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Design and Implementation of a Cloud-Based Manufacturing Execution System for SMEs

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ABSTRACT

This study proposes a multi-tenant, modular, microservices-based, cloud-based MES system designed to meet the digital transformation needs of small and medium-sized manufacturing enterprises (SMEs). The platform is designed as a microservices-based Software-as-a-Service (SaaS) solution accessible via a standard web browser. The platform provides RESTful API support to facilitate easy integration with other applications. A key contribution of the proposed model is its ability to provide real-time data processing and advanced analytics capability. The system provides instantly monitoring of basic production data such as production tracking, downtime-quality analysis, and Overall Equipment Effectiveness (OEE) calculations. In addition to OEE components analysis, the platform supports resource planning and automation processes, document viewing on operator terminals, and event-based alarms for critical production events. Implementation results demonstrates that SME's can obtain actionable production insights(e.g., OEE trends, downtime loss) with a low deployment effort and scable cloud architecture.

Keywords **:** Manufacturing Execution Systems, Cloud Computing, Smart Manufacturing

KOBİ'ler için Bulut Tabanlı Üretim Yürütme Sisteminin Tasarımı ve Gerçekleştirilmesi

ÖZ

Bu çalışma; küçük ve orta ölçekli işletmelerin (KOBİ) dijital dönüşüm ihtiyaçlarını karşılamak üzere tasarlanmış çok kiracılı, modüler ve mikro hizmet tabanlı bir bulut MES modeli önermektedir. Platform, standart bir web tarayıcısı üzerinden erişilebilen mikroservis tabanlı Hizmet Olarak Yazılım (SaaS) çözümü olarak tasarlanmıştır. Ayrıca, diğer uygulamalarla kolay entegrasyon sağlamak amacıyla RESTful API desteği sunmaktadır. Önerilen sistemin temel katkısı, gerçek zamanlı veri işleme ve ileri analitik yetenekleri sağlama kapasitesidir. Sistem; üretim takibi, duruş ve kalite analizi ile Genel Ekipman Etkinliği (OEE) hesaplamaları gibi temel üretim verilerinin anlık izlenmesini sağlamaktadır. OEE bileşen analizine ek olarak platform; kaynak planlama ve otomasyon süreçlerini desteklemekte, operatör terminallerinde doküman görüntüleme imkanı sunmakta ve kritik üretim olayları için olay tabanlı alarm mekanizmaları sağlamaktadır. Uygulama sonuçları, KOBİ'lerin düşük kurulum maliyeti ve ölçeklenebilir bulut mimarisi sayesinde üretim içgörülerini (örneğin; OEE trendleri, duruş kayıpları) etkin bir şekilde elde edebileceğini ortaya koymaktadır.

Anahtar Kelmeler **:** Üretim Yürütme Sistemleri, Bulut Bilişim, Akıllı Üretim

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INTRODUCTION

Manufacturing companies are under constant pressure to improve efficiency and quality while responding to fluctuating demand, shorter delivery times, and increasing product variety. At the same time, these pressures make unplanned downtime, speed losses, and quality defects more critical and important, increasing the need for real-time, data-driven decision-making on the production floor (Sahoo & Lo, 2022). Aside from the challenges brought by the competitive environment, transformations in information technology provide an environment to take production processes further. To be competitive, manufacturing facilities need to be aware of these transformations and keep up with them. The most important condition leading to success here is to understand important developments and to change the course in the right direction at the right time and with the right methods. Considering these factors, manufacturing companies need to be flexible and agile to keep up with the world. Therefore, the ability to collect, contextualize, and act on production data in real time is a key requirement for smart manufacturing initiatives (Mantravadi & Møller, 2019).

Manufacturing Execution Systems (MES) are an important layer between operational control and production floor applications. In line with the ISA-95 model (Czvetkó & Abonyi, 2023), MES supports the management of production operations by real-time monitoring, traceability, and coordination between the shop floor and higher-level business systems (Chen, 2005; Saenz de Ugarte et al., 2009). Recent systematic reviews indicate that MES implementations contribute to real-time decision support and operational efficiency within Industry 4.0 environments (Talan & Gupta, 2026).

In the past, many companies managed their facilities with simple, manual systems and spreadsheets. Cloud based manufacturing approaches provide increased flexibility, adaptability, and reduced system complexity in smart production contexts (Gharibvand et al., 2024). Now, with the decrease in technology costs and Software as a Service (SaaS) methods and cloud computing technologies, facilities of all sizes are investing in these software solutions to digitalize their processes and factories. Cloud-based systems offer easy access, simple maintenance, and low-cost solutions(Dutta et al., 2022; Pessl & Rabel, 2022). In addition, they promise hardware independence to companies; therefore, they especially lead the way for small and medium-sized enterprises to digitalize without making large investments.

Based on these needs, this study proposes a cloud-based MES model designed specifically for SMEs. The originality of the proposed model lies in its combination of (i) a modular architecture, (ii) a multitenant SaaS structure enabling tenant-level data separation, (iii) a microservice based application providing scalability, and (iv) an OEE centric operational model that transforms raw production floor events into actionable performance indicators. The model supports ERP and production floor/IoT integration via RESTful APIs and provides real-time dashboards and reports for production tracking, downtime analysis, quality loss monitoring, and Overall Equipment Effectiveness (OEE) trends.

The paper is organized as follows: Section 2 reviews MES and cloud-based MES studies. Section 3 presents the OEE-based operational methodology and the proposed system design. Section 4 describes the implementation, modules, and reporting interfaces of the prototype. Finally, Section 5 concludes the paper and outlines future research directions.

1. LITERATURE REVIEW

1.1. Manufacturing Execution Systems - The Journey of Digitalization of Manufacturing

The concept of Manufacturing Execution System (MES) emerged in the mid-1990s to address the Enterprise Resource Planning (ERP) layer's insufficiency in real-time management of operations on the shop floor. The MES concept was developed to make a connection between the shop floor and ERP layer (Saenz de Ugarte et al., 2009; Shojaeinasab et al., 2022).

With the development of internet systems and software technologies, especially after the 2000s, it has become clear that production processes cannot be managed only with applications such as enterprise resource planning due to various reasons, such as the change in the dimensions of competition, the expansion of supply chains, and the increase in product variety. Because, in order to manage manufacturing processes cost-effectively, the need to collect, analyze, and report the data generated in manufacturing processes has emerged. MES has started to be widely used in this sense, especially since the 2000s.

According to ISA 95 standards, a manufacturing system consists of five basic levels, as shown in Figure 1 (Chen, 2005; Mantravadi & Møller, 2019). The figure presents the five-layer architecture defined by the ISA-95 standard, highlighting the positioning of the Manufacturing Execution System (MES) between enterprise-level systems (ERP) and control systems. It demonstrates how MES facilitates data exchange and operational coordination across different organizational levels. MES connects the lower and upper levels as the unit that manages the production operations. According to the literature, MES is the management of many production operation activities such as production, maintenance, and quality. However, if real-time data collection and interpretation are not included, factories targeting digitalization will fall short in meeting customer needs (Chen, 2005). The use of computer-aided technologies is essential for the operation of all these structures.

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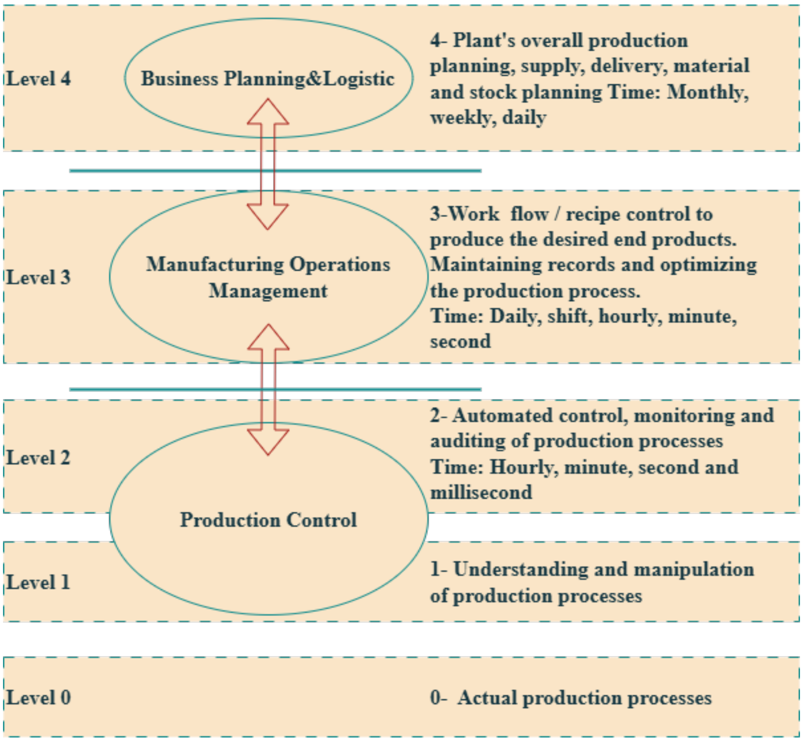

Figure 1: The ISA-95 Model

Historically, many companies' production departments opted for custom-designed information systems for their shop floors, gathering production data locally in spreadsheets or other databases. This approach complicated software maintenance and data connection (Mantravadi & Møller, 2019). Digital transformation is not just about installing specific software or hardware—it's a much more comprehensive change. It's part of a broader "business transformation" that involves redesigning business processes. Digital transformation moves traditional paper-based and manual processes into a digital environment, making information instantly accessible and centralized so that other supporting systems and decision-makers can easily access and use this data.

Digital transformation is critical for smart manufacturing companies. Many businesses that want to take part in the digital transformation journey are using different technologies to digitally evolve their manufacturing operations (Panchal & Shaikh, 2024). Small and medium-sized businesses may have limited ability to implement digitalization solutions such as MES. For example, they have budget constraints. Companies have limited budgets to invest in computers, servers, and software. Or they lack sufficient technical personnel to set up and maintain such systems (Helo et al., 2014).

1.2. Cloud-based Manufacturing Execution Systems

Cloud computing refers to the delivery of computing services—such as data storage, processing power, and software—over the internet instead of relying on local servers or personal devices (Mell & Grance, 2011). This shift emerged as organizations faced growing demands for scalable, cost-efficient, and accessible IT resources. Traditional infrastructures required substantial investment and maintenance, making them less practical for smaller enterprises. As data volumes increased and the need for remote access became more prevalent—especially with the rise of mobile technologies and global connectivity—cloud computing became a practical and necessary solution to meet modern business and user demands.

Cloud computing is generally categorized into three main service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) (Gharibvand et al., 2024a; Mell & Grance, 2011). IaaS provides virtualized computing resources over the internet, such as servers, storage, and networking hardware, allowing users to manage operating systems and applications without maintaining physical infrastructure. PaaS offers a platform and environment for developers to build, test, and deploy applications without dealing with the complexities of underlying infrastructure. SaaS, on the other hand, delivers fully functional software applications over the web, accessible via browsers, which eliminates the need for local installation or maintenance. These models offer varying levels of control, flexibility, and management, enabling businesses to choose solutions that best match their technical and operational needs.

Any web-based application can be used by the customer on-premises. However, the ideal stage for it to be fully compatible with the cloud infrastructure is to reach the SaaS level (Lenart, 2011). At this stage, the customer can use the application by simply renting from a ready environment without having to invest in any resources such as hardware, server, operating system, etc. Numerous manufacturers are now adopting a cloud-based method known as Software as a Service (SaaS) for their MES solutions. Since this solution is cloud-based, there is no need for you to maintain server hardware or software (Ko et al., 2022), also there is no requirement for special storage space. Additionally, updates, bug fixes, and even upgrades are automatically provided. This setup minimizes disruption and downtime compared to traditional on-premises system upgrades. Since on-premises manufacturing execution systems are usually applications that can only run on a specific operating system, or they have specific hardware requirements, and can run only on the local network of a plant. Also, it is hard to make them accessible at any time and for all users. The cloud solution removes these special requirements, and it makes the system accessible. Special hardware and software are not required. Internet browsers are the only need for the users (Pessl & Rabel, 2022). Whether your team members are stationed in the factory, traveling internationally, or working remotely from home, they have the ability to log in and stay updated on current events.

Cloud-based Manufacturing Execution Systems (MES) offer numerous advantages over traditional on-premises solutions. One of the key benefits is the reduction in upfront capital expenditures and overall Total Cost of Ownership (TCO), as infrastructure, maintenance, and upgrades are handled by the service provider. These systems also provide high scalability and flexibility, enabling manufacturers to easily expand operations across new lines or facilities. With real-time data access from any location, remote monitoring and decision-making become more efficient. Additionally, cloud-based MES solutions can be deployed faster due to pre-configured modules, significantly shortening time-to-value. In terms of cybersecurity, leading cloud platforms offer robust protection, including encryption and continuous backups. Integration with other enterprise systems like ERP or SCM is also more seamless, thanks to cloud-native APIs and services. Finally, cloud-based MES platforms are continuously updated by vendors, ensuring users always have access to the latest features and improvements without manual intervention.

1.3. Advantages and Contribution of the Proposed Model

Based on the literature above, this study presents a cloud-based MES model with the following specific advantages:

(i) A multi-tenant SaaS architecture suitable for serving multiple SMEs, providing tenant-level data isolation;

(ii) A modular structure with optional extensible capabilities such as ERP integration, automation/IoT data collection, document viewing, and event-based alarms that can be added to the core model;

(iii) A microservice-based application supporting independent deployment, sustainability, and scalability; and

(iv) Facilitating operational decision-making processes with an OEE-centric operational model and reporting layer providing real-time Availability, Performance, Quality, and OEE analytics for continuous improvement.

2. METHODOLOGY

2.1. Overall Equipment Efficiency- based Operational Model

The proposed cloud-based Manufacturing Execution System platform is fundamentally structured around the principles of Overall Equipment Effectiveness (OEE), which serves as an important performance indicator in modern manufacturing environments. Thanks to the data collected instantly from the production site, the targeted and realized OEE components of the factory are analyzed and calculated, and reported according to the factory layout breakdowns (company, department, operations center group, operations center). The proposed system provides information to company managers about production bottlenecks, quality deviations, and unplanned stops. The OEE-based developed system ensures that operators and managers are constantly informed about equipment efficiency, leading to data-driven decision-making and process optimization. The platform supports manufacturers in Industry 5.0, continuous improvement, and lean manufacturing processes.

Overall Equipment Efficiency (OEE) is one of the indicators commonly used in measuring the performance of production systems. OEE is a system in which the total machine performance is measured, monitored and evaluated with data obtained from the machine, which is one of the most important sources of production. The basic function of MES is to provide basic performance measures that can be used in manufacturing processes, such as availability, performance, quality rates, and OEE, which is the product of these three rates. These measures can be used to measure the successful performance of a machine as well as the holistic performance of a process, an operation center, a line, or a factory. The OEE metric is used to improve the performance of the plant by focusing on quality, efficiency, and machine utilization to reduce non-value-added activities in manufacturing processes. OEE is based on losses shown in Table 1, which are related to machinery under three main headings. These are availability loss, performance loss, and quality loss.

Table 1: OEE-Based Losses

Loss Category	Subcategory	Description
Downtime Losses	Breakdown Losses	Losses due to unexpected equipment failures leading to unplanned downtime and production interruptions.
Downtime Losses	Setup and Adjustment Losses	Losses during product changeovers, including machine setup, tooling adjustments, and startup calibration.
Performance Losses	Minor Stoppages and Idling	Short interruptions caused by small issues such as material jams, sensor blockages, or minor breakdowns.
Performance Losses	Reduced Speed Losses	Losses caused by operating at speeds lower than the equipment's designed optimal speed.
Quality Losses	Process Defect Losses	Losses associated with defective units and rework during regular production.
Quality Losses	Startup Yield Losses	Losses due to defects generated during machine startup before reaching stable production conditions.

As can be seen, availability is a measure of how much a machine can be used during the time it is supposed to work. It indicates the proportion of planned production time in which the equipment is actually running, after subtracting downtime. Performance represents how close the equipment operates to its designed speed during the running time. Quality reflects the percentage of units produced according to specifications without being reworked or scrapped (Ng Corrales et al., 2020). All of these can be formulated as shown in Equations (1)–(4). These three multipliers give the OEE value. OEE is an important parameter that needs to be focused on for a company to work efficiently. The company should decide how to manage its downtime, quality losses, and performance values. The MES system to be used should support this structure and provide instant information to the company about the

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relevant metrics, and contribute to the company's recovery strategy. All this structure is integrated within the developed cloud-based system.

$$Availibility = \frac{(Planned\ Production\ Time - Downtime)}{Planned\ Production\ Time} \quad (1)$$

$$Performance = \frac{(Ideal\ Cycle\ Time \times Total\ Output)}{Operating\ Time} \quad (2)$$

$$Quality = \frac{Good\ Output}{Total\ Output} \quad (3)$$

$$OEE = Availibility \times Performance \times Quality \quad (4)$$

Planned Production Time is the scheduled time allocated for production; Downtime includes unplanned and planned stops recorded in the MES; Ideal Cycle Time is the theoretical minimum time to produce one unit; Total Count includes all produced units (good + defective); and Good Count (also referred to as "Good Output") represents conforming units that pass quality checks(Eswaramurthi & Mohanram, 2013; Niekurzak & Lewicki, 2025).

In an ideal manufacturing environment, an Overall Equipment Effectiveness (OEE) score of 100% signifies optimal performance—zero defects, maximum speed, and full utilization of scheduled production time. However, in real-world applications, even high-performing plants generally achieve an OEE of around 85%, which is recognized as the world-class standard (Tortorella et al., 2021). Small and medium-sized enterprises (SMEs) often struggle with OEE measurement due to the dispersion of production data across various systems or, in some cases, the absence of systematic data collection (Emon & Khan, 2025; Rahayu & Wicaksono, 2024). This fragmentation inhibits operational visibility, making it difficult for managers to analyze performance trends or identify improvement areas.

Implementing a Manufacturing Execution System (MES) addresses this issue by centralizing all relevant production data and enabling real-time monitoring of equipment performance. MES platforms allow for automated data acquisition and provide actionable insights that support data-driven decision-making to improve OEE (Honarpour et al., 2012; Oliveira et al., 2025). At the organizational level, OEE is frequently tracked by senior management as a strategic indicator, where upward trends signify ongoing efforts toward operational excellence (Zhang et al., 2024).

2.2. System Design and Architecture

In recent years, the increasing complexity of production processes and the growing demand for real-time data in manufacturing environments have highlighted the limitations of traditional, on-premises Manufacturing Execution Systems (MES). On-premises systems often complicate production monitoring processes due to limited accessibility, scalability issues, and high maintenance and hardware costs. In response to these challenges, cloud-based MES solutions have emerged as a promising alternative, offering enhanced flexibility, lower total cost of ownership, and improved integration capabilities. This study presents the design and implementation of a modern cloud-based MES platform that addresses these challenges.

The Cloud-based Manufacturing Execution System (MES) developed in this study is grounded in a modular microservices architecture, which facilitates scalability, maintainability, and ease of deployment. The proposed system's microservice architecture is shown in Figure 2 below. The figure illustrates the decoupled service structure of the system, including API Gateway, independently deployable microservices, and database interactions.

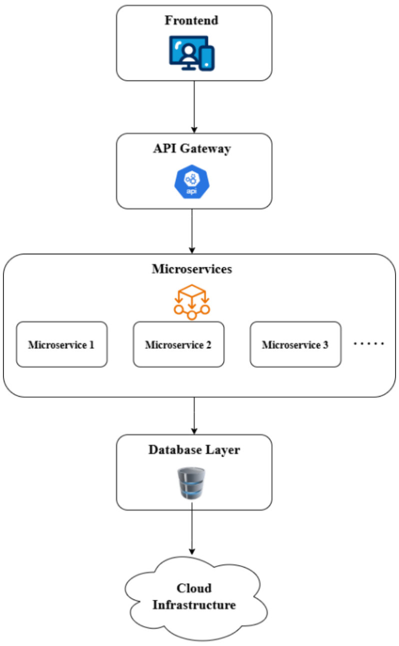

Figure 2: Proposed System's Microservice Architecture

The system's architecture consists of independent components that perform unique functions. With API gateways, users can perform their transactions in the application securely from their web or mobile devices. API gateways direct transactions to microservices. These microservices are separated according to the transactions they will perform. At the same time, thanks to this decoupled architecture, they can be processed independently when necessary. Each service interacts with the database layer to perform its data-related operations. The entire system is deployed on cloud. Having this infrastructure also provides opportunities such as scalability, flexibility, and ease of access. Among the advantages of the system are important gains such as modularity, technology, and hardware independence, and the ability to develop and deploy independently.

Furthermore, the system is fundamentally designed with a multi-tenant architecture, allowing multiple client organizations to operate independently within a shared infrastructure. Each tenant benefits from isolated data management and configurable environments, accompanied by a multilingual and role-based web interface developed using modern web technologies. Figure 3 presents the tenant-level data isolation mechanism within a shared cloud infrastructure. Each tenant operates within an isolated database environment while sharing common application services, ensuring scalability, security, and resource optimization. The architecture of the multi-tenant system is given in Figure 3 below.

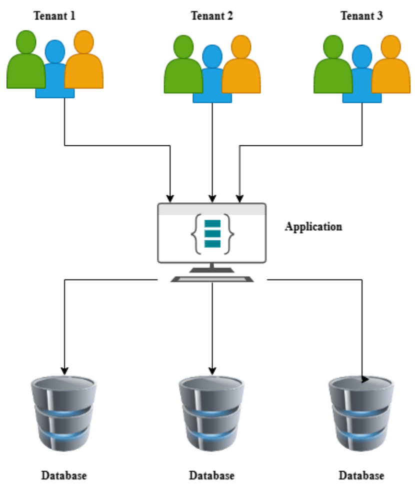

Figure 3: Proposed System's Multitenant Architecture

The system architecture is composed of several key layers, each responsible for a distinct functional domain. The proposed system's layered architecture is depicted in Figure 4. The figure depicts the system’s architectural layers, including Presentation, Application, Data, Security, Integration, and Deployment layers. It explains how responsibilities are separated across layers to enhance maintainability, flexibility, and interoperability with external enterprise systems.

Presentation Layer: This layer comprises a browser-accessible, responsive web interface supporting multilingual capabilities and role-based access control, ensuring accessibility for a global user base.

Application Layer: The platform's core logic is implemented through independently deployable microservices, each responsible for specific operational tasks such as production processes, OEE (Overall Equipment Effectiveness) computations, downtime and quality analysis, production tracking, and reporting system. This modular approach enhances system flexibility and robustness.

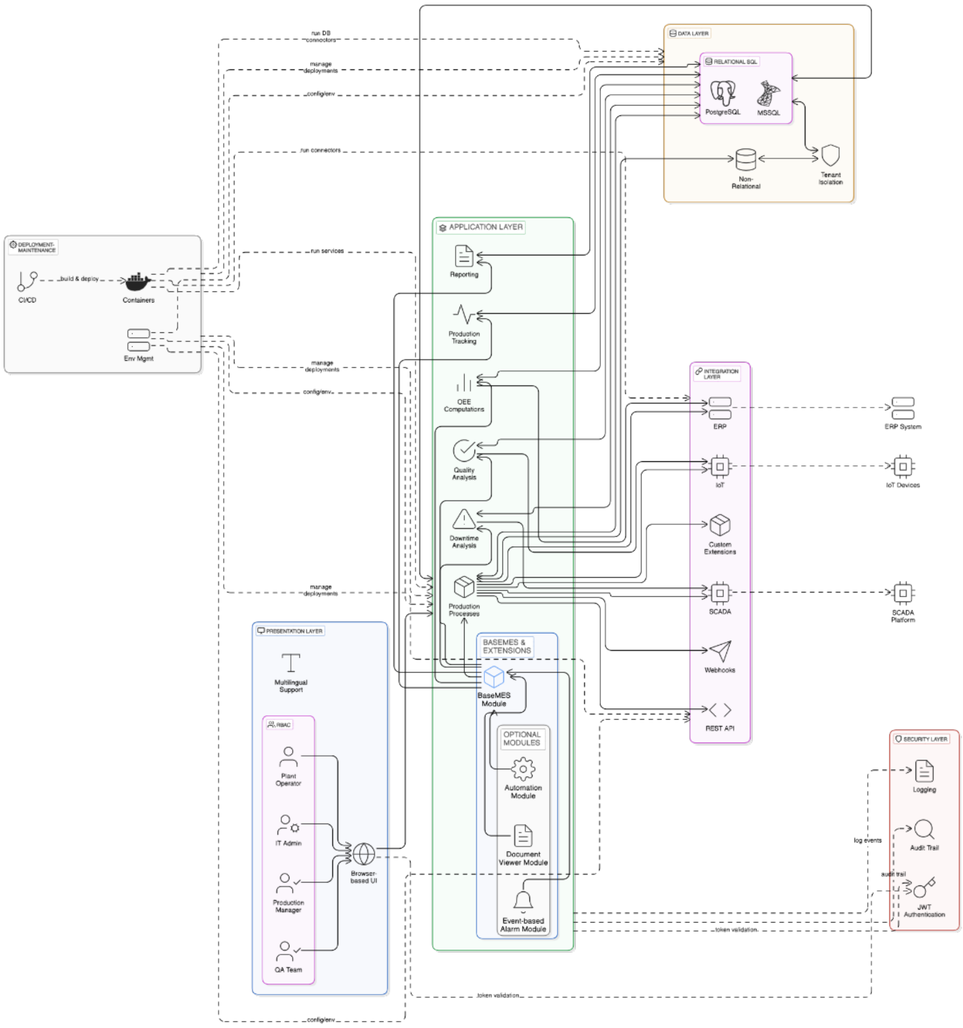

Figure 4: Proposed System's Layered Architecture

Data Layer: A database-agnostic structure allows seamless integration with multiple relational and non-relational database systems. The architecture provides data isolation at the tenant level to maintain both performance efficiency and data security.

Security Layer: Secure system access is enforced using token-based authentication mechanisms such as JSON Web Tokens (JWT). Additionally, comprehensive logging and audit capabilities are integrated to ensure traceability and compliance.

2.3. Data Management and Tenant Data Management

Since the proposed MES is offered as a cloud service to multiple organizations, the application includes a data management mechanism focused on tenant isolation, access control, and traceability. The system provides an isolated database to each tenant (Figure 3), and tenant context is implemented at the application level through authenticated user

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requests. Role-based access control (RBAC) restricts access to functions and data based on user roles (e.g., plant operator, IT admin, production manager).

For operational availability, data management rules are implemented to ensure consistent production reporting: master data is centrally managed within BaseMES; all critical actions are logged for auditing and troubleshooting. Backup and restore operations are performed at the cloud database layer, and logging/monitoring supports incident analysis and continuous improvement. These practices address data management challenges frequently discussed for cloud-based production platforms (Gharibvand et al., 2024).

Integration Layer: This component facilitates interoperability with external enterprise systems—including ERP, SCADA, and IoT platforms—via RESTful APIs and webhooks. It also allows for custom extensions to be developed by third parties or internal developers.

Deployment-Maintenance: Containerization of services and integration with CI/CD pipelines enables automated system updates and efficient management of deployment environments.

Collectively, this architecture enhances the operational resilience, configurability, and global scalability of the proposed cloud-based Manufacturing Execution System, positioning it as a robust Software-as-a-Service (SaaS) solution for modern manufacturing enterprises.

3. IMPLEMENTATION AND RESULTS

In this study, the system was implemented by considering the technical and sectoral infrastructures included in the methodology detailed in Section IV.

A. Implementation Overview

The development stages of this cloud-based MES platform, which stands out with its modular structure, include the development of the core architecture and the development of modules that can be added to this core module. The system was developed using Blazor Server (.NET 8), Entity Framework Core, RESTful APIs, and SQL-based backend technologies. Through the agency of the front-end components which are used, it brings dynamic user interfaces and responsive design to the application. In addition, the system is hosted on Microsoft Azure.

B. Modular Structure of the System

The BaseMES module serves as the core layer of the proposed MES system, including data management and operational execution functionalities. It includes critical inputs such as plant structure, operation, and operation order, stock, downtime, and quality definitions. In addition to its data management capabilities, the module provides user interfaces for both field operators and office-based administrative personnel. Within the office layer, operation orders— entered either from manual entry or through integration with existing ERP systems— are transferred to the system. In the production area, there are terminals which are the basic tools used to collect data. Operators authenticate themself in authorized terminals, access their assigned operation orders, and initiate production activities accordingly. During production, the system enables real-time data entry related to events such as quality defects and machine downtimes, ensuring immediate feedback and traceability. Production is monitored instantly in the office layer with the Factory Monitoring Screen, Dashboard, and analytical reports.

The Automation Module enables production data to be obtained from IOT and machine sensor data. This data is not limited to production quantity information. It can also be other metrics such as machine pressure, temperature, and downtime signal. The ERP Integration Module establishes a two-way connection between the MES platform and enterprise resource planning systems and provides data exchange. Definitions such as operation orders, material lists, and stock cards are transferred from ERP to MES with integration. Thus, data consistency is guaranteed. Manual and time-consuming process load is also reduced. After the completion of production operations, production end records are transferred to ERP. The developed integration works with many ERP systems. API-based integration allows easy integration with web-based systems. The Technical Infrastructure of the MES system is shown in Figure 5.

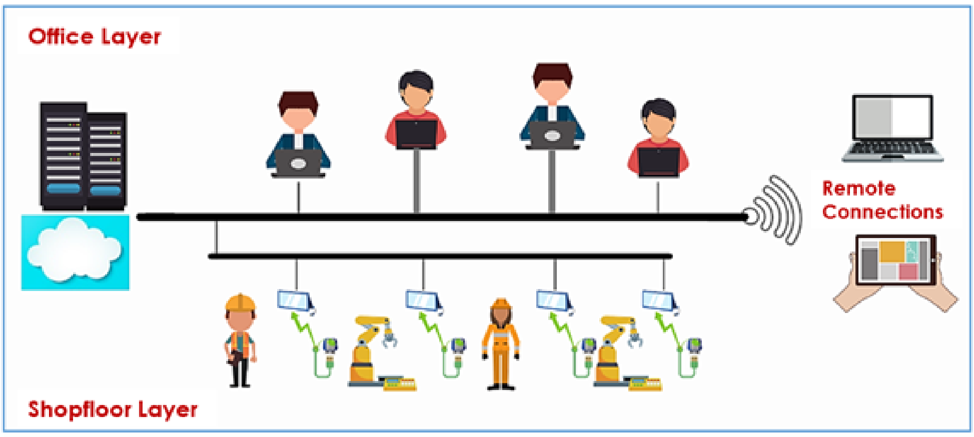

Figure 5: Technical Infrastructure of MES

With the Document Viewer Module, document entry can be made to the system based on the operation center, operation, and operation order. The operator can access the relevant documents from the operator screen during production.

The Event-based Alarm Module was developed to provide real-time notifications to authorized users about important events occurring in the production area. Notifications are sent to authorized users via e-mail. These events include information such as downtimes, production start-end processes, and quality defects. This mechanism allows operators,

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auditors, and relevant stakeholders to receive instant information about important events occurring in the factory, allowing faster responses to possible problems.

C. System Interfaces and Reports

User Interfaces:

The system has been developed using modern web development technologies. It includes user-friendly, responsive screen designs. The proposed system includes screens that both operators and administrators will use. Operators interact with intuitive screens optimized for touch terminals. Some of the screens are shown in Figures 6, 7, 8, and 9 below. Figures 6–9 collectively illustrate the operational workflow of the proposed MES platform at both shop-floor and managerial levels. The interfaces demonstrate how production orders are executed, how real-time events such as downtime and quality losses are captured, and how this data is transformed into structured monitoring and analytical views. These figures provide evidence of the system's practical implementation, user-centered design, and its capability to support OEE-based performance tracking within a cloud-based architecture.

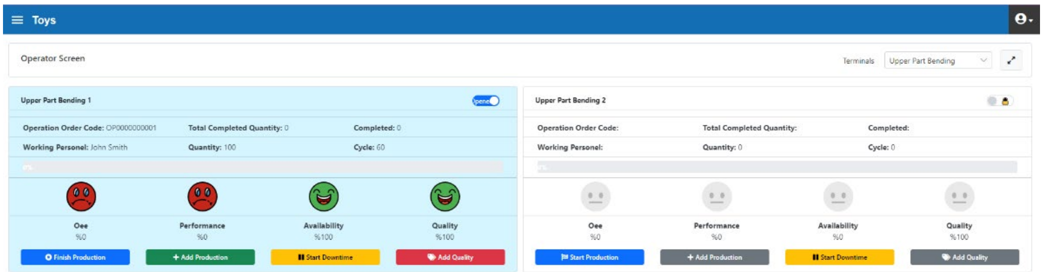

Figure 6: Operator Screen Instant Monitoring

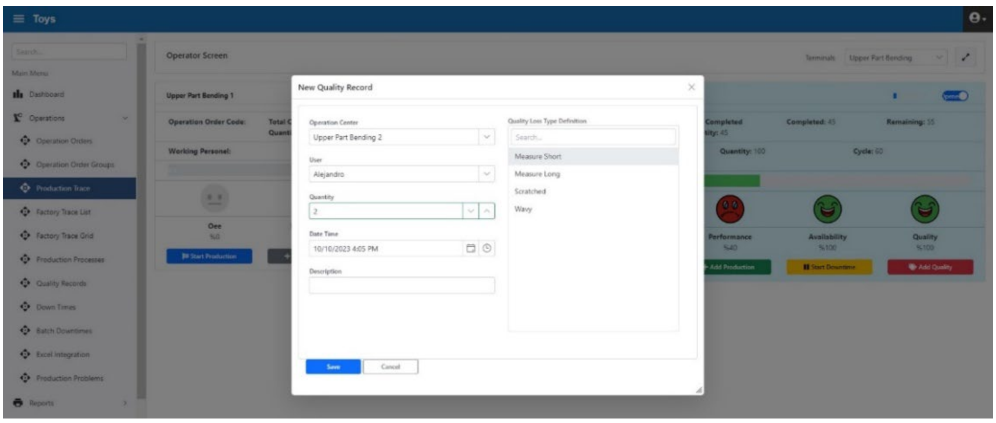

Figure 7: Operation Center Quality Loss Input

In addition to the definition screens that administrative users can access, there are also screens that allow them to trace production available in the proposed system.

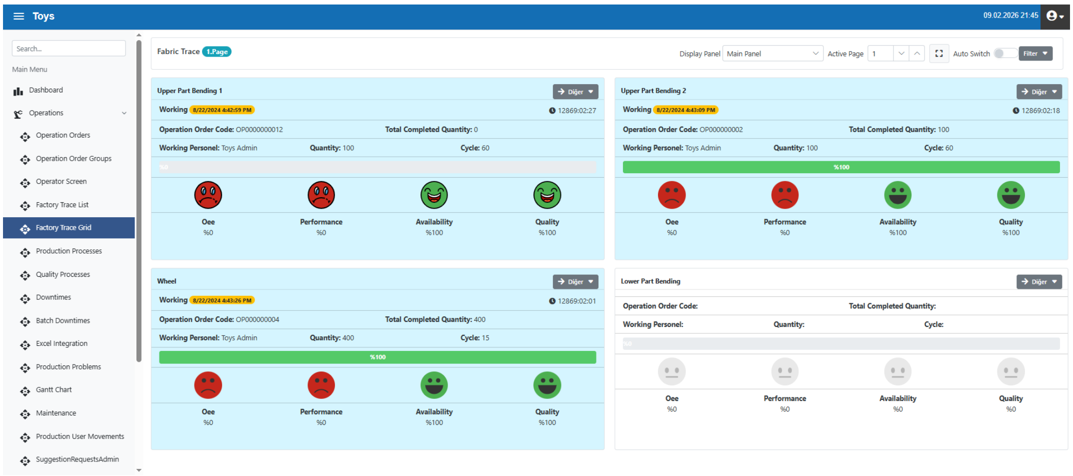

Figure 8: Factory Monitoring Box Form

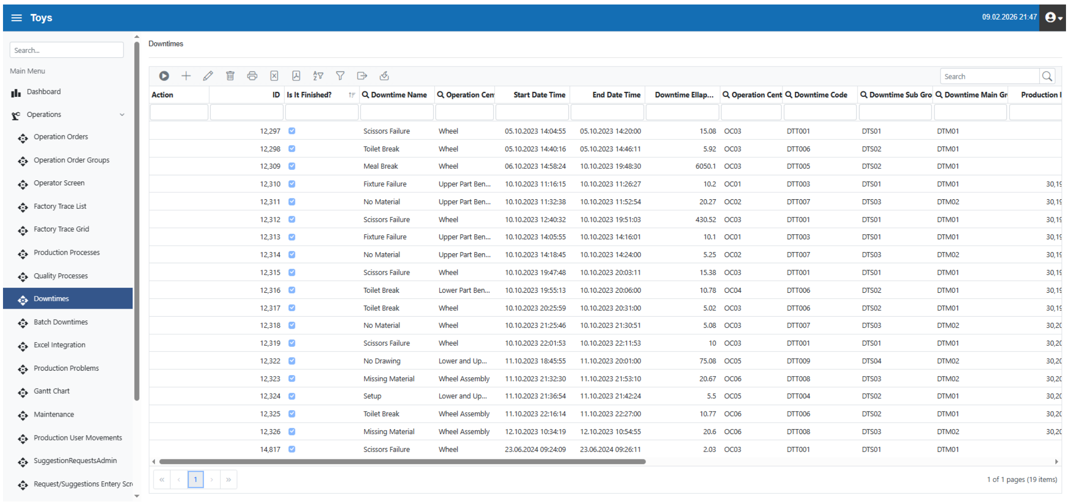

Figure 9: Downtime Transactions List

D. Report Generation and Visualization

The MES system includes dynamic reporting capabilities that allow users to filter, export, and visualize data according to selected criteria such as date ranges, work centers, operations, etc. Reports can be exported in Excel or PDF format and are generated based on live production data. System-generated OEE summary and Quality loss main group reports are shown in Figures 10 and 11. The OEE summary report presents Availability, Performance, Quality, and overall OEE values across selected time intervals, supporting trend analysis and operational improvement initiatives.

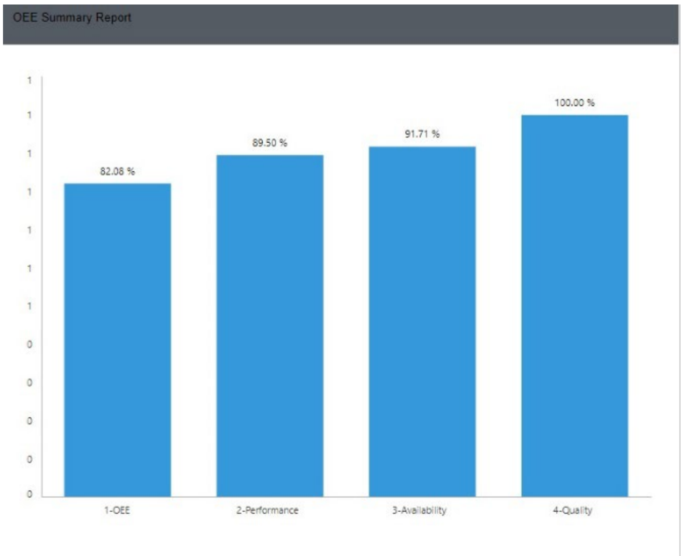

Figure 10: OEE Summary Report

Figure 11: Quality Loss, Main Group Report

Quality loss, main group report categorizes defect data into main quality loss groups, enabling management to identify recurring defect patterns and prioritize corrective actions. These reports assist management in identifying bottlenecks, improving process efficiency, and ensuring compliance with quality standards. Dashboards and visualizations are auto-refreshed at predefined intervals, ensuring real-time insight into factory operations.

CONCLUSION

This study presented the design and implementation of a cloud-based Manufacturing Execution System (MES) platform developed to support the digital transformation of small and medium-sized manufacturing enterprises (SMEs). The proposed system offers real-time production monitoring, ERP integration, collecting data from automation devices, document viewing in the production area, and event-based alarm mechanisms, all within a scalable and configurable architecture. By leveraging modern web technologies and service-oriented design principles, the system ensures ease of deployment, usability, and adaptability across different production environments. The integration of the OEE-based operational model into the system architecture has enabled more structured and measurable performance tracking.

The system's architecture is based on microservices and an OEE-based operational model. The proposed model enables continuous performance measurement and improvement. This structure enhances transparency across production processes, allowing managers to make data-driven decisions regarding downtime, quality loss, and equipment efficiency. The integration of OEE indicators not only supports operational visibility but also provides a solid analytical foundation for strategic production planning. On the other hand, the proposed approach demonstrates how cloud-based MES solutions can bridge the technological gap between SMEs and large-scale manufacturers by using digital manufacturing tools. The modular structure of the design promotes flexibility and facilitates the addition of new capabilities into the system. Flexibility of the system provides additional features and easy integration, such as predictive maintenance, AI-based performance forecasting, and mobile access interfaces. In future work, the system will be enhanced with advanced data analytics and machine learning algorithms to enable predictive and autonomous decision support. Integrating these intelligent components will transform the proposed MES from a reactive monitoring tool into a proactive optimization platform. Overall, this research contributes to the advancement of cloud-based MES solutions by providing both a practical implementation and a conceptual framework for scalable digital transformation in manufacturing.

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