Manufacturing Operations Management for Smart Manufacturing – A Case Study

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Abstract. Industry 4.0 was introduced early in the last decade. That introduction spawned related concepts like "Smart Manufacturing" and digitalization, as well as a proliferation of digital manufacturing technologies for supporting systems. The industry experienced widespread puzzlement over how to apply these concepts in practice and which roles "Manufacturing Executions Systems" play and will play in this context.

This paper outlines the change from classical Manufacturing Execution System (MES), with a focus on manufacturing execution including data collection, to monolithic Manufacturing Operations Management (MOM) with an extension of the functionality regarding quality management, planning inclusive scheduling and a collaborative MOM, which stands out from its predecessors through broad horizontal integration and cloud applications.

These parameters lead to an evolution of the Collaborative MOM towards a MOM for Smart Manufacturing, which harmoniously combines, controls and regulates the interaction of technologies such as IIoT, RAD, AI, Edge Computing, Cloud with the MOM functions and therefore enables new production systems like a cyber-physical production system (CPPS).

Keywords: MES, MOM, CPPS.

1 Introduction

Due to a variety of external and internal influences, such as increasing globalization, a steadily rising individualization of products and a related increase in complexity, which on the one hand directly affect the products but also have a strong influence on the associated production processes, the requirements on production systems are growing [1]. Concerning the growing requirements of modern production systems, the focus is on the following aspects: self-organization, decentralization, adaptability, networking, closed cycles and resource efficiency, live status of all production resources, customer integration in engineering and production as well as flexible process sequences and an open architecture [1].

Due to a large number of available solutions, most companies are currently using different technologies, detached from each other, to realize selective improvements in terms of process flexibility and output. Flexibility, agility and efficiency are essential components of future production landscapes. However, companies must go a step further and consider how production landscapes can be holistically and sustainably aligned to dynamic market changes, as this is the only way to fully exploit their potential [1] [3]. This paper describes based on a case study how technologies and systems interact harmoniously via a holistic approach and thus optimally master existing and future requirements.

2 MOM Evolution towards Smart Manufacturing

2.1 MES Evolution to MOM

The concept of MES has evolved into a broader and more valuable solution: Manufacturing Operations Management. During the 1990s the focus was on Stand-alone MES for improved manufacturing execution [7]. A best-in-class MES had to provide manufacturing digitalization, standardization, orchestration & collaboration, enforcement and contextualization with a focus on a specific industry. It was (and still is) critical to provide a rich set of industry-specific OOTB functionalities and a vertical integration with the specific production styles of such industry.

During the 2000s the manufacturing scope evolved from pure execution to broader coverage of manufacturing disciplines. From MES to monolithic MOM to digitalize manufacturing execution, quality management, planning and scheduling mostly working as disparate processes & systems under a monolithic MOM umbrella [9]. The traditional MES/MOM functions are defined in IEC 62264-1 [4].

Recently the monolithic MOM evolved even further to an integrated MOM where applications are synchronized through common communication systems (see Fig. 1). This is crucial to connect quality improvements, with manufacturing processes and efficiency logic. Integrated MOM systems must also align with modern technologies: mobility, security, usability, flexibility, agility, etc.

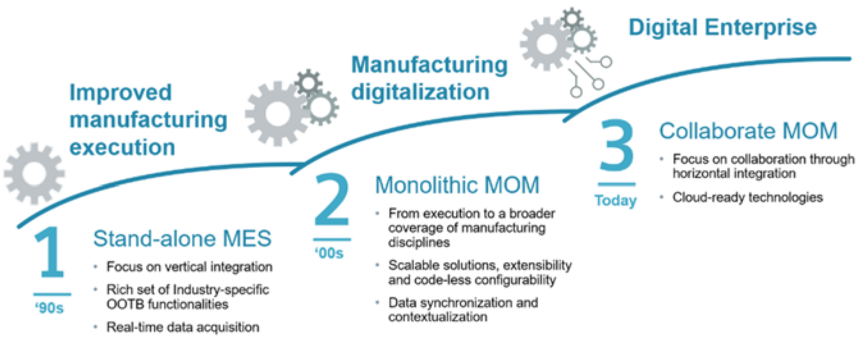

Fig. 1. MES evolution towards MOM

Regardless of the manufacturing industry segment, the manufacturing processes for OEMs or supplier tier, or the maturity of the business, one thing is clear: manufacturing enterprise will go through a continued digital transformation, no matter how digitalized they are today [6]. The question is what, when, and how will that transformation take place? Importantly, the functionality of manufacturing operations management has existed since the second industrial revolution — long before digitalization began. MOM functions always need to occur in any manufacturing setting, irrespective of advancement in production methods, level of automation and supporting systems & technologies – MES/MOM, IIoT, RAD, Edge computing, on-premise vs cloud [4]. What changes is the mechanism or system that performs MOM functions, and the delivery mechanisms for those functions. This calls for more modularity in the MOM functions for flexibility and agility to fulfill the deployment across different technologies and able to meet the transformation and manufacturing data & processes orchestration towards digital excellence in Industry 4.0 and Smart Manufacturing journey.

2.2 MOM Evolution to MOM for Smart Manufacturing

There is an increased transformation in the industry where traditional mass production "make to stock"-environments are transitioning to mass customization modes [5]. In such transformations, the need for flexibility and agility in manufacturing operations is becoming more prevalent.

This need for flexibility & agility is driving the need for increased automation to the line (robots & automated inspection devices), material handling systems (e.g. AGV's). With increased automation and human-machine interactions in shop-floor, how engineering data, manufacturing process, quality and supply chain data is harmonized along with AI principles to orchestrate the data across the systems and processes is more critical for factories of future / smart manufacturing. This calls for a robust connectivity & brokering function as an interoperating module across the systems with streamlined data flows. In the realm of IIoT, cloud and other advanced technologies, MOM for Smart Manufacturing should architecturally address the data orchestration and brokering function.

Specific to MOM, architectural advancements of modular MOM functions towards smart manufacturing functions leveraging IIoT & Cloud is the pivot. As certain functions will remain close to shop-floor data & network latency needs [4] [2], flexibility in architecture is critical.

The gathered information has to be made available for all necessary participants or IT-systems. Therefore, the focus of horizontal integration of a collaborate MOM has to be widened to also include the vertical integration to enable cyber-physical production systems (CPPS) [8]. As in Fig. 2. depicted, MOM must evolve from a "Collaborate MOM" further to a "MOM for Smart Manufacturing" to address the above-mentioned challenges. Current production architectures and IT-systems don't support that high degree of collaboration combined with the functionality to orchestrate those information.

Fig. 2. MOM evolution towards Smart Manufacturing

3 Case Study

A good case study for this aspect is a manufacturer of electric motors, used for the oil and gas industry, paper production, as well as for the use in subways, trains and trams in Germany.

The manufacturer faced the challenge that its products are in direct competition with products on the world market which is currently characterized by overcapacity. This intensified competitive situation requires a cost and time optimized production of the products, with constant high quality. In addition to these external influences, the following factors represent internal motivation drivers. On the one hand, this is the increased variance of the products and the associated complexity concerning order processing and all associated processes and, on the other hand, the insufficient documentation of the “as-built” of the products.

One of the main problems here was excessive processing time, which in turn had a negative effect on costs and the time it took for the customer to receive his order. The reasons for the high processing time were a lack of transparency regarding the workstations and their production resources (e.g. status regarding capacity utilization or availability of production resources and tools and materials) and inefficient detailed planning and order control based on this, which had a particularly serious effect when malfunctions occurred.

From these challenges, concrete requirements and functions for and on the production system have been derived and developed: live status of all production resources, real-time localization, smart products/components, networking, mobile apps, AGVs, flexible adaptation of defined processes, open system architecture.

The idea was to design and implement an innovative production system based on an existing MOM (Mix between Collaborate MOM and a MOM for Smart Manufacturing) by using new technologies and methods (IIoT, RAD, Edge Computing, AI, ...), which meets the requirements in a particularly efficient way.

The system now consisted of individual modules, each of which fulfills a specific task. The challenge now was to find an answer to the elementary question: how can such a system, consisting of a multitude of different solutions (hardware and software components), be made to work together and finally be made controllable?

The solution is a new module for the MOM for Smart Manufacturing. The following describes how the developed system is built and how it works. The central element for controlling and regulating such a system is organized communication. All participants in the production system must be enabled to exchange relevant information for specific production tasks with each other. For this purpose, we have implemented a so-called coordinating-app with the help of a RAD platform, which realizes the communication within the system in combination with an MQTT-Broker (Message Queuing Telemetry Transport protocol) which works according to the publish and subscribe principle. This protocol uses topics and payloads to share information among the system participants. We used JavaScript Object Notation (JSON) for the transfer of information via payload linked to the different topics. The system participants e.g. the product, the workstations, the AGVs but also the IT-Systems are managed within the app and their communication is defined and organized and so leveraging IIoT. This application regulates which information can be provided by which participant and for which participants this information could be relevant, for example, for processing a production order. According to this principle, the respective participant (MQTT-Client) publishes its information, which can then be received and processed by the others if required. This approach makes the IT landscape simpler, in particular, the standardized interface and the faster exchange of information between clients are major advantages. Figure 3 shows the implemented communication structure within the production system with all participants. To explain how the system works, this is described in more detail using the processing of production orders. The orders come roughly scheduled from the ERP level and are fed into the control and regulation level together with product information from the PLM level (e.g.: 3D models). In this layer the actual state of work cells, resources, material availabilities will be considered and an optimized manufacturing date, with consideration of all production orders, will be determined. This production date is updated in the production order and triggers the intralogistics for commissioning and in-time supply for production. The result is transferred to the MES which then passes the order information (work plan, including work instructions, required production resources, quality information, skills required for processing, dependencies, pre-conditions regarding the production sequence) on to the individual intelligent products and to other relevant participants (e.g. workstations and operators). The products, therefore, have all the plannable information that is required for production. All other information, such as the status of individual production cells, is obtained by the products independently via the developed communication concept. In addition, process and quality parameters are recorded, linked to the production order and processed in the MES. That information enables the creation of an “as build model” of the product. The previously defined communication forms the framework for efficiently processing the order within the system.

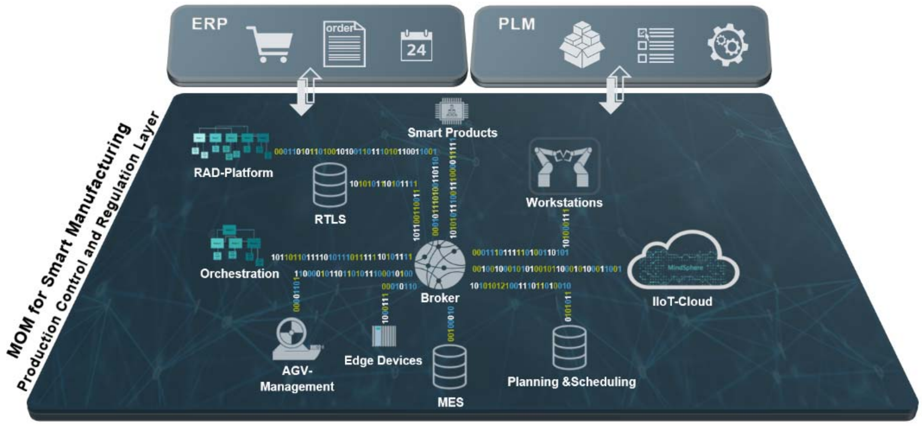

Fig. 3. IT-Architecture

In concrete terms, the module consists of two software components. A master app and a client app. Figure 4 contains the definitions of the terms used in the following and shows the relationship between information - topic - category including visual representation.

The master app performs the following tasks:

- System description:
  - Selection and addition of system participants based on predefined categories or creation of new categories
  - Selection of predefined topics depending on the selected category or creation of new topics and assignment to categories
- Manage the system participants:
  - Create and delete categories
  - Create and delete system participants
- Organization of communication:
  - Creation and deletion of information that can be transported using topics
  - Assigning and solving information to topics
  - Creating and deleting topics
  - Assigning and solving topics to categories
  - Selection whether the topic is subscribed by category or published by it.

Whereby the client app covers the following range of functions:

- Installation on the operating system of the system participants or Smart Production Tag
- Initialization: Configuration of the app after installation, with the goal of providing system participants with information
- Communication from system participant to Client App:
  - Selection of the protocol (OPC UA, MQTT, REST, SOAP, ...)
  - Characteristics of the interface: Which data should be propagated?

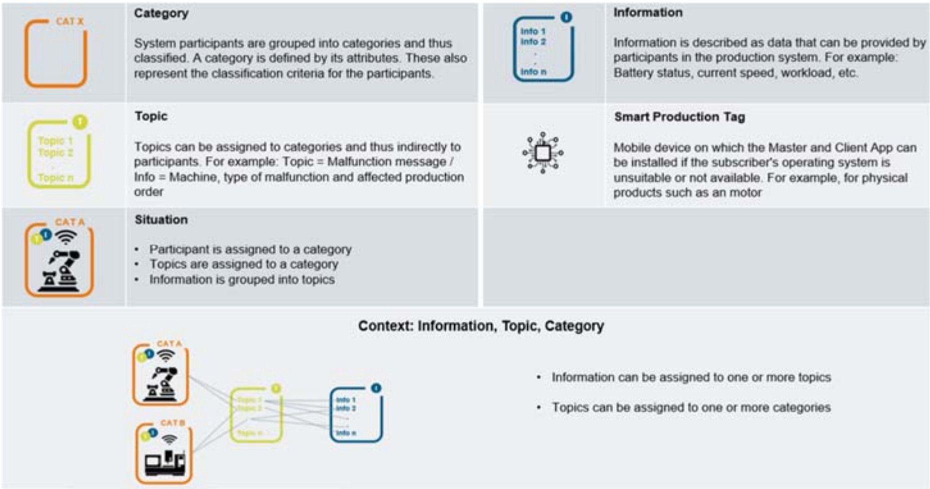

Fig. 4. Relationship between information - topic - category

The result is a concept for the standardized exchange of information and based on this, an organized collaboration across all components within a production system. Furthermore, it can be seen as a preliminary stage of a self-organizing production system. The presented IT-Architecture is a prototype approach in a test environment. To achieve this high degree of communication and collaboration within a production different IT-Systems, like MES, AGV-Management, etc., as well as different system interfaces must be evaluated and implemented. To simplify the implementation of such a production architecture current collaborative MOM systems with an already high degree of horizontal integration must evolve further into a MOM for Smart Manufacturing (see Fig. 2). A MOM for Smart Manufacturing provides functionalities to orchestrate a production system and thus is the foundation of a production architecture with a high degree of horizontal and vertical integration. The described communication principals between the participants could be implemented in a current MOM system to achieve a MOM for Smart Manufacturing.

4 Conclusion

This case study shows how a manufacturing approach according to the Industry 4.0 initiative could be implemented with a holistic IT-structure. Collaborative MOM systems need to further evolve into a "MOM for Smart Manufacturing" to not just ensure a collaboration between different IT-Systems, like IIoT and RAD, but also to orchestrate the data gathered and shared along those data driven self-organizing production systems.

Furthermore, a MOM-solution for Smart Manufacturing must be extensible and scalable to support customer-specific processes. MOM for Smart Manufacturing is therefore to be understood rather as a layer that combines all relevant functions for smart production in harmonious and highly efficient interaction. To realize a digital transformation, as shown in the presented case study, a flexible IT-architecture is needed to introduce new IT-systems and MOM-functions in a stepwise manner to minimize disruptions of manufacturing and business processes.

Acknowledgment

This work was carried out with the knowledge and experience gathered from the project “Road to Digitalization” (R2D), which was supported by the Bavarian state ministry of economy, media, energy and technology and several companies.

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