DATA COLLECTION STRATEGIES IN MANUFACTURING OPERATIONS

Jabiyeva A.
Doctor of philosophy in engineering, associate professor Azerbaijan State Oil and Industry University. AZ 1000, Nasimi, Baku, Azerbaijan.
Bakhtiyarov B.
PhD candidate, Azerbaijan State Oil and Industry University. AZ 1000, Nasimi, Baku, Azerbaijan
https://doi.org/10.5281/zenodo.14169148

Abstract

Effective production management relies heavily on comprehensive knowledge of the state of the production system. While many modern companies implement ERP (Enterprise Resource Planning) systems to manage business operations, a critical gap often exists between the business and manufacturing layers. Bridging this gap necessitates the direct acquisition of data from the production environment, followed by its analysis and presentation in a user-friendly format. Different manufacturing systems, due to the diversity of equipment and conditions, require tailored approaches for data collection, which is largely influenced by the level of automation within the system. This paper presents a comparative analysis of methods used for data acquisition in both automated and non-automated manufacturing systems. It explores the role of automation equipment—such as sensors, actuators, PLCs, DCS, CNC, HMI, and SCADA systems and automatic identification technologies like barcodes, RFID, and vision systems. Additionally, communication solutions such as fieldbus, wired and wireless networks, alongside information exchange standards like OPC and MTC, are discussed. The integration of these technologies is critical for enhancing real-time monitoring, decision-making accuracy, and overall production efficiency.

Keywords: PLC, SCADA, OPC, MTC, automatic identification systems

Introduction. In the current highly competitive global market, proficient production management is vital for the success of any manufacturing firm. A key factor contributing to this success is the capacity to gather timely and precise information regarding the operational status of production machinery. This data encompasses production orders, machinery and equipment performance, product flow, finished goods, employee efficiency, and product quality. By collecting this essential information, management can make wellinformed decisions, enhance production workflows, and ensure optimal performance. To streamline operations and establish effective processes, the collected data must be transmitted directly or via the manufacturing execution system (MES) to enterprise resource planning (ERP) systems. As systems progress, the methodologies for data collection gain increased significance in executing operations. In an electronic production setting, control systems are equipped with advanced technologies that capture time signals for managing automatic processes, supported by communication networks that enable seamless information exchange. Additionally, supervisory control and data acquisition (SCADA) systems and human-machine interfaces (HMI) are frequently utilized for processing and storing production data. However, the integration of various devices, networks, and software from different manufacturers or especially when data harmonization is lacking and when dealing with large files can create substantial challenges. The ability to sift through and analyze vast amounts of collected data to extract the most relevant insights is crucial for ongoing improvement. Organizations that depend on manual or semi-automated processes often struggle with inadequate data collection, which is performed manually and can result in delays and uncertainty. Outdated information hampers the monitoring of manufacturing processes and leads to inefficient use of materials and resources. These challenges underscore the necessity of establishing a robust system for gathering and managing manufacturing data, irrespective of the automation level within a company. In less automated environments, Programmable Logic Controllers (PLCs) employ various data collection techniques. This paper will also explore the significance of data acquisition systems (DAS), the Industrial Internet of

Things (IoT), and SCADA in contemporary manufacturing, examining how these technologies can enhance production management, conserve resources, and improve overall efficiency. By tackling issues related to data collection and implementing effective solutions, manufacturers can refine their processes in alignment with business objectives, ultimately boosting profitability, efficiency, and competitiveness in the marketplace.

Method

In standard production systems, data acquisition occurs through various applications, including the automatic control of technological processes, machinery diagnostics, and the management of the manufacturing system within a company. Addressing the challenge of data acquisition for management purposes primarily necessitates classifying production systems based on characteristics that influence data availability. A key criterion for this classification is the level of automation within the technological processes. Based on this criterion, production systems can be categorized into the following types: 1. Automated systems utilizing advanced control devices with network interfaces, 2. Automated systems employing older or less sophisticated control devices that lack communication interfaces, 3. Mechanized systems that do not incorporate any automation, and 4. Systems where most operations are conducted manually or with basic equipment and tools.

Additionally, the methods and tools for data acquisition should be classified to facilitate the development of a data acquisition methodology tailored for management needs. Figure 1. Illustrates the proposed classification of data acquisition methods aimed at enhancing company management.

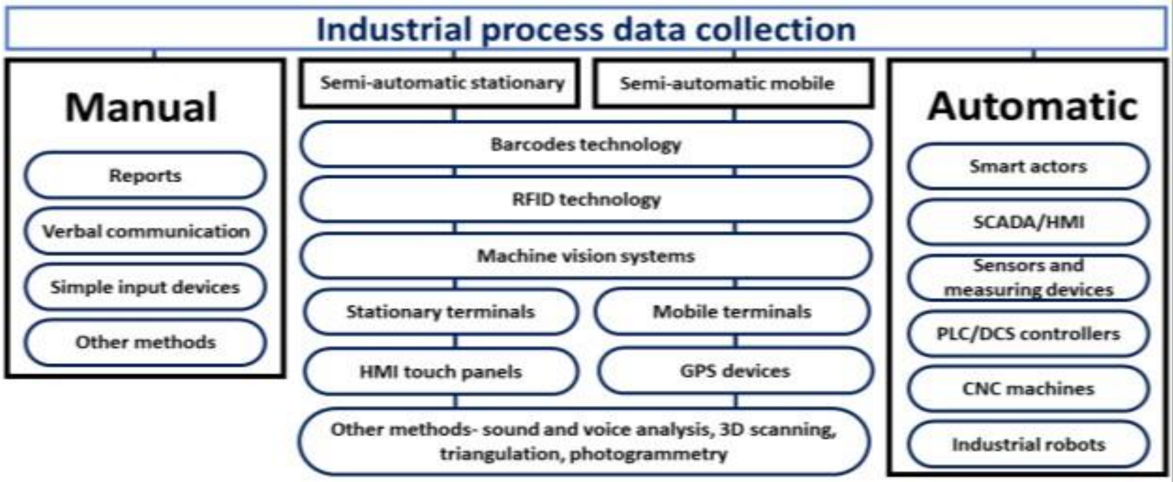

Figure 1. Classification of methods of data acquisition from production systems In companies where manual processes predominate, information retrieval primarily relies on a method known as manual acquisition. This approach is founded on direct communication among employees at various management hierarchy levels. However, this method has several drawbacks, particularly in the context of modern industrial systems, as it tends to be inefficient. Manual acquisition is often prone to errors and delays, and requiring workers to divert their attention from primary tasks to maintain records can further diminish productivity.

To meet the demands of contemporary management support systems (ERP, MES), there is a necessity for more reliable and efficient solutions. This need gives rise to a method called semi-automatic acquisition (also known as assisted manual acquisition). While this approach may still require some level of worker intervention, it minimizes such involvement and supports employee actions with hardware and software tools designed to reduce data acquisition errors and enhance speed. Semi-automatic data acquisition can be implemented using either stationary or mobile hardware and software solutions. The technology of automatic object identification serves as the foundation for many of these solutions, enabling data acquisition for management purposes from non-automated, semiautomated, and fully automated production systems alike.

Currently, various methods are employed for automatic object identification, including barcodes (optical reading), magnetic tracks, radio frequency identification (RFID), image analysis (machine vision), and voice recognition, among others. On the other hand, automatic acquisition refers to the retrieval of data from technological processes through automatic control systems, occurring without human intervention. Data is sourced from sensors, industrial controllers, CNC machines, robots, “smart” actuators, SCADA systems, and other related sources [2]. In this context, automatic identification and machine vision systems are frequently utilized to assist in process control and data acquisition.

Manual data collection: Automation, robotics, and mechanization significantly reduce the need for human involvement in the production process; however, certain processes remain non-automated, primarily due to a lack of profitability. Depending on the nature of the production process, employees may serve various roles, including manual operators, warehouse personnel, machinery operators, and transport equipment handlers. The information gathered from these workers is often entered into management support systems by mid-level supervisory staff or data entry personnel. This data can be input directly into business layer systems (e.g., ERP) or into various document templates using standard word processors or spreadsheets.

Research and practical experience show that employees are not always reliable sources of information, as they tend to report data with significant delays and errors caused by subjectivity, negligence, or intentional misinformation. The most frequently employed method for manual data acquisition involves collecting information from employees through conversations (either direct or over the phone) or through forms and reports, often utilizing simple software tools such as word processors and spreadsheets. However, these methods fall short in modern enterprises, highlighting the urgent need for the development of alternative, more dependable data acquisition methods. Figure 2. The scheme of the Manual Data Acquisition in

Manufacturing model is shown

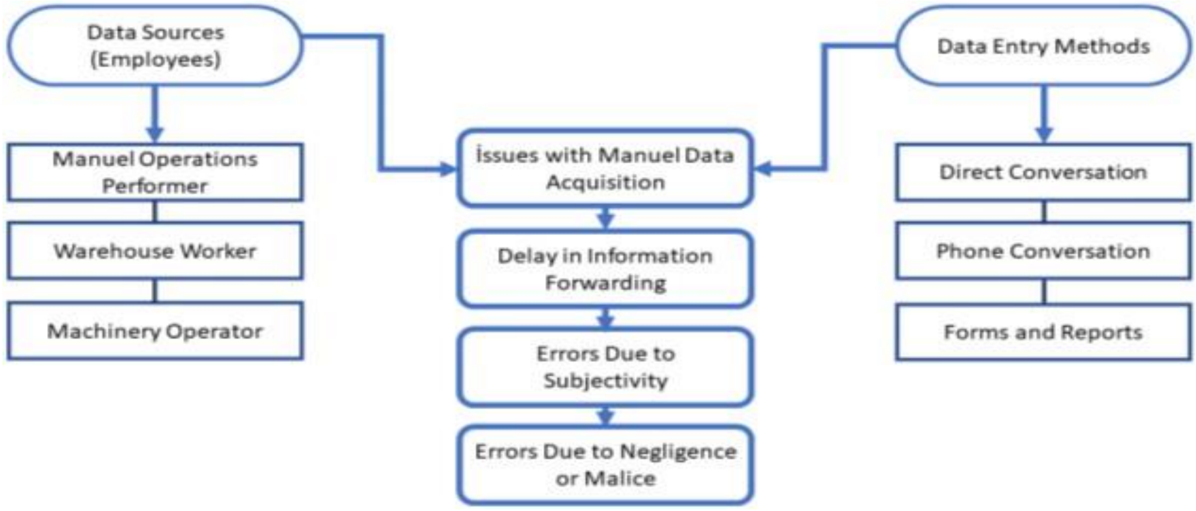

Figure 2. Manual Data Acquisition in Manufacturing

Automatic data collection: Automatic data acquisition for management purposes is feasible in automated production systems. These solutions address the majority of data acquisition needs from the automatically controlled segments of the production system.[3] Typically, data acquisition for process control is performed automatically, eliminating the need for employee involvement. The data collected for process control can also be utilized for management purposes, although preprocessing and suitable interfaces are often required.

The components of industrial automation systems that can serve as data sources for ERP systems include: control and measurement devices installed on machines and equipment, such as sensors and transducers; quality control equipment; actuators for industrial automation like solenoid valves, servo drives, frequency inverters, and metering pumps; automatic identification systems like barcode readers and RFID; machine vision systems; control devices including PLCs, industrial computers, operator panels (HMI), distributed control systems (DCS), and supervisory control and data acquisition systems (SCADA); and machinery involved in processes, including CNC machine tools, industrial robots, transport systems, and palletizing systems.

These devices can be categorized into two types: primary and secondary data sources. Typical primary sources include sensors and measuring devices that respond directly to changes in physical processes. Devices such as industrial controllers (PLC, DCS), CNC control systems, and industrial robots are considered secondary sources as they relay signals from primary sources while generating new data based on control algorithms that process the original data. SCADA systems also function as secondary sources by integrating data from various types of sources. Additionally, SCADA systems can collect data from process operators or supervisors through manual input or generate data via implemented master control algorithms. The model of Automatic Data Acquisition in Manufacturing Systems is given in figure

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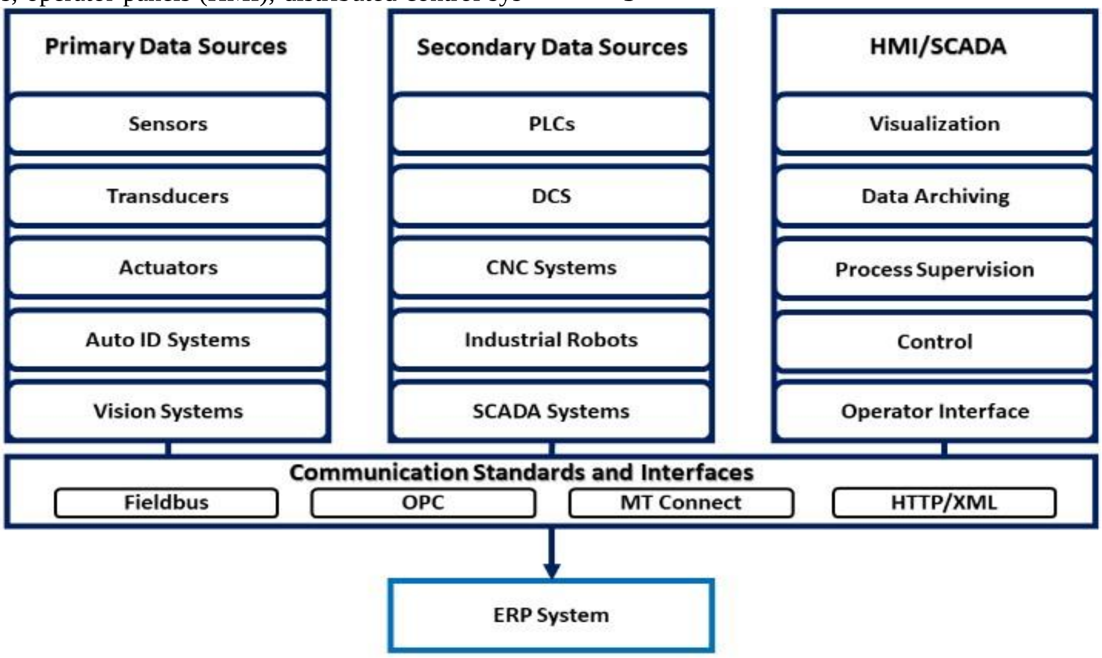

Figure 3. Automatic Data Acquisition in Manufacturing Systems

Primary data sources primarily consist of various types of sensors and transducers that convert physical phenomena occurring in the environment into electrical signals. Sensors are capable of measuring or detecting various parameters, such as temperature, pressure, position, motion, acceleration, and the presence of objects within their operational range. The signals produced by these sensors can be analog, binary, or digital. Selecting the appropriate type and placement of sensors in an automated process is the responsibility of the system designer. Sensors provide crucial information about the status of the manufacturing process, the machine environment, and the condition of the machine itself.

In modern industrial automation, actuators equipped with self-diagnostic systems and communication interfaces can also act as primary data sources. Examples of such devices include advanced servo drives and frequency inverters. Additionally, automatic identification systems and machine vision systems can be employed in process automation technology for direct system control. Devices and systems that depend on data from primary sources are classified as secondary data sources. These secondary sources can also generate new data based on raw input, which is essential for control purposes. Examples of such devices include industrial controllers (PLC, DCS, IPC), industrial robots, CNC machines, and SCADA systems.

Programmable Logic Controllers (PLCs) are currently the most significant technical tools for automating production processes. Essentially, they are specialized industrial computers operating under real-time operating systems. PLCs collect data from sensors and measurement devices, execute control algorithms, and communicate with other devices. Modern PLCs facilitate data sharing with PCs, other controllers, measuring instruments, actuators, and elements of the human-machine interface (HMI) through communication modules that adhere to various standards. In practice, PLCs integrate most sensors and actuators within the process control layer. Their communication interfaces enable access to the PLC's memory and stored values for inputs and process variables, allowing this information to be downloaded.

More and more companies are incorporating advanced machinery into their production systems, such as CNC (Computer Numerical Control) machine tools, DNC

(Direct Numerical Control), and industrial robots. In terms of architecture, CNC control systems resemble traditional computers tailored for specific machines. From a data acquisition perspective, the communication capabilities of these control systems are particularly significant. Standard CNC equipment includes a range of binary inputs and outputs, as well as sensors that monitor the machine's status [4]. More modern machines typically feature at least a serial interface or communication network interfaces, facilitating data acquisition.

HMI (Human-Machine Interface) and SCADA

(Supervisory Control and Data Acquisition) systems are hardware and/or software solutions that enable visualization, archiving of process data, and supervision and control of technological processes. SCADA systems can operate as the master control for PLCs and other devices, such as CNC machines. Most SCADA systems empower operators to control processes and input additional data, while also logging the actions performed by the operator. These capabilities position SCADA systems as integral components that consolidate data from various control systems, serving as a robust foundation for management information acquisition.

Data collected from control systems must be transmitted to higher-level systems within the enterprise through suitable interfaces that enable integration at both hardware and software levels. A significant issue arises from the high fragmentation in the automation systems market, characterized by numerous competing standards and solutions put forth by various hardware and software manufacturers [5]. This fragmentation affects both control systems and industrial communication networks. Networks connecting different levels of automated control (fieldbus) generally follow the standard OSI model; however, their implementations often depend on the specific hardware manufacturer. This dependence leads to a disorganized communication structure within the production system, ultimately reducing efficiency. As a result, there have been efforts to establish uniform standards and communication protocols, such as OPC and MTC, that facilitate access to data in control systems. The OPC standard established dedicated servers that are responsible for collecting and sharing various types of data from industrial control devices. Through OPC, both current and historical data, as well as alarms and events, can be made accessible to client software [6]. Typically, each server is designed for a specific family of PLC devices from a particular manufacturer or adheres to a specific standard.

Accessing data in a standardized format, provided by OPC servers, is achievable through OPC client modules that are integrated into applications needing data from control systems, such as SCADA, MES, and even ERP systems. Clients can communicate with any OPC server using the standard OPC protocol, allowing them to retrieve data from PLCs produced by different manufacturers. Many SCADA systems include an integrated OPC client for communicating with PLCs, as well as an OPC server that can supply data to other clients.

MTC is a new universal communication standard that facilitates access to data from CNC machines. By utilizing MT Connect, data gathered from various machines is presented in a unified, object-oriented format. This standard is built on common web technologies, including HTTP and XML. Devices that are compatible with MTC process information locally and subsequently provide it in a standardized format for any client applications [7].

When client software requests data, an MT Connectcompatible machine sends a formatted XML file containing information about its current status and ongoing processes. This file can be easily understood by any software.

Semi-automatic data collection: The adoption of semiautomated data acquisition methods in companies arises from the need for solutions that are more efficient and reliable than manual data collection. One of the simplest ways to enhance manual acquisition is by providing lower-level employees with access to computer terminals equipped with software that supports data entry. These terminals can be either fixed or mobile, and the data input programs should be designed to facilitate easy entry while minimizing the risk of errors [8]. However, this approach still requires employees to spend significant time typing long strings of characters. This issue can be addressed by implementing automatic identification systems, which typically utilize labels containing coded information along with corresponding readers for quick and accurate reading.

Among automatic identification systems, barcode technology and RFID technology are the most prevalent. Additionally, vision systems can be included in this category, as they do not require labels and have different application ranges.

Barcode technology is the most employed automatic identification method, primarily serving warehouse management systems [9]. One of the key advantages of barcode technology is the low cost of the labels. These benefits make it the preferred identification method in production systems, logistics, and warehousing [10-11]. The deployment of barcode scanners at various points within the production system enables the collection of information regarding the flow of materials, semifinished products, and finished goods, as well as equipment tracking.

RFID systems (Radio Frequency Identification) utilize wireless data transmission. RFID labels (tags) are compact and can withstand various environmental conditions, such as heat, cold, dirt, mechanical damage, moisture, and chemicals. They also offer a longer operational range, typically from a few millimeters to several meters. This technology enables the detection and identification of objects from a distance, regardless of their orientation, thereby eliminating the need to manipulate items and facilitating automatic data acquisition [12]. Semi-Automatic Data Acquisition methods are shown schematically in figure 4.

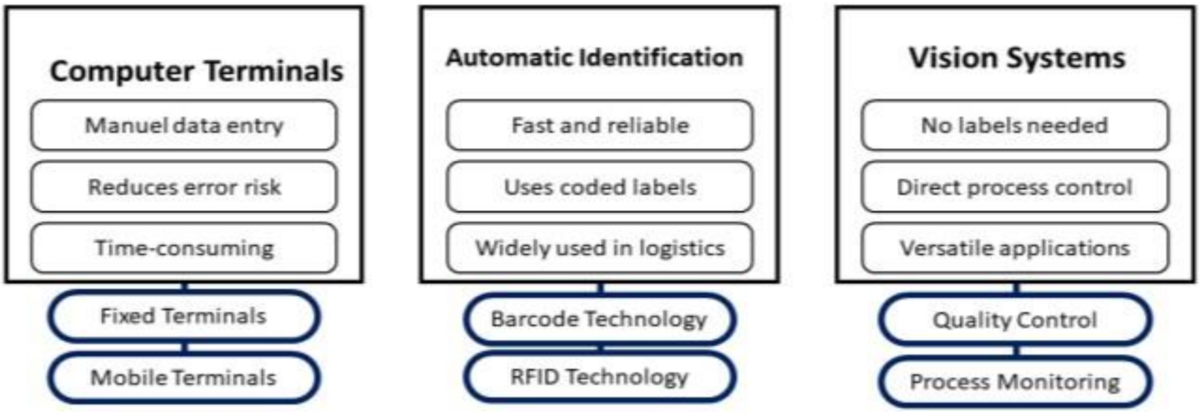

Figure 4. Semi-Automatic Data Acquisition Methods

Machine vision technologies typically act as a sensory system that directly oversees a process or a portion of it. Vision systems employed for quality control or sorting can deliver immediate information regarding the quantity of produced components and their quality standards [13]. Additionally, these systems can monitor and control mobile robots or analyze the movement of large items (such as tanks, wagons, etc.) throughout various stages of the production process. Manufacturing Information Acquisition System (MIAS): The examination of data acquisition methods and tools for management purposes has highlighted the necessity for developing a methodology to establish a universal information acquisition system within the enterprise. It is advisable to define a distinct category of information systems known as Manufacturing Information Acquisition Systems (MIAS), which would be responsible for gathering data from the production system to meet the requirements of enterprise management. Manufacturing Information Acquisition System algorithm scheme is shown in figure 5.

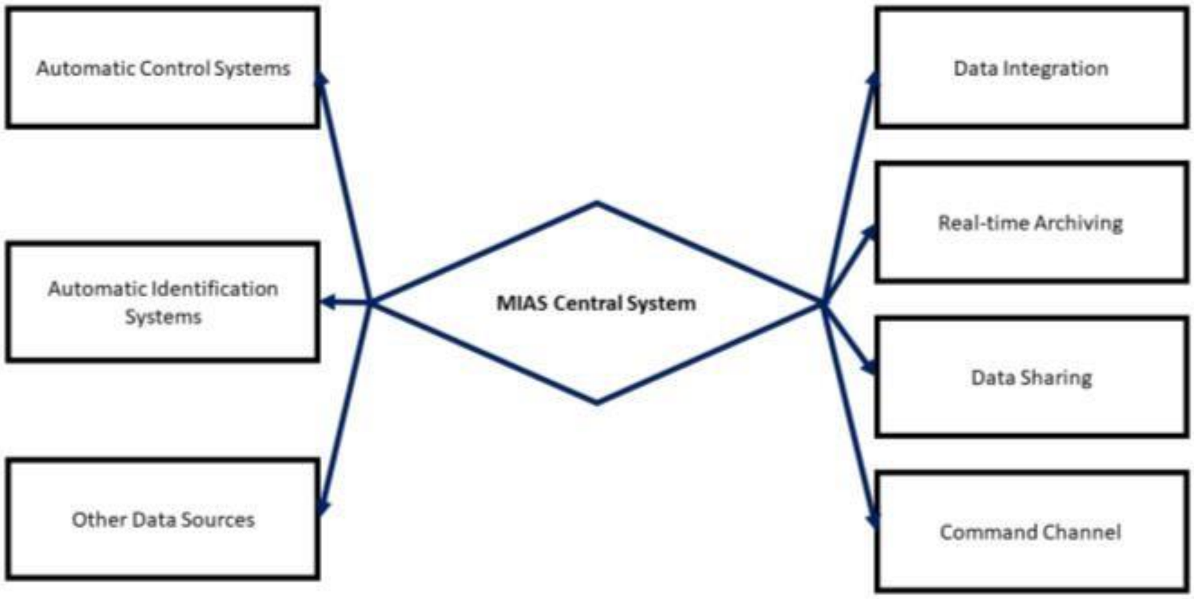

Figure 5. Manufacturing Information Acquisition System

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