How MongoDB enables Next Generation Manufacturing Execution Systems

By Humza Akhtar, PhD

Executive Summary

Over the last two decades, Manufacturing Execution Systems (MES) have been an essential industrial software for production execution and shop-floor automation. However, the advent of Industry 4.0 has created a demand for a next-generation MES that can process large amounts of time series sensor data generated by Industrial Internet of Things (IIoT) devices and merge it with production execution data. Integrating IIoT technologies with legacy MES software has proven challenging due to the monolithic design, inflexible data model, and poor horizontal scalability of relational databases used to store MES data.

In this paper, we will discuss the challenges associated with traditional relational databases used in MES software and how MongoDB addresses these challenges, allowing IIoT devices and MES to work collaboratively and synchronously, meeting Industry 4.0's scalability, flexibility, and interoperability requirements.

What is a MES?

A Manufacturing Execution System (MES) is a software system used in manufacturing to issue production work orders, track the production process, and capture data and outcomes of the manufacturing process in real-time. It controls various variables, such as equipment, personnel, and materials, to ensure that manufacturing operations are executed efficiently and effectively. The ultimate objective of an MES is to ensure that manufacturing operations are controlled and executed effectively and efficiently.

Figure 1 shows a simplified view of how MES integrates with other manufacturing systems during daily operations. MES takes in the production orders and specifications from Enterprise Resource Planning (ERP) software and creates a detailed production schedule based on the availability of resources and equipment and the production workflow. Once the schedule is created, the jobs are dispatched to the correct work centers with instructions to begin production. During the course of production, MES captures the jobs status, equipment process parameters, and other Key Performance Indicators (KPIs) that help decision-makers understand how current operations can be optimized to improve production output.

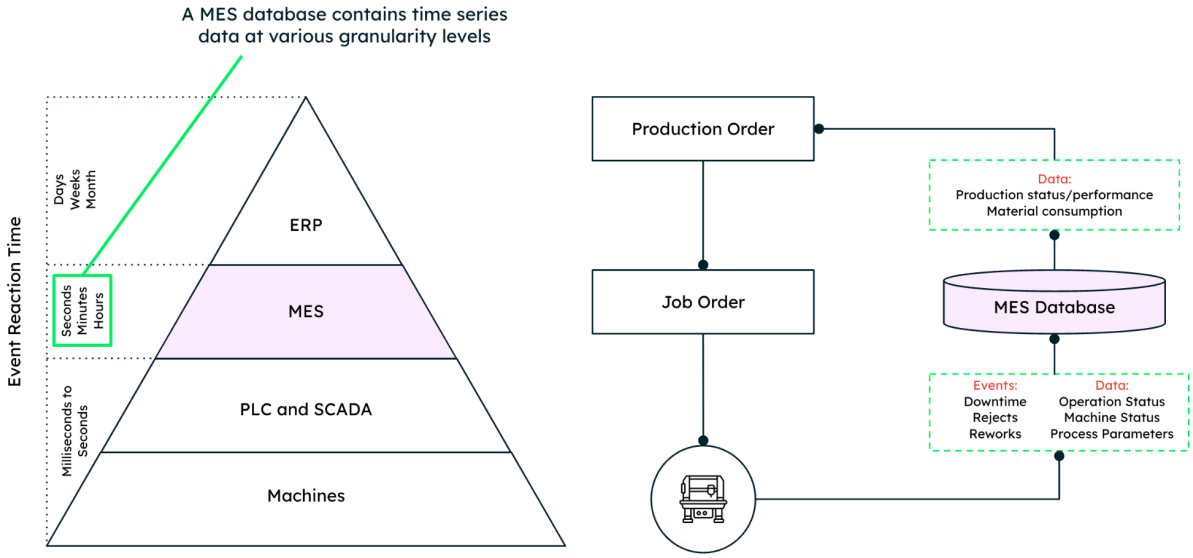

Figure 1: MES as the interface between ERP and the machines on shop floor

MES history and core functions

Manufacturing companies have always strived to find ways to collect data from their production processes and equipment. In the early 1970s, the term SCADA (Supervisory Control and Data Acquisition) was introduced and these systems enabled real-time manipulation and control of production parameters. These systems, although well suited for collecting real-time data from PLCs, had an issue when it came to the comprehensive and central management of manufacturing plants. It proved difficult to connect them to ERP systems since they were not built to understand terms such as production orders and inventory items. By the late 1980s, these issues gave way to the creation of a specialized software system called MES to enable manufacturing plants to connect the OT (machines and SCADA) and IT (ERP) layers and act as a single source of truth for understanding and improving production processes and operations.

In 2000, the International Society of Automation (ISA) created the early version of the ANSI-ISA-95 standard that established a standard for MES terminology and functions as well as standardization of MES interfaces between other systems. The 11 core functions of MES are listed in Figure 2.

Dispatching	Performance Analysis
Quality Management	Operations Scheduling
Data Collection and Acquisition	Resource Allocation and Status
Process Management	Labour Management
Production Tracking and Genealogy	Maintenance Management
Document Control	

Figure 2: Core functions of a Manufacturing Execution System

MongoDB enabling next-gen manufacturing execution systems

The next-generation MES software is defined by the following seven capabilities or characteristics (Figure 3).

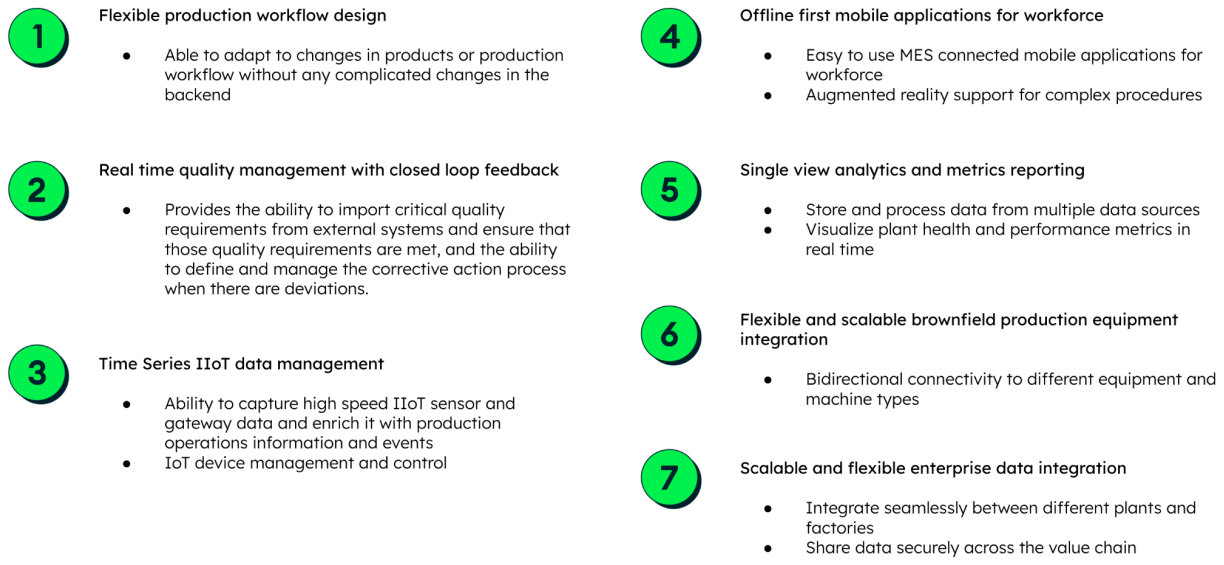

Figure 3: Seven critical capabilities of a next generation MES

To support these characteristics, the MES database needs to handle a variety of information coming from multiple sources (Figure 4) and therefore it is very important to choose the right database.

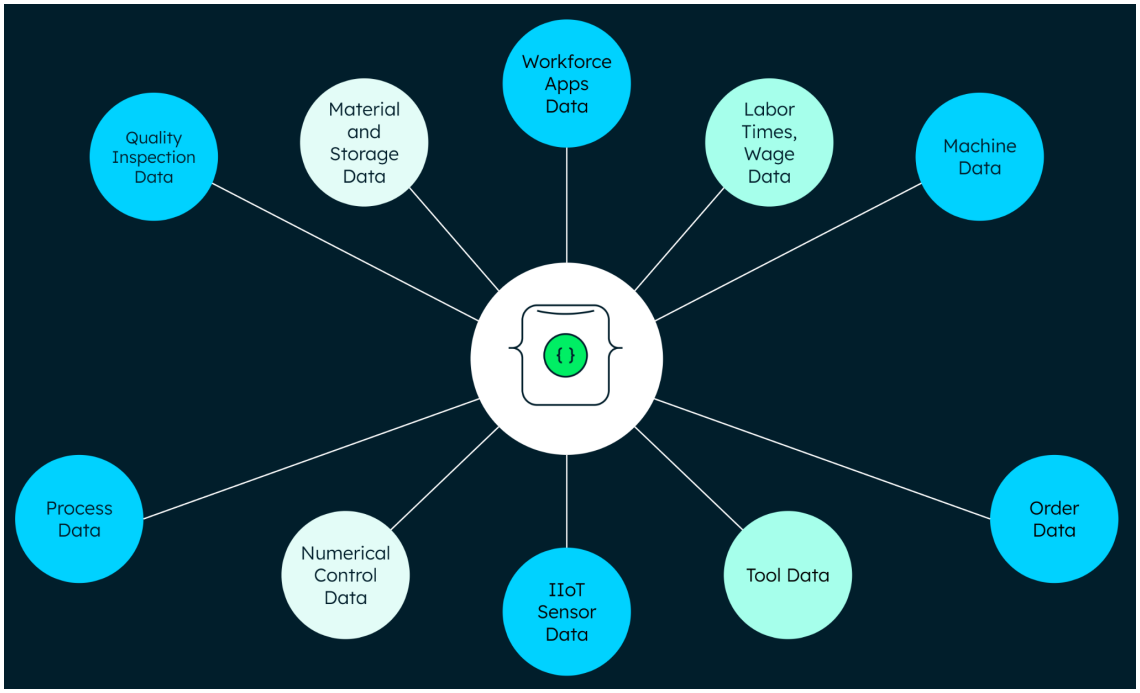

Figure 4: A MES database needs to handle data from variety of sources

Database systems for MES software are often selected based on historical preferences.When MES systems were first introduced, relational databases were the only player on the market and quickly became the de facto choice. Two additional reasons are listed below:

1. Initial Digitization: Decades ago, manufacturing data was mainly relational, collected, and stored using pen and paper. There were physical folders filled with papers containing production orders, production plans, and shift information. When MES was introduced, relational databases sounded like a good idea to digitize papers into tables of information containing relationships between them. Product variety was minimal,and IIoT was nonexistent, so there was no real need for frequent schema updates.

2. Single Machine Assumption: MES was introduced long before the internet gained massive popularity, therefore it was architected around the assumption that this software would run on a single machine. This statement was true for relational databases as well at the time. The lack of sensor technology meant that the shopfloor will generate just enough data that a single machine MES will be able to handle.

Fortunately, the world has evolved. The relational databases used in traditional MES systems struggle to handle the massive amounts of IIoT data and product and process varieties that are common in today's manufacturing plants. Each generation of connected machines comes with new sensors, bringing greater data volume and variety along with it — as well as potential new business insights. The data generated by these equipment tends to be large in both volume and frequency, placing a strain on the underlying relational database. This data is also time series forcing manufacturers to invest in a specialized time series database just to store IIoT data. This leads to the expense and complexity of yet another data silo, slow and fragile data integration with production operation data in MES, and archiving of aged data.

Now let us look at where relational databases may struggle when it comes to the desired capabilities of a next-generation MES and how MongoDB can help to overcome those challenges.

	Critical Capabilities of Next Generation MES	Challenges With Relational Databases for MES	How MongoDB Addresses These Challenges
1	Flexible production workflow design and deployment	As product variety and automation increases, more time is needed to add tables and columns for the SQL DB and to keep schema updated The database schema redesign to suit complicated processes results in time and productivity loss	 Data modeling using dynamic documents enables varying object representations in a single collection and removes abstraction. This makes it easier to deal with evolving production processes
2	Real time defect detection and quality management with closed loop feedback	Multiple ETL jobs are required to connect and integrate with multiple brownfield quality inspection databases and systems resulting in IT sprawl and increased complexity	 Freedom to run anywhere means you can run MongoDB close to the equipment all the while

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			automatically syncing select collections with Atlas using Cluster-to-Cluster Sync  App Services and Triggers to send events and notifications with shop floor applications and equipment
3	Time series IIoT data management	Multiple IIoT sensors and data sources sending data in different formats putting a strain on underlying RDBMS. This can result in high latency leading to bad user experience	 MongoDB's time series collections automatically store time series data in a highly optimized and compressed format, reducing customer storage footprint, as well as achieving greater query performance at scale
4	Offline first mobile applications for workforce	Mobile app databases need to be kept in sync with the central MES database to update the track and trace records resulting in more time spent on keeping application running and in sync	 Using Realm SDK and Device Sync, mobile apps stay in sync with the central MES Atlas database - all in realtime App UI updates immediately in response to shop floor alerts and notifications and works regardless of network connectivity issues
5	Single View analytics and metrics reporting	The metrics reporting module needs to correlate MES data with IIoT sensors/gateways data to present a single view of factory performance to the stakeholders. There is time spent on correlating all this data using complicated SQL scripts at the expense of	 Aggregation framework gives flexibility to get value out of the data without added complexity and fragility of SQL

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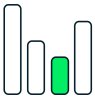
		value added activities.	 For historical data reporting, Atlas Data Federation allows natively querying and combining data across different data sources such as MongoDB Atlas and AWS S3 without complex integrations  Atlas Charts can be used create powerful visualizations right on top of MongoDB data without needing any additional software or code
6	Flexible and scalable brownfield production equipment Integration	Many different types of machines and controllers to integrate resulting in tons of custom software on top of standard MES deployment resulting in increased time to market	 The power of MongoDB can be utilized on the shop floor level and if needed continuously be replicated to MongoDB Atlas on Azure, AWS, GCP or a self managed MongoDB cluster anywhere MongoDB is designed from the ground up to be a distributed database. MongoDB's horizontal, scale-out architecture can support huge volumes of IIoT data
7	Scalable and flexible Enterprise data integration	Significant data integration effort is required to combine BOM, recipe, material management, inventory status and order data into one data model	 MongoDB documents can represent data of any structure while each document can contain different

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		Increased complexity of final system dealing with multiple databases and data models	fields. Documents map to the objects in code, so they are much more natural to work with. There is no need to decompose data across tables, run expensive joins, or integrate a separate Object Relational Mapping (ORM) layer. Data that is accessed together is stored together so end users get higher performance

Looking at the typical MES data model in Figure 5, as we progress from the inner to the outer data model, the data becomes more varied and unstructured. Due to our document-oriented data model, MongoDB is the ideal database to model both structured and unstructured data. MongoDB embraces the variety and volume of IIoT data without compromising performance. By leveraging time series collections, we can eliminate data movement and blend time series with the rest of the MES data easily. **The next generation of MES needs a database that can not only model relational data but is flexible enough to handle product variety and is fast enough to capture high-speed IIoT data, making MongoDB an ideal solution.**

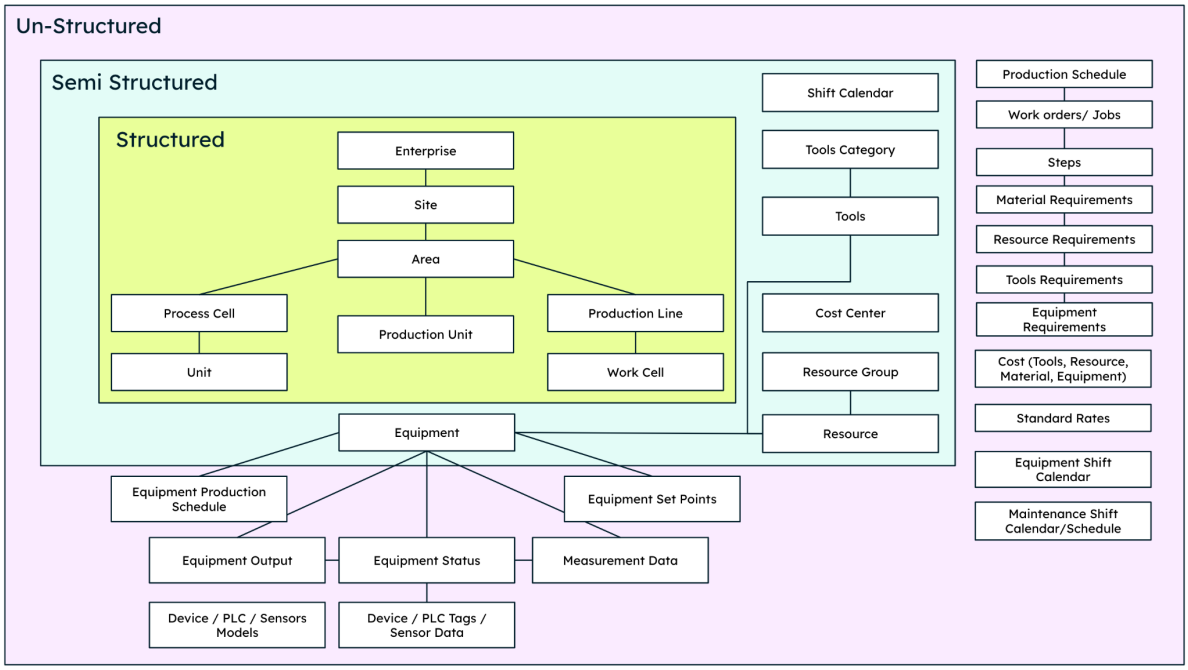

Figure 5: A typical MES data model. Each white box represents one or more database tables in a relational database system (Inspired from: Unver, Hakki. "An ISA-95-based manufacturing intelligence system in support of lean initiatives." International Journal of Advanced Manufacturing Technology 65)

Conclusion

The manufacturing industry is growing more competitive and complex, with customers demanding faster turnaround time and lower-cost production. A manufacturing execution is crucial for tracking and optimizing production operations but it is still using rigid relational databases that makes it difficult to scale. MongoDB is a mission critical and general purpose database that not only covers traditional relational strengths but also additional NoSQL and big data strengths and innovations (Figure 6) making it the ideal database for manufacturing execution systems.

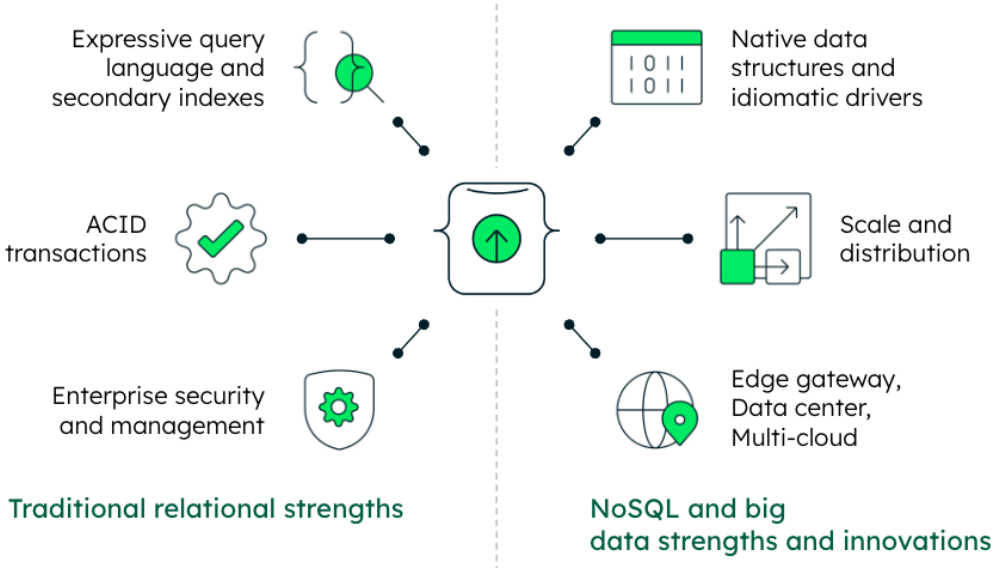

Figure 6: MongoDB as the ultimate combination of all data paradigms

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To learn more about MongoDB, visit MongoDB.com

About the author

Humza is a Principal in the Industry Solutions Team at MongoDB looking after Manufacturing and IoT use cases. Prior to joining MongoDB, he was working at Ernst & Young Canada as a Senior Manager, in digital operations business consulting practice. Humza did his PhD at Nanyang Technological University, Singapore, and worked with the Singapore manufacturing industry for a number of years on Industry 4.0 research and implementation. He has spent most of his career enabling smart and connected factories for many manufacturing clients. In 2020-2021, He established a multi-year strategic roadmap for Singapore's smart supply chain initiatives. His book on Industry 4.0 is the first book of its kind detailing the real-world implementation of concepts related to digital manufacturing.

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