacting actual production. Over several weeks, extensive tests with this PLC were conducted, progressively refining the system toward the desired performance goals.

The tests involved the continuous operation of the PLC to verify system stability, inputting various data points to observe the responsiveness of the web interface, and simulating different PLC states (*Run*, *Stand-by*, *Stop*) to ensure that the interface accurately displayed the corresponding status.

Testing began with data extraction from the PLC at different time intervals, ranging from 1 to 5 seconds, achieving 100% data accuracy across all intervals. Reconnection tests were also performed to verify that the program could resume operation after a connection loss without requiring a complete restart, resulting in the addition of a Snap7 reconnection feature [15]. Furthermore, tests at various times throughout the day were conducted to verify accurate OEE calculations and data storage during shift changes.

The final results are illustrated in Figure 8, where data from the PLC is received by the local server and displayed on the real-time graphical interface. Figure 9 shows the OEE values segmented by the three work shifts for any date range selected by the user.

At the top of the historical interface, users can select a specific day with a slider and choose the work shift, allowing a detailed view of each shift across multiple days. A line chart displaying OEE values over the selected days and a Pareto pie chart for stoppages are also included, as shown in Figure 10.

To validate user experience, a web-based interface with sample data was developed to be accessible both inside and outside the company, facilitating ease of access for usability surveys. This interface allows potential Alianza Team users to become familiar with the system. The survey included responses from

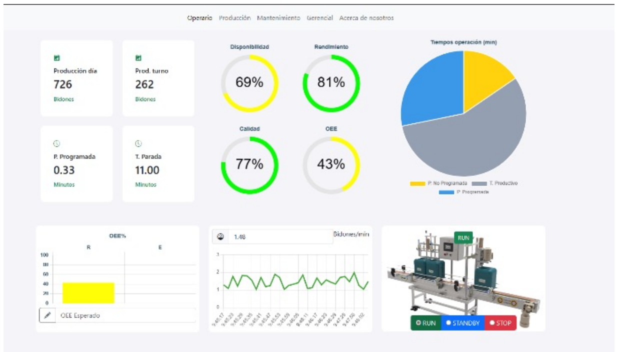


Figure 8. Real-Time Interface.

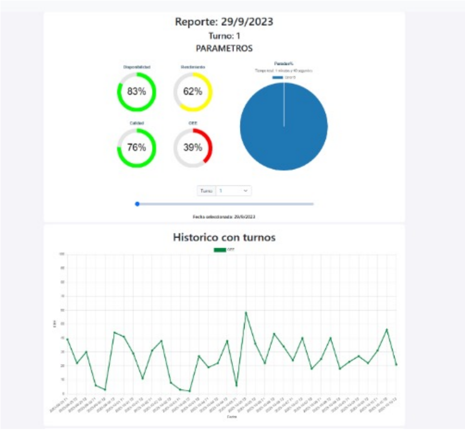


Figure 9. Historical Data Interface.

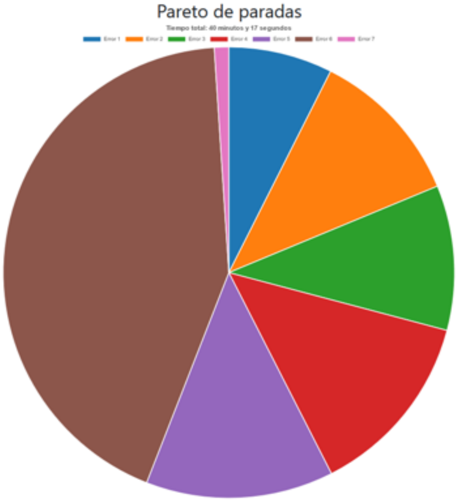
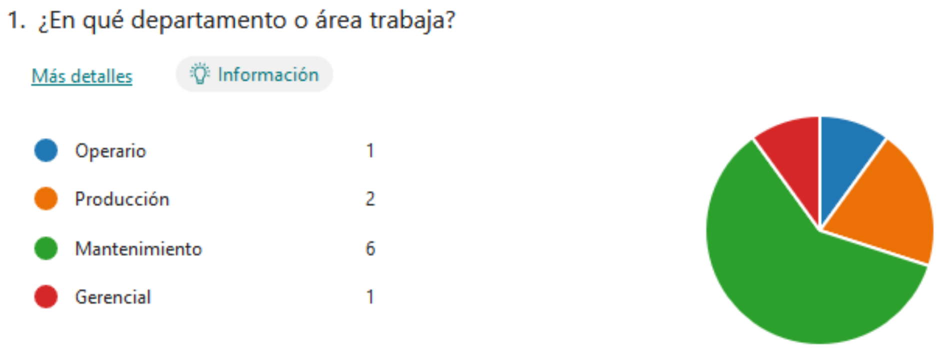


Figure 10. Overall Pareto of Stoppages.

ten participants, seven from Alianza Team and three from ELEIA, spanning maintenance, production, management, and operations personnel. Figure 11 shows the personnel distribution.

The survey revealed that respondents from maintenance areas found the web interface intuitive and easy to access, with an 83% positive response rate, Figure 12. Users noted good load times and straightforward navigation, while also affirming the information provided was relevant and useful for their respective roles. However, a production user mentioned difficulty accessing historical data, which will be addressed in future updates. Other feedback highlighted additional feature requests, such as downloadable reports for later consultation, improved security for stop data entry (suggesting the use of an access key), the inclusion of reprocessing counts, shift changes in reports, and a transition from a Pareto chart to a vertical bar chart.

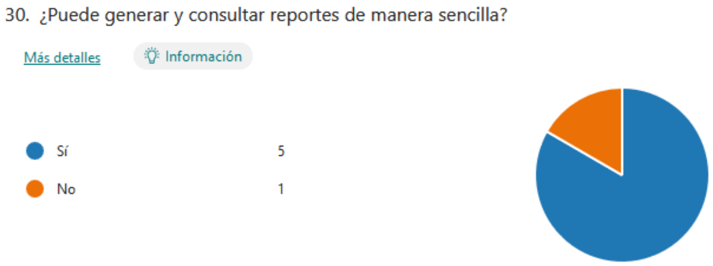
In the maintenance section, respondents suggested adding various features to enhance usability and functionality. They recommended replacing the Pareto chart with a line graph to improve data visualization, as well as tracking the number of reprocesses to offer deeper insights into operational efficiency. Users also expressed interest in the ability to edit shift schedules, which would provide greater flexibility in managing production data. It was proposed to replace the slider with a drop-down menu for easier navigation, along with implementing enhanced security measures to protect sensitive information. Additional suggestions



1. ¿En qué departamento o área trabaja?

● Operario	1
● Producción	2
● Mantenimiento	6
● Gerencial	1

Figure 11. Survey Workspace.

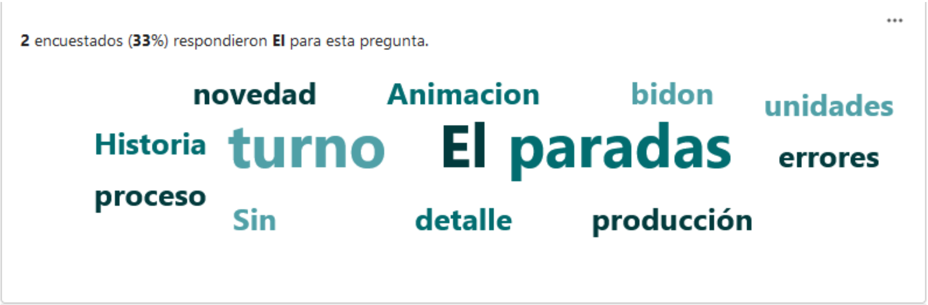


30. ¿Puede generar y consultar reportes de manera sencilla?

● Sí	5
● No	1

Figure 12. Maintenance Report Interface.

included enabling PDF report generation for convenient record-keeping, displaying daily production data in historical reports, and incorporating animations to visually represent the production process, as presented in Figure 13. Finally, respondents requested a more detailed categorization of stoppages, allowing for more granular analysis of downtime causes. These insights highlight specific user needs and potential areas for improvement.



2 encuestados (**33%**) respondieron **El** para esta pregunta.

Figure 13. Additional Maintenance Information.

3.1. User Feedback and Interpretation

To provide a concise overview of the system's reception, Table 1 summarizes the key findings from the survey, integrating both quantitative metrics and qualitative insights from maintenance and production personnel. The analysis revealed positive impressions about usability, but also specific recommendations for enhancement.

This feedback will guide future improvements and adjustments, ensuring AutOEE's continued alignment with user needs and its potential for broader integration into production environments.

Table 1. Summary of User Feedback and Interpretation

User Feedback	Interpretation
83% of respondents found the interface intuitive and easy to navigate.	The platform's user-centered design meets the expectations of maintenance staff and aligns with usability goals.
Users confirmed fast load times and easy access to relevant operational data.	System performance and content accessibility are adequate for daily operations.
A production user reported difficulties accessing historical data.	Highlights a need to improve the historical query module for broader accessibility.
Requests for downloadable reports (e.g., in PDF format) for later review.	Indicates demand for offline access and better data portability.
Suggestion to add password protection for critical inputs like stop entries.	Security concerns are valid and warrant implementation of access control mechanisms.
Desire to replace Pareto charts with vertical bar or line graphs.	Users seek clearer, more interpretable data visualizations.
Proposal to include reprocessing counters and more detailed shift-change tracking.	Adds granularity to performance metrics, enriching process analysis.
Request to replace slider controls with drop-down menus for date navigation.	Aims to simplify navigation and improve input precision.
Interest in animated representations of production flows.	Users value dynamic and engaging visualizations that enhance understanding.
Call for more detailed categorization of stoppages.	Indicates the need for refined failure analysis to support continuous improvement.

4. Discussion

The implementation of AutOEE presents both significant advancements and areas for further improvement in optimizing production line efficiency. Through a meticulous testing process with ELEIA's support, AutOEE demonstrated its potential in capturing real-time data and calculating OEE metrics reliably in a simulated environment, closely mirroring actual production conditions at Alianza Team. The system's ability to display real-time status changes—such as shifts between *Run*, *Stand-by*, and *Stop* states—proved effective in ensuring that personnel could monitor machine performance accurately and respond to downtime events promptly.

A key benefit of AutOEE is its capability to extract data at variable intervals and maintain accuracy even during connectivity interruptions, thanks to the Snap7 reconnection feature [15]. This adaptability highlights the system's resilience in environments prone to network disruptions. However, some limitations were observed in user accessibility and functionality, as shown through feedback from both ELEIA staff and Alianza Team employees.

The survey results revealed several user experience improvements that could make AutOEE a more comprehensive tool for operators and managers alike. The suggestions for additional features—such as editing shift schedules, generating PDF reports, and providing detailed categorization of stoppages—illustrate the need for a flexible and user-friendly interface. Enhanced security measures were also suggested, underscoring the importance of data protection within operational software [23].

Implementing these enhancements would not only meet the immediate needs of the users but also contribute to a scalable solution that can adapt to varying production requirements.

4.1. Addressing Limitations and Future Directions

While AutOEE has proven successful in addressing the immediate operational needs of Alianza Team, some limitations were identified during the development and testing phases. One of the main constraints is the reliance on local network infrastructure, which limits scalability and introduces potential points of failure during network disruptions. To address this, future iterations of the system could explore hybrid solutions combining local and cloud-based architectures, ensuring both reliability and scalability.

Additionally, feedback from users highlighted challenges in accessing and visualizing historical data efficiently. Simplifying the user interface and incorporating advanced filtering options could significantly improve the usability of the platform. Security measures, such as encrypted communication and access keys for critical operations, were also suggested as necessary enhancements to align with industry standards for data protection [23].

While the proposed prototype successfully addresses the specific operational needs of the Alianza team, it presents certain limitations. These include the absence of integrated predictive analytics, a fixed data model adapted to the current industrial layout, and limited interoperability with third-party systems. Additionally, some interface components require further validation in high-throughput environments.

Despite these constraints, the architecture and modular design of the system allow for scalability across different industrial sectors. By abstracting the data input layer and employing standard communication protocols, the system can be adapted to various production contexts such as food processing, packaging, and assembly operations, with minimal reconfiguration.

Finally, expanding the system's modularity to accommodate multiple PLCs and production lines is crucial for broader adoption. Future efforts will focus on implementing a distributed architecture capable of supporting larger-scale operations, which would pave the way for comprehensive performance monitoring across multiple facilities.

5. Conclusions

The implementation of AutOEE marks a substantial step toward optimizing efficiency in the production line. The pressing need for accurate, real-time insights into machinery performance drove the development of a system that automates OEE calculations, delivering clear benefits for decision-making and continuous improvement. Close collaboration with the client, including regular on-site visits and adjustments tailored to specific company requirements, has strengthened the relevance and practical value of AutOEE.

While the system has achieved significant successes, there are technical limitations, particularly its reliance on the local network and its focus on a single machine. These constraints highlight the need to explore enhanced connectivity options to increase the system's flexibility and scalability. Despite these limitations, extensive testing with real-time and simulated data has validated the system's reliability and functional accuracy. The ability to provide real-time data visualization along with access to historical records has met the client's initial expectations and requirements.

To ensure AutOEE's continued success, several recommendations can further enhance its impact: exploring alternative connectivity options, conducting staff training sessions, and implementing ongoing monitoring to maintain system effectiveness. Additionally, future-proofing the system with a modular design would support easy expansion and adaptation to evolving client needs, including addressing user feedback and recommendations gathered through surveys.

In summary, AutOEE not only meets Alianza Team's current needs for operational efficiency and informed decision-making but also lays a foundation for ongoing improvement and the potential to expand into additional production areas, supporting a sustainable pathway toward long-term productivity gain.

Future work will focus on extending the pilot system into a robust production-ready solution by incorporating advanced features requested by users, such as detailed stoppage categorization, downloadable PDF reports, and secured data entry mechanisms. Integration with predictive analytics and machine learning models for anomaly detection is also planned, along with the deployment of mobile-friendly interfaces and enhanced visualizations tailored for decision-makers. In addition, scaling the system across multiple production lines and facilities is envisioned to validate its adaptability and long-term impact on operational efficiency. Finally, future work will focus on extending the pilot system into a robust production-ready solution by incorporating advanced features and structured improvement methodologies, as suggested by Guillén et al. [6], to systematically enhance equipment effectiveness.

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