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# The State of Knowledge of Cloud Computing Technology for Manufacturing Automation Systems

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***Abstract***

*The manufacturing sector is grappling with the need to adapt to rapid technological changes, and leveraging cloud computing is becoming crucial for staying competitive and resilient. The presentation of knowledge in this work focuses on highlighting the specific challenges and opportunities in integrating cloud technologies into manufacturing systems. It aims to answer critical questions such as how cloud computing can enhance manufacturing automation, solve problems, and benefit to the industry. The methodology employed in this research takes a comprehensive and top-down approach, aligning and exploring the practical aspects of implementing these X-as-a-Service (XaaS) model in manufacturing setups. The research also acknowledges the shift from legacy Distributed Numerical Control (DNC) systems to modern solutions like MTConnect and Open Platform Communication (OPC) for data exchange in automated manufacturing systems. Emphasizing the important of data collection and real-time monitoring, the study highlights the role of Industrial Internet of Things (IoT) sensors deployed at various points of manufacturing system components (machine tools, spindles, cutting tools, production units, etc.). These sensors capture real-time production and condition data, enabling informed decision-making in manufacturing systems. This research not only presents the latest knowledge but also offers insights into the challenges, strategies, and methodologies involved in the successful integration of cloud-based technology into manufacturing automation systems. It also aims to serve as a valuable resource for manufacturers, researchers, and industry professionals navigating the transformative journey toward cloud-powered manufacturing.*

***Keywords****: cloud computing, manufacturing automation, top-down approach, IoT Sensors, data exchange, Industrial Internet of Things (IIoT)*

**Abstrak**

Sektor manufaktur sedang bergulat dengan kebutuhan untuk beradaptasi terhadap perubahan teknologi yang cepat, dan memanfaatkan komputasi awan menjadi hal yang penting untuk tetap kompetitif dan tangguh. Presentasi pengetahuan dalam karya ini berfokus pada menyoroti tantangan dan peluang spesifik dalam mengintegrasikan teknologi awan (*cloud*) ke dalam sistem manufaktur. Hal ini bertujuan untuk menjawab pertanyaan-pertanyaan penting seperti bagaimana komputasi awan dapat meningkatkan otomatisasi manufaktur, memecahkan masalah, dan memberikan manfaat bagi industri. Metodologi yang digunakan dalam penelitian ini menggunakan pendekatan komprehensif dan top-down, menyelaraskan dan mengeksplorasi aspek praktis penerapan model X-as-a-Service (XaaS) dalam pengaturan manufaktur. Penelitian ini juga mengakui peralihan dari sistem Distributed Numerical Control (DNC) lama ke solusi modern seperti MTConnect dan Open Platform Communication (OPC) untuk pertukaran data dalam sistem manufaktur otomatis. Menekankan pentingnya pengumpulan data dan pemantauan real-time, penelitian ini menyoroti peran sensor Industrial Internet of Things (IoT) yang ditempatkan di berbagai titik komponen sistem manufaktur (peralatan mesin, spindel, alat pemotong, unit produksi, dll.). Sensor-sensor ini menangkap data produksi dan kondisi secara real-time, sehingga memungkinkan pengambilan keputusan yang tepat dalam sistem manufaktur. Penelitian ini tidak hanya menyajikan pengetahuan terkini namun juga menawarkan wawasan mengenai tantangan, strategi, dan metodologi yang terlibat dalam keberhasilan integrasi teknologi berbasis awan (*cloud*) ke dalam sistem otomasi manufaktur. Laporan ini juga bertujuan untuk menjadi sumber daya berharga bagi produsen, peneliti, dan para profesional industri yang menentukan arah (mengemudikan) perjalanan transformatif menuju manufaktur bertenaga awan.

**Kata kunci:** *komputasi awan, otomasi manufaktur, pendekatan* top-down*, Sensor IoT, pertukaran data,* Industrial Internet of Things *(IIoT)*

## Introduction

In today's rapidly evolving landscape, the manufacturing sector finds itself at the crossroads, compelled to embrace innovation to remain competitive and resilient. The cloud computing technology emerge as a pivotal force, poised to redefine the way manufacturing systems operate and adapt. This paper delves into the state of knowledge surrounding cloud computing technology in the context of manufacturing automated systems, shedding light on the challenges and opportunities it presents.

Manufacturers face an ever-increasing need to adapt to the dynamic and disruptive forces shaping the industry. One such force is transformative potential of cloud computing. This work serves as an exploration of the specific challenges and prospects that arise when integrating cloud technologies into manufacturing systems. We address questions, such as how cloud computing can augment manufacturing automation, solve critical problems, and drive innovation across the industry.

The methodology underpinning this work is anchored in a comprehensive, top-down approach. Drawing inspiration and delve into the practical aspects of implementing these X-as-a-Service (XaaS) models within manufacturing environments. In recognizing the industry's shift from legacy Distributed Numerical Control (DNC) systems, we explore modern solution like MTConnect and Open Platform Communication (OPC) as integral components of data exchange in automated manufacturing systems.

Central to our study is the crucial role of data collection and real-time monitoring. We emphasize the deployment of industrial Internet of Things (IoT) sensors strategically placed throughout the manufacturing system's components, including machine tools, spindles, cutting tools, and production units. These sensors capture real-time production and condition data, providing a foundation for informed decision-making within manufacturing systems.

This research not only presents the latest knowledge but also offers invaluable insights into the multifaceted landscape of cloud-based technology integration in manufacturing automation systems. Its objective is to serve as a guiding resource for manufacturers, researchers, and industry professionals as the navigate the transfomative journey towards harnessing the power of cloud computing in the manufacturing sector. As we embark on this exploration, we unveil the potential for cloud technology to revolutionize the future of manufacturing, ensuring its continued relevance in an era of digital transformation.

The following paragraphs discuss literature review, serves as foundation to cloud computing technology, especially in manufacturing automated systems, followed with requirement of manufacturing automated systems, data exchange and monitoring through MTConnect and OPC-UA, software tools cloud computing that can be used in transforming and adapting of manufacturing systems, the reference architecture, some examples of specific cloud computing application into manufacturing components, IoT sensors, and strategy and benefit of applying cloud computing into automated manufacturing systems.

## Literature Review

Cloud computing is a technology that enables users to access computing resources, such as servers, storage, and applications, over the internet on a pay-per-use basis. Rather than owning and managing their own physical computing infrastructure, users can rent and use resources from cloud service providers. Typically, Cloud Computing Technology (CCT) involves a provider offering different level of services (Rashid & Chaturvedi, 2019), such as Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS). Implementing or adopting CCT has been elaborated by Attaran & Woods (2018). The focus on CCT of small medium enterprises activities are seen as prospective to performed improve efficiencies, spur capital investment savings, simplified operations, scalability,

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improved information visibility, sustainability, and faster deployment (Huang et al., 2012). It sees as major enabler for manufacturing industries, especially Small and Medium Enterprises (SMEs) to gain a success and survive in their business (Jaleel et al., 2014) (Zhang et al., 2015).

Most of automated manufacturing systems contain complex flow of production processes (Wu, 2002) (Wei et al., 2017) that may consists of integrated of automated storage and retrieval system (AS/RS), industrial robots, computerized numerical controller of machine tools (CNC), Shop Floor Control (SFC), Manufacturing Execution Systems (MES), Computer Aided Process Planning (CAPP), Computer Aided Design and Computer Aided Manufacturing (CAD/CAM), Enterprise Resource Planning (ERP), Supervisory Control and Data Acquisition (SCADA) and many more technological based applications and tools that spanning from department of design, fabrication, quality-control, assembling, packaging to delivery of goods, etc. Figure 1 shows a diagram of a manufacturing system.

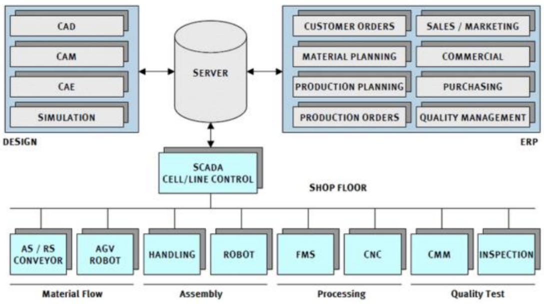


**Figure 1.** Manufacturing systems (adapted from Kostal & Velisek, 2011)

In the age of big-data, data is a key factor that connect manufacturing devices into the cloud computing facilities through the Industrial Internet of Things (IIoT). Shop floor data through devices and systems in industrial setting to enhance manufacturing metrics (Zhu et al., 2018), (Ferrer et al., 2018) such as efficiency, productivity, effectivity, utilization, availability, which is shown as Key Performance Indicator (KPI).

The MTConnect (Edrington et al., 2014) is an industrial open-source standard for exchange data between shop floor equipment (CNC machine tools, industrial robots, etc.) and software application for monitoring and data analysis (https://www.mtconnect.org/getting-started). The MTConnect contains XML and HTTP protocols based to support the connectivity to networked manufacturing environment up to the usage of cloud technological facilities. It is also knows as Cyber Physical Machine Tool (CPMT) (Liu et al., 2018).

The term of cloud manufacturing (Adamson et al., 2015) is introduced to manufacturing systems where the technology of cloud computing portion enabling on the platform, software, and infrastructure. The reference architecture and framework is discussed.

The following paragraphs will elaborate the requirement of manufacturing automated system, the communication protocol MTConnect and OPC-UA, the cloud computing technological support, the reference architecture for migrating manufacturing systems into IoT and cloud-based technology, and supporting software specifically need in this adoption of cloud computing technology.

## Requirement of Manufacturing Automated System

Manufacturing systems' key performance indicators (KPIs) (Caccamo et al., 2022), (Zhu et al., 2018) are summarized as follows:

1. Overall Equipment Effectiveness (OEE): OEE measures the efficiency and utilization of manufacturing equipment. It takes into account factors such as equipment availability, performance, and quality to determine the overall effectiveness of the equipment.
2. Cycle Time: Cycle time is the total time required to complete one cycle of a manufacturing process, starting from the beginning of one unit to the beginning of the next. It helps assess the speed and efficiency of the production process.
3. Quality Yield: Quality yield measures the percentage of products or components produced that meet the required quality standards. It indicates the effectiveness of the manufacturing process in producing defect-free products.
4. Downtime: Downtime refers to the time during which manufacturing equipment is not in operation due to unplanned breakdowns, maintenance, changeovers, or other factors. Tracking downtime helps identify areas for improvement and minimize production disruptions.
5. Throughput: Throughput measures the rate at which units or products are

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produced within a specific time frame. It reflects the productivity and capacity of the manufacturing process.

6. Inventory Turnover: It calculates how quickly raw materials or finished goods are used or sold within a given period. It helps evaluate the efficiency of inventory management and control.
7. Customer Order Fill Rate: It measures the percentage of customer orders that are completely fulfilled on time. It assesses the manufacturing process's ability to meet customer demand and deliver products promptly.
8. Scrap Rework Rate: Scrap and rework rate measures the amount of material or products that are rejected or require rework due to quality issues. It indicates the effectiveness of quality control and highlights areas for improvement.

The benefit for manufacturing systems by leveraging the capabilities of cloud technology is as follows:

a. Connectivity and networking: manufacturing automated systems needs to be connected to the Internet to access cloud services. High speed Internet connection is mandatory for seamless communication between the manufacturing system and cloud platforms.
b. Data collection and analysis: Cloud computing enables extensive data collection and analysis capabilities. Manufacturing systems can leverage cloud-based data storage and processing to collect, store, and analyze large volumes of data generated during the manufacturing process. This data can be used for process optimization, predictive maintenance, quality control, and other analytics-driven applications.
c. Scalability: Cloud computing provides scalable resources, allowing manufacturing systems to handle varying workloads efficiently. The ability to scale computing power and storage capacity on-demand enables manufacturers to adapt to changing production demands and handle peak periods without investing in additional on-premises infrastructure.
d. Remote Monitoring and Control: Cloud computing facilitates remote monitoring and control of manufacturing processes. Manufacturers can access real-time data, track production status, and monitor equipment performance from remote and anywhere through cloud-based applications. This accessibility enhances operational efficiency, facilitates timely decision-making, and enable quick response to any anomalies.
e. Collaboration and Integration: Cloud computing fosters collaboration and integration within ecosystem of manufacturing. It enables data sharing, insights, and resources among stakeholders (e.g. manufacturers, suppliers, customers, and service providers). Cloud-based platform supports integrations with other systems such as Supply Chain Management (SCM), ERP, CAD/CAM, SFC, CNC, etc. It streamlines workflows and improved visibility across the value-chain.
f. Security and Privacy: Manufacturing automated system must address security and privacy concerns with leveraging cloud computing. Encryption, access controls, and authentication mechanisms should be implemented to protect sensitive manufacturing data and prevent unauthorized access. Compliant to industrial standards and regulations are essential.
g. Optimization of Cost: Cloud computing offers potential cost benefits. By leveraging cloud services, manufacturers can reduce upfront capital expenditures on hardware and software infrastructure. They can benefit from pay-as-you-go pricing models, where costs are incurred based on actual usage, allowing for more cost-effective operations.

By harnessing the power of the cloud, manufacturers can enhance their operational efficiency, agility, and competitiveness in the rapidly evolving manufacturing landscape.

## OPC-UA and MTConnect

Communication protocol is a key to communicate between devices to higher hierarchy above. Legacy communication protocol such as RS485, LSV2, mostly for DNC link communication is not sufficient and outdated to support wider integration with cloud computing technology.

They are two key communication features to realize connectivity in the cloud computing era seen from manufacturing devices upward,

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namely, the Open Platform Communication Unified Architecture (OPC-UA) (Mahnke et al, 2009) and the MTConnect (Lu et al., 2019). OPC-UA is a widely adopted industrial communication protocol standard designed for secure and reliable data exchange of various devices and systems. It was originally an Object Linking Embedding (OLE) for Process Control (OPC) protocol and provides improved functionality, interoperability and security. Figure 2 shows OPC-UA environment.

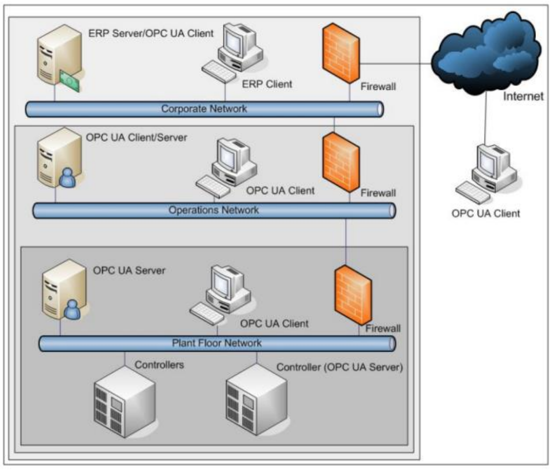


**Figure 2.** OPC-UA environment (adapted from Mahnke et al., 2009)

MTConnect is an open communication protocol specifically developed for the manufacturing industry to facilitate the exchange of data between shop floor equipment, devices, and software applications. It focuses on machine tool data collection and monitoring for real-time analysis and optimization. The MTConnect standard defines data tags and the behavior of a software agent. Figure 3 shows MTConnect connecting device to application.

To work seamlessly between those two standards; MTConnect and OPC-UA, a companion document has been published. The document provides a mechanism to collaborate and to extend the reach of manufacturing data exchange standards (MTConnect Institute & OPC Foundation, 2012). Table 1 shows the comparison of OPC-UA and MTConnect (Liu et al., 2018).

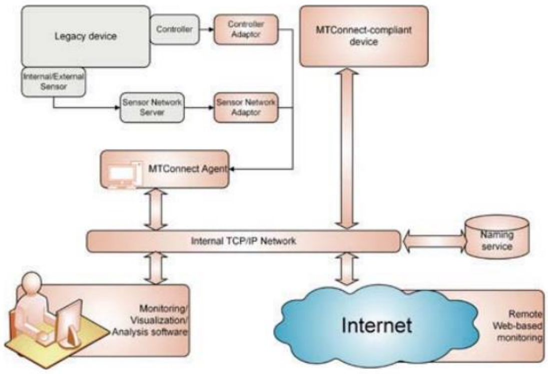


**Figure 3.** Signal flow from device to application using MTConnect (adapted from Edrington et al., 2014)

**Table 1.** Comparison of standards

| | MTConnect | OPC-UA |
|---|---|---|
| Standard domain | Machine tools | Any system in manufacturing |
| Information modeling method | Specifically design for CNC machine controller; XML schemas in standard | Generic and flexible; user can design their own information model and data types |
| Extensibility | Relatively low; achievable thru extenstion of standard | High; any information model can be built upon the meta model |
| Definition of data | Data dictionary is concisely defined for CNC machine tools | No domain specific data defined in the standard |

### The Available Technology

Cloud computing is a model for delivering computing resources and services over the Internet on a pay-per-use basis (Breivold, 2017) (Wang et al., 2015). Cloud manufacturing use cloud computing technologies in the manufacturing industry to optimize production processes and create profitable value-added for feature manufacturing company (Breivold, 2019).

Cloud technology focuses on (1) infrastructure (IaaS) that provides virtualized computing resources, such as servers and storage, (2) platform (PaaS) that provides a platform for developing, deploying, and managing applications, and (3) software (SaaS) that provides access to software applications that are hosted by the provider.

They are some cloud computing technologies that can be implemented or used to support manufacturing processes (in term of platforms, infrastructures, and software applications as following.

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*Platform as a Service* (Paas): (1) Microsoft Azure IoT Suite (Klaffenbach et al., 2018): provides cloud-based tools and services for building and deploying IoT applications in manufacturing, including data ingestion, analytics, and machine learning capabilities. (2) Amazon Web Service (AWS) IoT Core. This includes scalable connection of manufacturing devices to the cloud. It allows the integration of real-time data processing, connecting sensors to the cloud (Amazon Web Services, 2020).

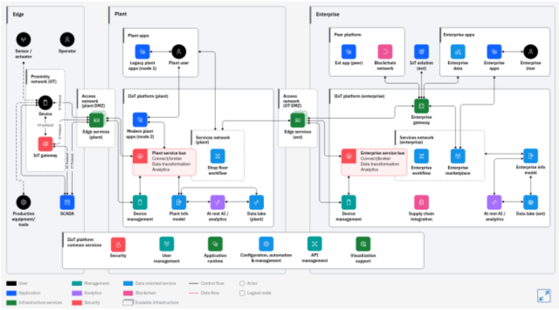

**Figure 4.** The reference architecture to identify existing and needed functions for digitization in manufacturing[2].

*Infrastructure-as-a-Service* (IaaS): (1) Google Cloud Platform (GCP): offers a wide range of IaaS solutions for manufacturing including virtual machines, storage, networking and container orchestration with Kubernetes. (2) IBM Cloud: it provides IaaS offering such as virtual servers, storage, and networking infrastructure than can be used to support manufacturing automation. In Figure 4 shows the reference architecture for manufacturing[1], as the deployment of the IBM Cloud.

In the classification of edge computing, there are Siemens Industrial Edge [2] and General Electric's Predix Edge [3]. Both has cloud connectivity to enable real-time analytic, decision making at factory floor, reducing latency and improving responsiveness.

Software application such as Manufacturing Execution Systems (MES) is available such as SAP Manufacturing Execution, it is a cloud-based MES that integrates with production equipment, systems, and data sources to provide real-time visibility, control and manufacturing operational optimization. While, Wonderware MES offers cloud-enable MES software that connects with shop floor devices, collects data, and provides production monitoring, tracking, and reporting functionalities (Wonderware MES/Operation, 2023).

Those software above are some examples of proprietary application to support cloud computing technology. Next, the following is the open-source application that might be used that may be specifically to choose depends on the manufacturing requirements, integration needs, scalability and other relevant factors to the specific use-case. They are, among other, Cloud Foundry[4], OpenShift[5], Apache Stratos[6], and Deis[7]. Most of them are PaaS to support cloud computing and may be deployed to manufacturing systems. A complete list of survey is provided by Damjanovic-Behrendt & Behrendt, (2019).

## The Reference Architecture

Deploying X-as-a-Service (XaaS) above requires a re-thinking of the reference and system architectures of the manufacturing systems to be implemented. A reference architecture is a predefined blueprint or template that provides a standardized and well-defined structure for designing and developing manufacturing systems. The characteristics components include: standardization, modularity, best-practices, components, security, and scalability. While a system architecture (Wu et al., 2013) refers to a specific design and structure of a manufacturing system tailored to meet the unique needs and requirements of a particular organization or production environment. The characteristics may include hardware and software components, data flow, integration systems, customization, scalability and flexibility, and performance and efficiency. We explore further some reference architectures hereunder.

IBM's reference architecture is shown at Figure 4. It represents the generalization in practices of manufacturing digitization performed by IBM, RedHat, and their partners. They provide 3 layers, namely, edge, plant, and

[1] *https://www.ibm.com/cloud/architecture/architectures/industry-40/reference-architecture*

[2] *https://www.siemens.com/global/en/products/automation/opic-areas/industrial-edge.html*

[3] *https://www.ge.com/digital/sites/default/files/download_assets/predix-edge-from-ge-digital-datasheet.pdf*

[4] https://www.cloudfoundry.org/

[5] https://www.redhat.com/en/technologies/cloud-computing/openshift

[6] https://stratos.apache.org/

[7] https://deislabs.io/

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enterprise. Between layers is connected by edge-services (plant and enterprise) where which each of them are connected through IIoT platform services. These services consist of security, user-management, application runtime, configuration and automation management, API management, and visualization support.

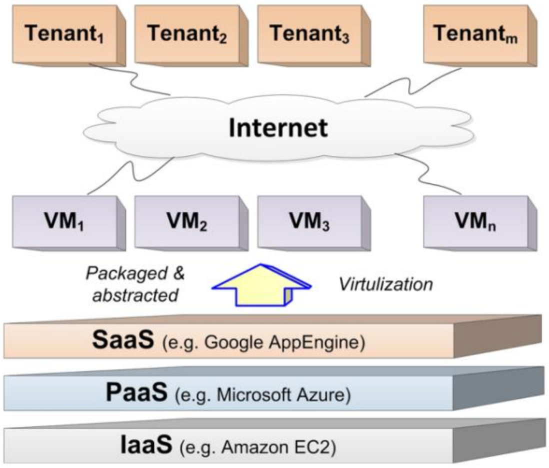


**Figure 5.** Structure of cloud computing (Wang et al, 2015)

Figure 6 shows cloud-based computing manufacturing (Cloud Manufacturing) architectural structure (Wang et al, 2015). It shows the role of MTConnect networked machine tools, industrial robots, and connecting to higher hierarchy within the upstream departments such machine parameters, process data, monitoring data, design code, maintenance and prognosis (Gao, et al, 2015) to communicate and exchange data. Those data exchange brought further up into the cloud computing follow the organizational structure of the manufacturing companies in term of cloud computing virtual services (X-as-a-Service). Figure 6 illustrates the structure of cloud computing. The 3 layers are shown and abstraction and virtualization represents by virtual machines that in turn represent the tenants. In private cloud of manufacturing, this might be manufacturing's internal structure.

Hybrid manufacturing cloud development (Lu et al, 2014) proposed customize-able could services depends to the specific requirement of the manufacturing companies. They are acknowledged as unique and specialized. Therefore, the cloud deployment must be customize-able and configurable, especially in manufacturing setting, such as private cloud, community cloud, public cloud, and hybrid cloud. Hybrid cloud is a composition of two or more clouds such as private-, public-, or community-clouds. Those clouds are distinct entities and offering benefits of modes of multi-deployment.

From cloud computing side-view, adopting manufacturing automation system requires reference architecture as the guidance. This can be described by prescriptive automation work (Vater, et al, 2019). Figure 7 shows a reference architecture as reference to map manufacturing system into the technology of edge- and cloud computing.

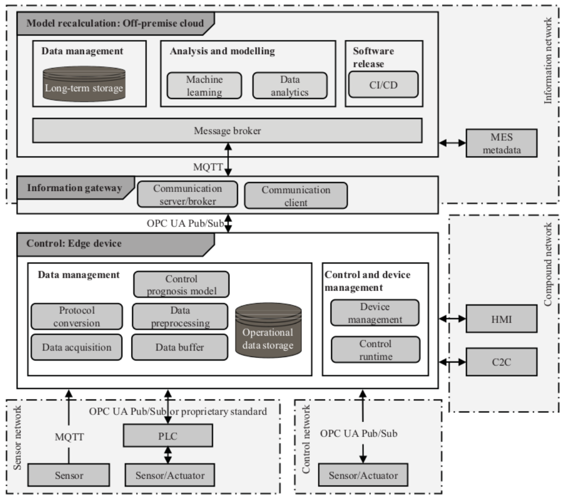


**Figure 6.** Reference architecture of prescriptive automation (Vater, et al, 2013)

This architecture is based on derived requirements such as methods, solution components (including the control of manufacturing systems, database to apply prognosis model, etc.), autonomy of control, process responsiveness, visualization of process and control, scalability of modeling performance, interoperability, real-time and physical connections, data storage and processing, etc. Refer to Vater et al., (2013) of the requirement.

### IoT Sensors for Manufacturing

Manufacturing disturbances exist in the shop-floor. These can be found in the form of machine vibration due to harsh machining processes, temperature increase, cutting tool missing or broken, wrong CNC part programs and it need to be revised, process status reconciliation, unavailability of jigs or fixtures, etc. These occurrences need to be visible to higher hierarchy in manufacturing. IoT sensors enable real-time visibility of manufacturing environment toward decision making [8]. IoT sensors are a system that use connected devices to monitor and control components of manufacturing equipment. Most of them are smart devices. Data is collected from smart devices and software systems allow companies to react quickly when problems arise.

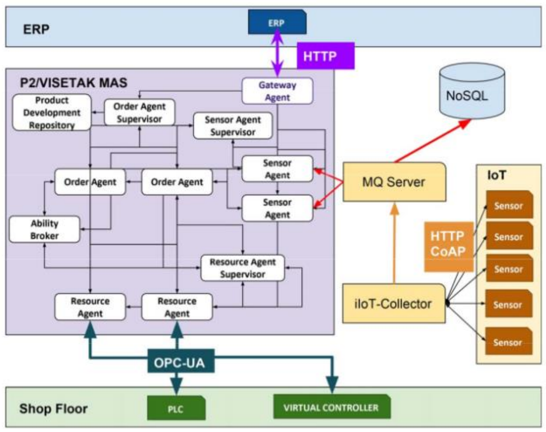


**Figure 8.** A three layers architecture of Shop Floor, Multi Agent Systems, and ERP. Adapted from Alexakos et al., (2018).

Figure 8 shows a three layers architecture of Shop Floor, Multi Agent Systems, and ERP. It shows the IoT sensors connected thru CoAP and MQTT protocols (Alexakos et al., 2018). OPC-UA facilitates for shop floor integration to Multi Agent Systems for data transfer to higher hiearchy (MTConnect Institute & OPC Foundation, 2012). Those IoT sensors are the bridge for data exchange within the shop floor to enable fast response for decision making.

## Some Software Applications

Cloud computing is a technology that enables users to access computing resources, such as servers, storage, and applications, over the internet on a pay-per-use basis. In manufacturing context, some software applications to be used is following.

a. Robotic Process Automation (RPA) Platforms (Ma et al., 2019): RPA platforms enable organizations to automate repetitive and rule-based tasks by employing software robots or “bots”. These bots could be deployed on the cloud to automate various manufacturing processes, such as data entry, inventory management, order processing, and more. They interact with existing software systems, mimic human actions, and perform tasks with high accuracy and efficiency.
b. Digital Twin Platforms (Liu, et al, 2015): Digital twin platforms create virtual (digital) replicas or simulations of physical assets, machines, or entire production lines. These platforms leverage cloud computing resources to store and process vast amounts of data, enabling real-time monitoring and analysis of the digital twin's performance. By connecting IoT sensors and other data sources to the digital twin, manufacturers can optimize processes, predict maintenance needs, and simulate scenarios for process improvement.
c. Manufacturing Execution Systems (MES) in the Cloud: Traditional MES solutions can be migrated to the cloud, providing manufacturers with centralized and scalable control over their production processes. Cloud-based MES platforms enable real-time visibility into production data, seamless integration with IoT devices and sensors, scheduling and resource management, quality control, and analytics. They allow manufacturers to monitor and optimize operations across multiple locations or even within a single facility.
d. Industrial Internet of Things (IIoT) Platforms: IIoT platforms provide a comprehensive infrastructure for connecting, managing, and analyzing data from a wide range of industrial devices, machines, and sensors. These platforms often operate in the cloud, leveraging its scalability and data processing capabilities. IIoT platforms enable manufacturers to collect, store, and analyze large volumes of data, perform real-time monitoring, conduct predictive maintenance, and gain insights for process optimization and automation.
e. Cloud-Based Robotic Control Systems (Vick et al., 2016): Cloud-based robotic control systems allow manufacturers to remotely monitor and control robots and robotic systems. These systems leverage cloud computing and real-time data transmission to enable centralized

[8] https://maxbotix.com/blogs/blog/iot-sensors-for-manufacturing

management, programming, and monitoring of robots across multiple locations. Cloud-based robotic control systems offer features like remote programming, real-time monitoring, predictive maintenance, and advanced analytics, facilitating efficient automation and collaboration.

## Conclusions

In this paper, it is shown a top-down development toward cloud technology based in manufacturing automated system. This might be started from the machine tools, devices, and equipment at the shop floor. CNC machine tools, industrial robots, sensors of the devices level in the manufacturing shop floor is to be connected and exchanged the data with the Internet network. Direct Numerical Control with the legacy communication protocol is being replaced with MTConnect and OPC-UA for connecting to the Internet through with or without IIoT backbone.

Connection to the Industrial IoT infrastructure is performed in exchange data from devices (mostly sensors) to get status on monitoring real-time condition. Protocols are used, and may be based on XML and http. Next, the cloud layers divided into three; platform, infrastructure, and most used software. Manufacturing companies will be requested to pay in term of X-as-a-Service provided. Initial investment cost is much lower compare to the ownership license.

Implicitly, these articles provide an approached to start cloud computing technological adoption to manufacturing systems by creating digital twin, proceed to Cyber Physical Systems (Production Systems, Machine Tools, etc.), laying up IIoT feature onto devices to seamlessly integrate data, deploy MTConnect and OPC-UA, and then jump to X-as-a-Service platform. Migrating all software tools used by wisely selecting based on their required requirement, specification and availability.

Some proprietary application software are available, and some open-source software is also provided. However, to select one to be used at manufacturing settings requires detail specification and consideration.

To migrate into cloud computing technology, the manufacturing automated system needs to have the system architecture. Comparing this architecture with the reference architecture to find the gap between them. Based on the gap matrix, one may find the appropriate solutions based on the differences in the requirement and specification. A use-case can be explored further to prove successful implementation.

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