Designing a Cloud-Based MES-SaaS Platform Model in Precision Machining

YEJI DO[1,2], JONGPIL JEONG[1*]
[1]Department of Smart Factory Convergence,
Sungkyunkwan University,
2066 Seobu-ro Jangan-gu, Suwon, 16419,
REPUBLIC OF KOREA

[2]SaaS Research Lab,
Hygino,
25 Simin-daero 248beon-gil, Dongan-gu, Anyang-si, Gyeonggi-do,
REPUBLIC OF KOREA

**Corresponding Author*

Abstract: - Smart manufacturing environments are spreading at home and abroad. As a result, SMEs are also recognizing the need for digital transformation. However, they are facing difficulties in introducing MES/ERP software due to the initial cost burden and lack of resources. Under these circumstances, this paper aims to design a cloud-based subscription MES platform that enables SMEs specializing in the precision machining industry to operate efficient production processes and improve productivity and competitiveness. To build a cloud-based subscription MES system, we collect and store manufacturing interlocking data based on the AAS standard and utilize data link sockets such as the EDC standard, which is an important factor in securing compatibility and integration between various systems. Therefore, we aim to design an MES-SaaS platform that enables SMEs to utilize MES and ERP software in line with the growth of the smart manufacturing environment.

Key-Words: - MES, Cloud Platform, SaaS, AAS, OPC-UA, EDC

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1 Introduction

A smart factory is a manufacturing execution system that utilizes cyber-physical systems (CPS) and digital technologies. It enables the optimization of the performance of manufacturing areas and the automatic execution of production processes in real time to adapt and learn from new conditions, [1]. Smart manufacturing provides insightful information by collecting and analyzing data from the manufacturing process. This can be used to diagnose and improve problems and reduce time to resolution. It offers the opportunity to increase the flexibility and productivity of manufacturing processes and is recognized as a new lean manufacturing approach that enables data-driven decision-making and execution.

By implementing a smart factory, many organizations can realize several benefits. First, by leveraging sensors, automation systems, and artificial intelligence technology to monitor and optimize production processes, they can increase productivity, reduce costs, and shorten production cycles. Second, real-time data collection and analysis can be used to monitor product quality and proactively detect quality anomalies to reduce scrap and increase customer satisfaction. Third, you can achieve sustainable operations through energy management, resource use optimization, and environmentally friendly production methods.

In addition, it can increase the reliability of the system by detecting abnormal conditions or failures in advance, [2]. Based on these benefits, many SMEs are adopting smart factories to enhance their competitiveness. Cloud computing has been identified by Gartner as a key strategic technology trend for 2023. The recent COVID-19 pandemic has increased the demand for remote services and contactless work. This has increased the demand for cloud computing in the industry. Companies that offer cloud computing services provide customers with a reliable and scalable infrastructure to support their business operations. These services help to improve productivity and efficiency across industries, [3].

The domestic precision machining industry is continuously expanding, increasing from 15,641 in 2010 to 21,896 in 2019, and the number of workers is decreasing, increasing the need and interest in ICT and digital transformation. SMEs face high initial costs and lack of resources to build and adopt software such as MES/ERP (enterprise resource planning). The lack of compatibility between MES/ERP solutions from domestic and foreign manufacturers is driving the need to configure and utilize modularized systems suitable for each industry.

In the precision machining industry, the need to develop industry-wide training and operational systems through ICT is becoming increasingly important, and many investments are being made in the digitalization of the manufacturing environment to improve efficiency and competitiveness.

For SMEs, we are focusing on the ripple effect in the economic, industrial, and social sectors and the ICT sector by applying our specialization in the precision machining industry and technical expertise in SaaS cloud-based subscription systems. Specifically, in the economic, industrial, and social sectors, the SaaS model has the advantage of reducing software license costs and server management costs to increase the economic efficiency of companies, and it can be applied to various industries because it is provided in the form of a platform. The SaaS model also improves accessibility, making software available to small businesses and those with smaller budgets, helping companies develop more sustainable business models.

This paper is organized as follows Section 2 describes in detail the theoretical background related to MES, cloud service platforms, AAS, and OPC-UA. Section 3 proposes the overall system architecture, hardware and software configuration, and MES-SaaS security architecture for building an MES-SaaS system. Section 4 discusses the limitations of on-premises MES and the challenges of moving to a subscription service. Section 5 presents conclusions and discusses future research plans.

2 Problem Formulation

2.1 MES (Manufacturing Execution System)

MES is a system that supports decision-making in the production department by optimizing production activities. It manages the production process from product order to shipment and aims to increase production efficiency by controlling and managing production facilities, processes, workers, and products by collecting and analyzing production site information in real time.

MES is the system responsible for manufacturing execution between production automation equipment and the enterprise-wide system, ERP (Figure 1). It manages field conditions by communicating production plans to the field and monitoring progress. It also performs on-site integrated management functions that aggregate performance, collect facility and quality status, and take necessary measures. Since ERP is a system for optimally allocating corporate resources and achieving management goals, business goals are written into work orders and delivered to the production site in a top-down manner. Therefore, it is difficult to understand the process from work order to production completion. MES, on the other hand, manages and controls processes and facilities through real-time data collection and monitoring of production sites.

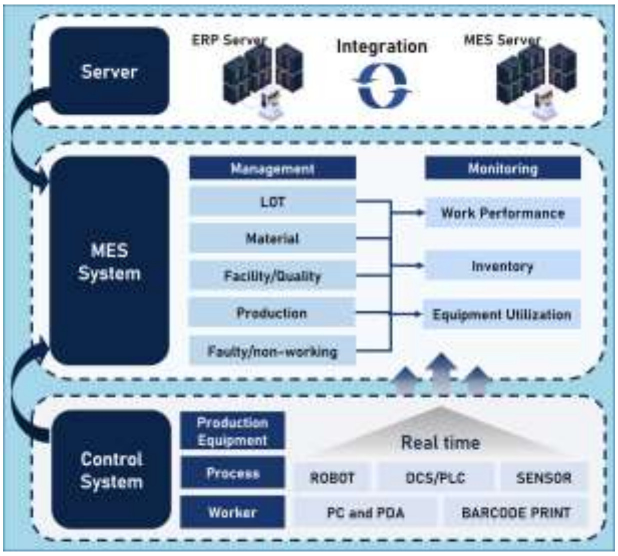

Fig. 1: MES System

It also analyzes data accumulated on the production floor to support production decisions. This helps to optimize production processes to shorten delivery times and reduce process rejects.

The Ministry of Trade, Industry and Energy defines a smart factory as "a factory that maximizes the overall efficiency of production by combining advanced manufacturing technologies such as information technology, software, and 3D printing in a customized way at the production site." Therefore, if the purpose of a smart factory is to improve the overall efficiency of production, MES is an essential element.

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2.2 Cloud Service Platforms

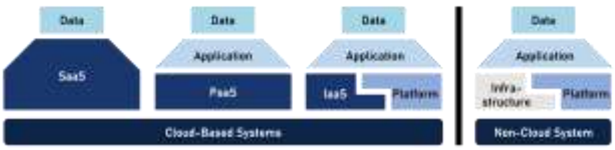

Fig. 2: Comparative Analysis of IaaS, PaaS, and SaaS: Part 1

Infrastructure as a service (IaaS) is an evolution of on-premises infrastructure that provides virtualized servers, storage, and networks. Server virtualization technology uses a hypervisor to partition a single physical server into multiple virtual servers. Each virtual server is a virtual machine (VM), which has independent hardware and behaves like an independent server, [4]. Users of IaaS services only need to pay for computing resources based on usage and time, which greatly reduces the initial investment cost. They also have full control over virtual machines and other computing resources, and can easily move existing applications to the cloud environment, increasing mobility and interoperability. However, it is important to be aware of issues such as security vulnerabilities in existing systems and potential exposure in the cloud environment, [4].

Platform as a Service (PaaS) provides developers with a foundation for developing scalable applications, unlike traditional systems. Applications in a PaaS cloud environment can be deployed immediately with flexible control over the resources and data processing required and can be gradually scaled to meet usage with no upfront costs. Although PaaS is a flexible and scalable service, different PaaS providers offer a variety of additional services to make program development more efficient and convenient. As a result, application services developed in different PaaS environments are less interoperable, less portable, and more likely to be vendor-locked. This highlights the need for PaaS standardization, but it is not expected to happen because standardizing various PaaS products means diluting the specialized features of each PaaS product.

Software as a service (SaaS) is the most comprehensive form of cloud computing, where the application software runs on the service provider's servers. The user sends input data to the cloud via a web browser and receives the processed results back. To do this, the communication between the cloud and the user's web browser is authenticated and encrypted based on a shared key value. The user does not need to install or manage any software and can immediately access the required functionality via a web browser.

SaaS allows users to use software through a web browser without installing a separate client program or going through a complex setup process, [5]. It also reduces the cost of software deployment and allows one license to be used on multiple computers. When providing cloud computing resources and outsourcing operations, SaaS providers can provide professional data management services such as security scans, backups, disaster recovery, etc. Thus, users are relieved of the burden of data management and security. Lastly, a comparative analysis of IaaS, PaaS, and SaaS: Part 1 and Part 2 are presented in Figure 2 and Figure 3 respectively.

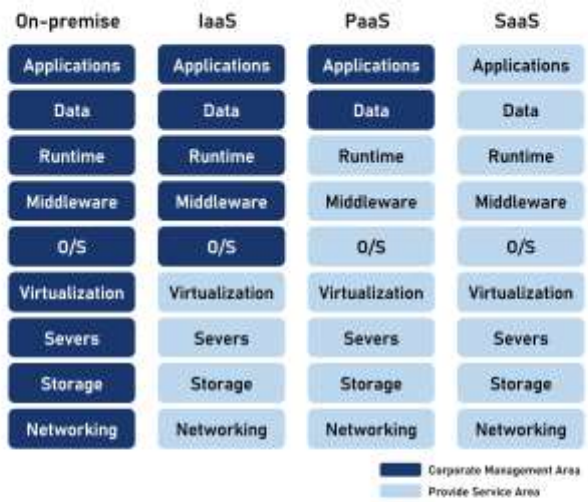

Fig. 3: Comparative Analysis of IaaS, PaaS, and SaaS: Part 2

2.3 AAS (Asset Administration Shell)

Germany's Industry 4.0 proposes a complete digital transformation of manufacturing based on IoT and CPS technologies, and the reference model RAMI 4.0 has been devised as a concept to realize this, [6].

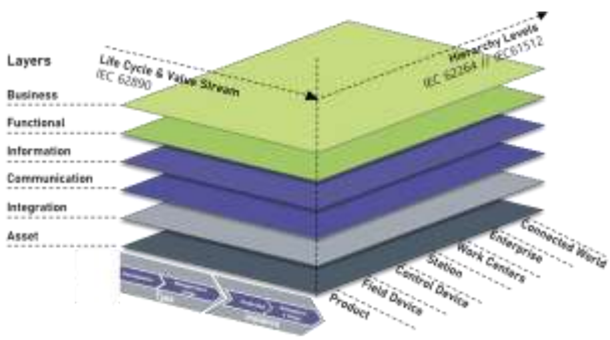

Fig. 4: RAMI 4.0 Reference Model

RAMI 4.0 is a three-dimensional model that includes all elements of the three layers (Figure 4).

On the left-hand side of RAMI 4.0, there is a unified hierarchy that spans from physical assets to functions. At the bottom of this hierarchy, "Assets" includes physical or non-physical assets. "Integration" refers to the communication of real-world assets with the virtual world through digital transformation. 'Communication' refers to the communication and connectivity between different assets (e.g. OPC-UA or Open Core Interface). "Information" means data information on all assets. "Functional" means the functionality of an Asset. 'Business' means the business part of the Company's operations. The left horizontal plane of the RAMI 4.0 cross-section shows the life cycle of a product. There are two product types in RAMI 4.0: finished products (Instacne) and prototypes (Type). In the prototype phase, you start with planning, design, and testing. During this phase, you develop, maintain, and test the product. In the finished product stage, production takes place based on a unique serial number. The rightmost horizontal axis represents the production automation layer. Production and Connected World are added to existing automation standards to show interoperability between facilities and products.

An AAS, also known as a management shell or asset management shell, is a virtual, digital representation of assets to perform interactions between Industry 4.0 (I4.0) components in Germany during the Fourth Industrial Revolution. In manufacturing, assets include not only plant equipment but also all physical and non-physical values from order to delivery.

AAS provides and manages all physical asset information and technical functions in manufacturing in the information world. The widespread implementation of AAS in future manufacturing systems will enable the modularity and autonomy of systems as production and process information collected along the manufacturing process cycle is digitized.

There are several requirements for applying AAS technology. First, the physical and non-physical assets of I4.0 components must be uniquely identifiable (identification), and the related asset information must be reliable and adequately described (representation). The AAS shall communicate with each other, both actively and passively (Communicate). The AAS should be operational for a specific period of time based on its lifecycle (lifecycle phases). The AAS must provide technical capabilities for asset-specific roles (capabilities). The AAS must provide a common sense definition and understanding of asset information exchanged between assets (interoperability).

2.4 OPC-UA (Open Platform Communication Unified Architecture)

OPC-UA is a standard interface recommended by the Model for Industry 4.0 (RAMI4.0), the communication layer of the international standard IEC 62541, [7]. It supports communication within a single machine, communication between multiple machines, [8], and horizontal and vertical communication between machine-to-machine (M2M) systems, [9]. OPC UA is an essential technology to ensure interoperability when building a smart factory. It can freely utilize the data assets of various devices and facilities that make up a smart factory. Therefore, it is built on OPC UA for high-level communication between systems, [7].

OPC UA solves the interoperability problems of the classic OPC standard by supporting data access (DA), alarms and events (AE), and historical data access (HAD) on a single server. The composition of OPC UA can be divided into an information model layer that extracts information items related to equipment and a communication model layer that delivers the extracted information items.

The composition of OPC UA can be divided into an information model layer for extracting information items related to equipment and a communication model layer for communicating the extracted information items. The information model layer provides a way to represent these resources in the form of computer-readable information to digitize physical manufacturing resources. The communication model layer contains standards for securing communication protocols through data communication between machines and servers and servers and clients. The OPC-UA standard document is presented in Figure 5.

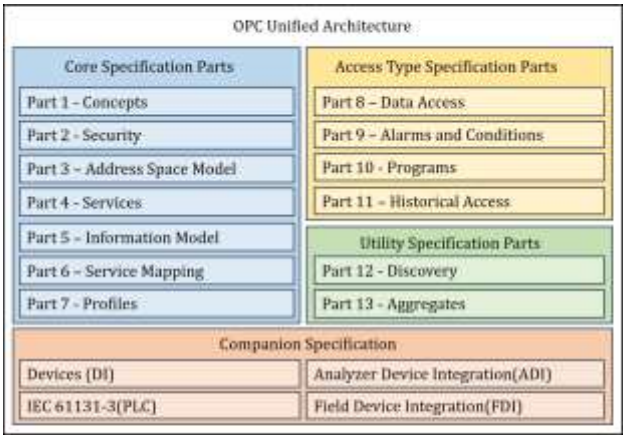

Fig. 5: OPC-UA Standard Document

2.5 EDC (Eclipse Data Connector)

Current data management environments exist in many forms, including centralized data management and distributed data networks, [10]. In general, centralized data management is when a central server controls the data and manages and distributes data from a central system. On the other hand, unlike centralized data management, distributed data networks are when data is distributed across multiple distributed systems or sources. These systems operate without a unified set of common rules, which can make it difficult to maintain data consistency and integrity.

EDC is a Java-based open source software application supported by the Eclipse Foundation, [11]. It is used as a tool for connecting heterogeneous data sources and systems in a standardized way. EDC enables enterprises to overcome data consistency and integration issues that can arise from centralized data management concepts or distributed data networks, [12]. This enables organizations to improve data quality and interoperability.

3 Problem Solution

3.1 MES-SaaS System Architecture

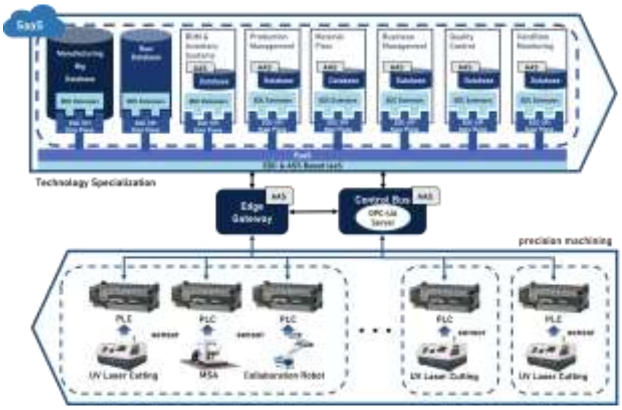

Fig. 6: MES-SaaS System Architecture

In the system architecture presented in Figure 6, we applied our industrial expertise in precision laser processing and technical expertise in cloud-based SaaS systems. In the architecture diagram, the bottom layer represents sensor data such as temperature, vibration, pressure, speed, and time from the UV laser, MSA, and collaborative robot, which are collected and controlled through the PLC.

The various sensor information collected was stored according to the AAS standard. To manage the information assets, we used the AutomationML AAS standard. This standard provides a basis for digitizing process assets, integrating them into a SaaS platform, and collecting data. To integrate and collect data on the SaaS platform and link data stored according to the AAS standard, an EDC standard data link socket is required. The EDC standard data link socket provides a system that compensates for the lack of data compatibility between different information assets and numerous manufacturers.

In the architecture, Figure 6, the top layer is designed to store the data collected by the AAS through the EDC socket to the big database through OPC-UA, which can be analyzed and utilized in the MES-SaaS platform. In addition, AAS is built for each solution of MES on the SaaS platform so that it can be operated independently without centralized control.

The solutions built on the SaaS platform include a bill of materials and inventory system, production management, material management, business management, quality management, and condition monitoring, which are used to manage the main assets of precision machining manufacturing companies. In addition, the solution can be expanded and used if necessary, and functions can be modified or supplemented. This makes it easy to integrate and use various solutions through the MES-SaaS platform.

Finally, as SaaS-based MES platforms are used by multiple companies, not just one precision machining manufacturing company, the initial cost of subscription MES can be lowered, and the advantage is that the solution can be used serverlessly without having to build an MES server locally. In addition, necessary data between companies can be shared, which can help utilize resources.

3.2 Hardware Configuration

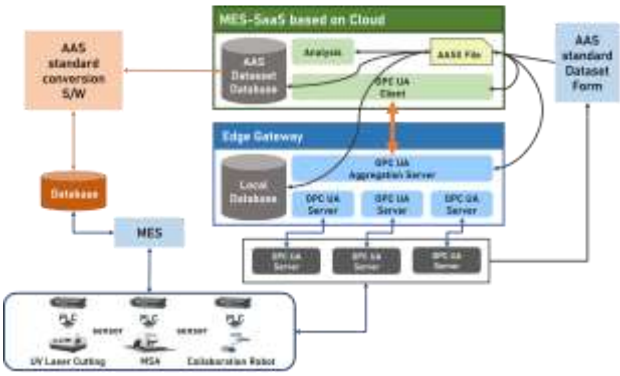

Fig. 7: Hardware and Software Configuration

The hardware consists of facilities such as UV laser cutting, MSA, and collaborative robots required for precision machining, which are linked to a PLC for automated control, facility collection, and monitoring. It also consists of a database to store data from the existing MES (Figure 7).

In addition, an Edge Gateway, which is responsible for collecting and storing data from PLCs, is required to configure a cloud-based MES-SaaS platform. The Edge Gateway and PLC work in a client-server manner and require OPC-UA communication. This provides complementarity by exchanging data between industrial devices and systems.

The edge gateway collects data through OPC-UA communication with the equipment referenced by the AAS and stores it in a local database in real-time according to AAS standards. The cloud-based MES-SaaS platform collects operational data by referring to the AAS and utilizes it to recognize, install, and configure equipment. It also constitutes a cloud environment with enhanced capabilities to process and analyze the collected data.

3.3 Software Configuration

In terms of software configuration, a traditional MES system works as a built-in infrastructure service. The system collects PLC data from existing production facilities and utilizes it in conjunction with the MES's database.

Fig. 8: Define the AAS Reference Model of S/W

To collect information stored in your database in the AAS standard format, you need AAS standard conversion software. This software consists of a logical Administration Shell a physical Raw Database and Asset Module. The Asset Module contains properties that define the unique characteristics of information and submodels for categorizing data. Submodels include Items, Attributes, From to, etc. This allows non-standard data to be converted to the AAS standard data format. The converted data is stored in the AAS database on the cloud server. The definition of the AAS Reference Model of S/W is presented in Figure 8.

The new equipment, which is not present in the existing system, operates through OPC-UA communication and collects AAS-based data. To utilize this collected data, it is first organized into the AAS standard data format and delivered to the AASX file and OPC-UA client through the cloud service. Then, the data is sent through the OPC-UA Aggregation server on the edge gateway, where it is organized according to the AAS standard. Finally, the collected data is stored in the AAS dataset database on the cloud server in AASX file format. Through this process, the information assets of precision machining facilities can be efficiently operated on a cloud-based MES-SaaS platform and used to effectively manage and analyze data.

3.4 MES-SaaS Security Architecture

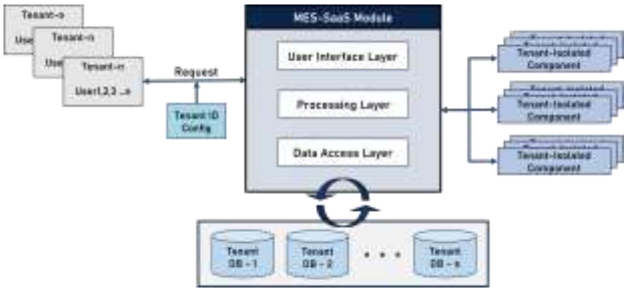

Fig. 9: MES-SaaS Security Architecture

In this study, it was implemented as a SaaS platform with a multi-tenant architecture to collect and manage information assets more securely in a cloud environment. The multi-tenant architecture works by allowing multiple users to share the same modules and resources. Each user or tenant is given a unique ID to access a specific module. This ensures that data and modules operate in an isolated boundary so that the data or actions of one tenant do not affect another. This protects each tenant's information and increases protection against data leaks and unauthorized access.

A multitenant environment enables rapid response to security vulnerabilities by unified applying security policies and updates across the platform, maintaining a consistent level of security across the system, and enhancing prevention and response to security threats. Additionally, it reduces costs and improves system efficiency by efficiently utilizing resources shared by multiple tenants. This reduces security infrastructure and management costs and supports efficient operations. In the end, a multitenant architecture provides consistency and efficiency in security policies and secures and protects information assets by separating and isolating data across tenants and managing security updates. The MES-SaaS security architecture is presented in Figure 9.

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4 Conclusion

4.1 Limitations of On-Premises MES

The importance of MES is increasing due to the rapid growth of smart manufacturing environments. The global market for smart factories was valued at $79.41 billion in 2021 and is expected to reach $191.02 billion by 2030, growing at a CAGR of 10.46%, [13], (Figure 10). This growth highlights the importance of organizations adopting MES to efficiently manage their production processes and improve productivity. MES supports companies' production processes by providing real-time information, optimizing production schedules, and controlling quality, and is recognized as a suitable solution for smart factories, which are modern manufacturing environments.

Fig. 10: Global Market Size of Smart Factories

Germany and the United States, both major manufacturing countries, are pushing hard to implement smart factories, emphasizing the convergence of manufacturing and technology. In particular, SMEs play an important role in the manufacturing economy, and these countries are actively supporting SMEs to build smart factories and have achieved various results, [14].

However, despite its high contribution to GDP, Korea's manufacturing industry has been relatively slow to become smart compared to other advanced manufacturing countries. In addition, since each manufacturer has its unique operating environment and requirements, it is difficult for each company to design and build an MES system due to the high initial cost and time required.

Traditional MES systems typically have a hierarchical and centralized structure. This means that the MES system collects data from multiple production departments or factories and is connected to a central server. The central server is responsible for monitoring the status of the production process in real-time, managing work orders, performing quality inspections, etc. The constraints in establishing smart factories for SMEs are presented in Figure 11.

Category	Constraints
Resource & Capability	- High investment costs - Lack of available resources - Lack of know-how - Lack of specialized personnel - High training needs for new technologies
Infrastructure	- Lack of IT infrastructure - Difficulty adapting to outdated equipment and production technology - Difficulty in selecting the right solution
Strategy	- Over-coverage - Lack of CEO engagement and drive - Lack of an understandable adoption strategy
Awareness	- Uncertainty about monetization - Lack of acceptance of new technologies and systems - Lack of awareness about smart factories
Policy & Standard	- Lack of universalized standards - Lack of security standards and regulations - Lack of active government resources

Fig. 11: Constraints in Establishing Smart Factories for SMEs

However, traditional on-premises MES systems have several challenges. These include costly and time-consuming custom development and configuration, lack of available resources, lack of know-how, solution selection, and lack of specialized IT departments. It can also be difficult to update or expand the system, and the typical centralized structure can limit flexibility and elasticity. To overcome these constraints, other approaches are emerging, such as subscription MES solutions. These approaches break away from the traditional centralized structure and adopt a cloud-based or distributed architecture to help you build and manage a faster, more flexible MES system.

4.2 Issues with Transitioning to Subscription-based Services

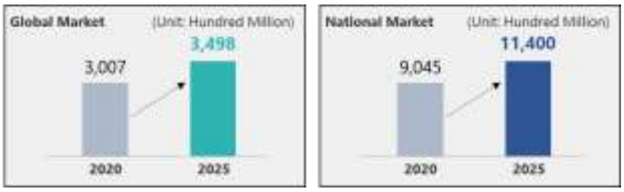

Fig. 12: Global Market Size of Smart Factories

Subscription MES is showing significant growth at home and abroad. The global market is expected to grow at a CAGR of 16.3% to reach USD 349.8 billion by 2025, while the domestic market is expected to grow at a CAGR of 14.9% to reach KRW 1.14 trillion by 2025 (Figure 12). The cloud-based subscription MES-SaaS platform is a solution that solves the problems of traditional on-premise MES, lowering the cost burden by virtualizing in-house resources and reducing hardware and software costs, [15]. In addition, you can enjoy the benefits of a flexible system at a reasonable cost as you can expand or contract the system as needed and pay only for what you use, and it is provided as a standard cloud service to minimize the cost of deployment and maintenance.

However, some issues can arise when switching to a cloud-based subscription MES. One of them is data migration and compatibility. This means that the data accumulated in the existing deployed MES system must be migrated to the new ME-SaaS. At this time, issues such as data format, structure, and compatibility may arise, and careful planning and transition strategies are required to prevent data loss or errors. Next, your existing MES system is likely customized to meet your organization's specific needs. You'll need to think about how to integrate and customize these features into your new MES-SaaS, and if necessary, develop and configure them. Next up is security and compliance. SMBs are particularly distrustful of data sharing and use when adopting the cloud, at 54.4%, which is 13.8% higher than wait-and-see. This distrust stems from concerns that data stored in the cloud can be easily shared or used inappropriately by operators or others. There is a need to have proper security policies and compliance measures in place. In addition, the SaaS model typically requires a monthly or annual subscription fee, so cost and budget management is important. Initial investment and operational costs need to be carefully calculated and managed. Finally, there are contractual and legal aspects. SaaS contracts and legal aspects also need to be considered. Legal commitments, data ownership, and transfer, contract duration, etc. should be clearly defined.

By considering these issues and doing enough planning and preparation before the transition, you can make the transition from an on-premises MES to a SaaS-based subscription MES go more smoothly.

4.3 Conclusion

The main goal of this paper is to implement a subscription MES-SaaS platform instead of an on-premises MES system. This will provide better accessibility, cost savings, ease of maintenance, ease of updates, scalability, and reliability for SMEs.

In addition, by converting sensor information and other informatization assets linked to PLCs in precision machining facilities into digital information based on the international standard AAS, interoperability, operability, continuity, and economy in data exchange with other solutions, companies, and countries can be achieved. By doing so, we aim to help manufacturing companies more smoothly transition their data assets to a subscription MES-SaaS platform.

Currently, we are mainly focusing on the design and implementation of MES-SaaS platform services for precision machining processes, but in the future, we plan to complement the solution for collecting and storing information assets by interlocking with the AAS base so that SMEs in other industries such as transportation parts equipment and bio-natural products can also utilize it. Through this, we will provide the systems required by various industries in the form of modules so that each manufacturer can select the functions they need and use them easily.

The future platform will establish a value-chain SaaS ecosystem based on data compatibility, providing innovative application services to gain a competitive advantage in a rapidly changing global business environment. The platform will provide innovative solutions to small and medium-sized enterprises in various industries, enabling them to thrive in the business environment.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflict of interest to declare.