



## An Overview of Next-generation Manufacturing Execution Systems

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# An Overview of Next-generation Manufacturing Execution Systems: How important is MES for Industry 4.0?

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## Abstract

The purpose of this paper is to understand the evolution of manufacturing execution systems (MES) in the digital transformation era. Theoretical propositions made on MES (based on literature survey) were empirically examined using three case studies in Danish companies. Findings gave an overview of Industry 4.0 ready MES and identified its role in factories of the future. It is a first attempt to analyze the concepts behind next-generation MES to give a primer on ‘MES as a digital twin’, via first iteration of results from cross-case synthesis of collected data. The paper also maps the current MES research pertaining to Industry 4.0 into key groups to highlight its significance in digital manufacturing.

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*Keywords:* Smart factories; Manufacturing operations management; Enterprise information systems; Digital manufacturing; Digital twin; Real-time systems; Conceptual; Review; Empirical case study, ERP software

## 1. Introduction

### 1.1. Industry 4.0 - Perspective

Industry 4.0 vision guides manufacturing enterprises to acquire high levels of digital capabilities. Like Germany, many other industrial countries are expected to join the bandwagon to boost their economies through manufacturing competitiveness using advanced techniques in manufacturing operations. Even though Industry 4.0 covers wide application area in the manufacturing sector, automation product innovation will play a key role in materializing Industry 4.0 objectives [1].

Industry 4.0 is an IT-driven change in manufacturing systems, as its design principles emphasize on interconnection (collaboration, standards, security) and information transparency (data analytics, information provision) for decentralized decision making [2]. ‘Smart factory’ is the fundamental concept of Industry 4.0 and to commission it, the field of ‘business information systems engineering’ (that includes innovative MES/ERP approaches) will come into limelight [3].

Owing to the enhanced digital capabilities of manufacturing enterprises, production operations could be planned, executed and controlled easily than before through traceability (ability to trace the history of all resources in the production process).

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Furthermore, Industry 4.0 model also expects to improve productivity by fulfilling the growing customer demands for faster real-time response via decentralized production control. These expectations can be fulfilled by MES to improve performance, quality and agility for globalized manufacturing businesses [4].

### 1.2. Enterprise Information systems (EIS) in Manufacturing

Advanced industrial automation systems include both plant control systems as well as enterprise software and digital services. *Enterprise information systems are made of computers, software, people, processes and data* [5]. EIS is an active field of study and undergoing re-conceptualization in the recent years. From the times in 1960s when EIS were first introduced as computers in the industry to replace the paper-based systems, till today, they developed along with the advancements that occurred in database systems and computer networks. They play an important role in manufacturing enterprises by supporting the business processes, information flows and analytics. EIS can be broadly classified into 6 types – [5]

- i. Enterprise resource planning (ERP)
- ii. Supply chain management (SCM)
- iii. Manufacturing execution systems (MES)
- iv. Customer relationship management (CRM)
- v. Product lifecycle management (PLM)
- vi. Business Intelligence (BI)

Enterprise interoperability and traceability is the need of the hour where ‘information systems’ will be pivotal in achieving such smart manufacturing. Smart manufacturing will have internet enabled devices on the shop floor, where as cyber physical systems (CPS) will handle interconnectivity between the physical assets and computational capabilities [6].

Same as ERP’s growth beyond the enterprise boundaries to have inter organizational collaborations for supporting emerging business requirements [7], the scope of MES has also been growing to include supply, design and business functions of the manufacturing enterprise. In order to leverage the potential of the next-generation MES tool (which is real-time compliant) in manufacturing ecosystem, it is essential to understand its importance for Industry 4.0. Motivated by this need, the paper attempts to study the role of MES in the digital transformation era.

The next section introduces the enabling technologies for smart factories to present the key constructs. After that, research methodology is discussed. Then the findings (from literature review and case studies) are presented which includes the empirically tested hypotheses using three case studies from the companies. In the subsequent section, findings are discussed and finally, the conclusions are drawn (where research gap was also identified for further research in future).

## 2. Enabling Smart Factories

Smart factories are key components of Industry 4.0 [8] and are context-aware to assist people and machines in the execution of their tasks using digital manufacturing tools such as MES (an industrial software).

Manufacturing operations management (MOM) as defined by ‘International electro technical commission (IEC)’ are the activities of manufacturing facility that coordinate, direct, manage and track the resources (equipment, materials and personnel) of the plant. According to the IEC 62264-3 standard, the elements of MOM are the operations management of production, maintenance, quality, inventory and other manufacturing activities. Whereas, ‘production data collection’ is an activity of gathering and managing production data for work processes or a production request. Factories of the future must effectively utilize the real-time production data to meet the needs of the customers.

To achieve the vision of ‘real time enterprises’, manufacturing companies are adapting service oriented infrastructures [9]. Such approach requires industrial internet to feature standard interfaces, even though the functionalities differ. As MES tool serves the purpose of this requirement by acting as a factory information hub, this study focuses on advanced MES for the factories of the future (Smart factories). Sauer [10] lists the trends in MES for factories of the future, through various examples such as – full integration with digital factory, simulation as a front-end in the sense of concurrent real-time simulation, vertical integration with the shop floor level, horizontal integration by means of a service-oriented structure and consistent data management, scalability ranging to decentral self-organizing production, task and role specific provision of users with information.

In this regard, many companies are aiming to meet the requirements of future factories by investing in the advanced enterprise software to effectively manage their production using the available data. Literature suggests that companies that invest more in technology-enabled initiatives, achieve increased competitiveness in future volatile markets [11] and positively drive their digital transformation strategy by exploiting digital technologies [12]. IT competence is already listed as a key skill for digital leaders [13] and the time is ripe for companies to merge IT strategy with business strategy [14]. In this situation, the role of manufacturing IT (especially MES/MOM systems) in manufacturing companies’ needs better understanding in theory. Accordingly, we hypothesize:

- H1) MES software is crucial to enable smart factories and thus, it plays a key role in Industry 4.0 manufacturing systems.
- H2) Manufacturing enterprises will take more initiatives to invest in MES to serve their future factories.
- H3) Next-generation MES can improve process performance through ‘visibility’ in manufacturing operations.

### 3. Methodology

The paper focuses on the latest research contributions in MES for which a systematic review strategy (see Fig. 1) was implemented and the future usefulness of next-generation MES was identified from the literature. This was further supported by explanatory case studies from three different manufacturing companies. Flynn et al. [15] six-stage framework was followed to conduct empirical case research on MES and its application in these companies. Case research allows the study of the phenomenon in its natural context allowing good use of existing experiences [16]. It allowed the study to reconcile the evidence from observations and data, with research literature. The cross-case analysis of the three cases contributed to validate and test the hypothesis.

First, a systematic literature review was conducted using the databases – Google scholar and Scopus. Emphasis was on the most recent publications, especially from 2010 – 2018, even though most of the literature on MES was found before 2010. Only peer-reviewed articles such as journal articles, conference proceedings and book chapters were considered. Initial selection of articles included references about ‘manufacturing enterprise information systems’, ‘ERP’, ‘MES’, ‘MOM’, ‘advanced industrial automation’, ‘Industry 4.0’, ‘smart factories’ and ‘smart manufacturing’. 106 articles were identified and Mendeley was used to manage the references from highly relevant 25 articles, screened from the 106. Excluded articles were articles written in German, articles written about MES software development and systems architecture. Qualitative synthesis of the 25 eligible (eligibility based on their links to Industry 4.0) articles was done to write about MES and its potential to realize Industry 4.0.

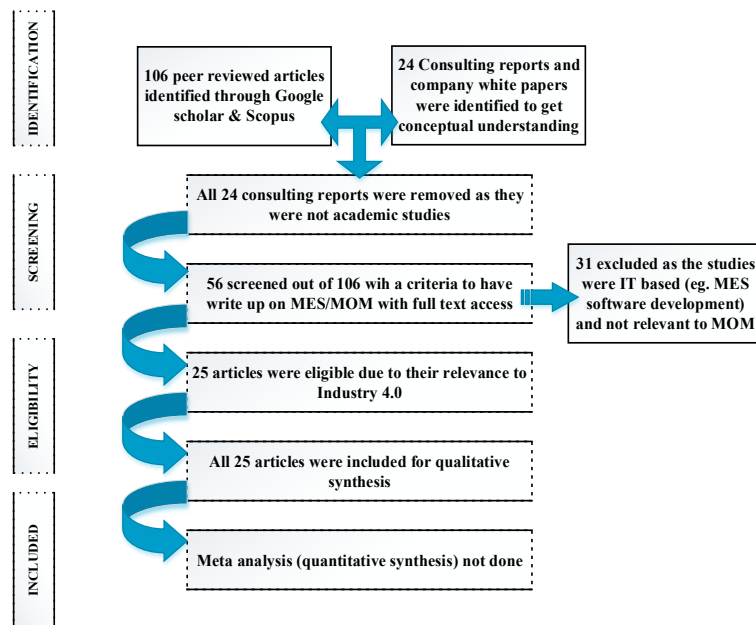


Fig. 1. Flow of information through different phases of a systematic review (figure adapted from (Moher et al., 2009)) [17]

Second, case study research (in cooperation with the companies) approach was chosen because it is a highly trusted method to develop new theories in operations management [18]. Due to commercial confidentiality, the three manufacturing companies are called as Company A (large Danish producer of dairy products), Company B (large slaughter house in Denmark) and Company C (Danish manufacturer and large player in renewable energy) throughout this article. Information about the state-of-the MES and future vision for MES in these companies was collected by conducting semi-structured interviews with AA (person from Company A), BB (person from Company B) and CC (person from Company C). Given the requirement to generalize, thematic coding and analysis was done to draw the conclusions.

### 4. Findings

#### 4.1. Links between MES and Industry 4.0 objectives from the literature

Current ‘MES research pertaining to Industry 4.0’ was identified as a result of mapping recent MES research into key groups considering its relevance to each group (see Table 1). Out of the 25 eligible articles, 16 were used for the mapping. Table 1 served in supporting the hypothesis 1 and hypothesis 3 and to further elaborate on those arguments in section 4.2 and 4.3.

Table 1. Studies with links to Industry 4.0 objectives (identified from the key groups of MES).

Author	Year	Evolution of MES			Implementation of MES			Usefulness of MES	Case studies on MES	Methods		
		Background	Old MES & Development	Concept for next-generation MES	Advances in MES	Steps to implement	Enabling technologies in smart factories			Conceptual	Empirical	Review
A Lobo	2016				*					*		
Bangemann [19]	2014	*		*								*
Cottyn	2011							*			*	
De Ugarte	2009		*									*
Demartini	2017						*			*		*
Govindaraju [20]	2016					*					*	
Hanel [21]	2011							*				*
Helo [22]	2014			*	*						*	
Itskovich [23]	2015					*				*		
Kang	2016	*					*					*
Kannan [24]	2017								*		*	
Lee	2014			*			*			*		
Mahmoud	2015							*	*		*	
Qiu	2004			*					*		*	
Sauer	2014	*		*						*		
Shrouf	2014						*			*		

## 4.2. Overview of MES from the literature

### 4.2.1 Evolution of MES

MES was developed in 70s to assist the execution of production, with the concept of online management of activities on the shop floor. It bridges the gap in-between planning system (such as ERP) and controlling systems (such as sensors, PLCs) and uses the manufacturing information (such as equipment, resources and orders) to support manufacturing processes. Like any enterprise information systems tool, MES too has evolved with time to integrate several extensions to perform various manufacturing activities using the sophistication of the computer technology advancements [25].

In the past, production departments of many companies preferred tailor-made information systems for the shop floor and were locally collecting the production data in spreadsheets or other databases, which made it difficult for software maintenance and data consolidation. MES was developed with a purpose to integrate multiple point systems and consequently software providers were able to package various production execution functions in the form of a MES software [26]. However, the next generation manufacturing is in the need for process improvement by further leveraging automation tools and real-time systems to completely avoid the paper work. This vision leads to the concept of smart factories (with industrial internet), where wireless technology and mobile information & communication technologies (ICT) become the key enablers for industrial internet. But such digitization in manufacturing is still at a nascent stage. The future factories will rely on real-time compliant software and ICT, where MES will have a greater role in smart factories than just providing features for manufacturing management [27]. This supports the hypothesis 1.

To qualify for Industry 4.0, the factories of the future will use information technology (IT) to digitize the manufacturing operations and use decentralized applications for production control. According to Kang [28], the aim of smart manufacturing is to improve competitiveness using innovative ICT technologies for effective and accurate engineering decision-making in real-time. And Cyber physical systems (CPS) and IoT have been supporting in realization of this vision. Hence, digitization of MES is also required for Industry 4.0 based manufacturing systems.

### 4.2.2 ERP-to-shop-floor integration

Of all the attempts to define the structural and architectural aspects of production management systems, ISA 95/ IEC 62264 standard achieved popularity among manufacturing practitioners for ERP-to-shop-floor integration. According to Alter [29], 'Integration' is the mutual responsiveness and collaboration between distinct processes, which can be at many levels and 'information sharing' is one of the levels of integration, dealt by ISA 95 standard. ISA 95 is information oriented and gives specification on vertical integration of a manufacturing enterprise by guiding the data flow within the automation systems. According to ISA 95 / IEC 62264 – 3, the levels of functional hierarchy are shown as below:

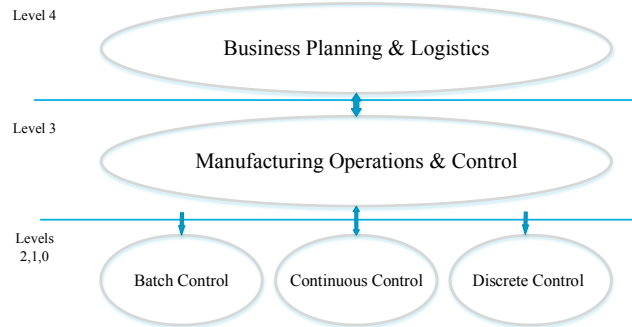


Fig. 2. ISA 95 levels of functional hierarchy

#### 4.2.3 Usefulness of MES

According to MESA International, the users of MES in companies have reported to benefit (such as reduced manufacturing time, improved product quality, predictive maintenance etc.) from MES [30]. However, no significant academic studies were found on business cases that reported the change in performance metrics of an organization due to the implementation of MES. There are consulting studies on improvements in process throughput and overall equipment effectiveness (OEE), but they all are either based on qualitative field study or survey data. Despite the belief that, in-depth manufacturing operational visibility and intelligence on the production data creates additional business value; there are no direct links in the academic literature where MES has been able to steer the business decision-making process. A study by Cottyn [31] illustrates how manufacturing visibility can promote continuous improvement in an organization. It also highlights the role of MES in continuous improvement, thus supporting lean objectives.

An empirical study by Qui [32] considers a case from semi-conductor industry to conclude that the semi-conductor manufacturers should invest into advanced MES to maintain their global competitiveness. A case study of an injection molding factory by Mahmoud demonstrates that MES is beneficial for industrial process performance [33]. Scholten [34] reports that some companies have found financial benefits from MES. Even though the tangible benefits (such as return on investment, ROI) of MES implementation are difficult to quantify, all these studies suggest that companies can benefit from MES and indicate the reasons for industries to invest in MES. Therefore, it supports hypothesis 2.

#### 4.3. Areas of importance for Industry 4.0

The new class of MES is expected to provide further real-time information to the operational departments by giving ‘all-round view’ of all resources involved in the production and will act as a ‘manufacturing cockpit’ [35]. With the advancement of integration levels and computing technologies, MES tool is evolving as an even powerful software package. It is expected to match customer needs for faster real time responses and manage complexities in production with expanded functionalities [32]. This is because the factories of the future must have seamless collaboration and data flow within all three enterprise layers such as – company management layer, production management layer and control/automation layer. Such factories are better equipped to deal with future demands by incorporating production management systems such as – target management, integration of applications and data, real-time data management, information management, compliance management etc. [36]. This supports Hypothesis 1, as it confirms the significance of MES and infers that companies must invest in such digital technologies for improving their overall business performance [11].

To provide better services to the customers, smart factories in Industry 4.0 are enabled by IoT technology to collect and analyze data gathered from smart devices and smart applications. In this way, smart factory enables the involvement of customers in the production design process [37] and necessitates the use of virtual manufacturing to simulate the production processes, thereby giving scope to explore each phase of the production process. This is the foundational concept for virtual factory which is a discrete event simulation with 3D visualization [38].

Lobo gives an overview on technology enablers for MES in Industry 4.0, from an innovation management perspective. And those include Mobile, Cloud, Big Data analytics, machine to machine (M2M), 3D Printing and Robotics [4]. ‘Information transparency’ which is listed as a design principle for Industry 4.0 [2] drives the ‘visibility’ through a smart factory due to its ability to exchange information in real-time beyond enterprise boundaries (through integration of IT systems) to deliver end-to-end solutions [8]. MES in smart factories is a real-time system that can provide critical production data to serve ‘visibility’, thus supporting the hypothesis 3.

#### 4.4. Case study results

First iteration of the case study research has been tabulated (see table 2) for cross-case synthesis, where semi-structured interviews from three industrial case studies were analyzed. Thematic analysis approach was followed as it allows to identify, analyze and report patterns within the data [39]. The analysis contributed to empirically validate and generalize the hypotheses, to finally draw the conclusions. To ensure the reliability and validity of the case research, data triangulation was done using archival documents, annual reports of the case companies, personal observation through field visits and interview results.

Table 2. Summary of collected qualitative data.

Company	A	B	C
Size (employees)	>10,000	>10,000	>10,000
Industry	Dairy	Meat processing	Electrical equipment
Interviewee	AA	BB	CC
<b>Observation 1</b> Vision for Industry 4.0 (HOW)	Focus on digital supply chains to create value from the data	To be a knowledge driven enterprise by discovering, articulating and effectively utilizing the data	Market development by leveraging data processing and analytics expertise to enhance its digital capabilities
<b>Observation 2</b> What drove companies to invest in MES? (WHY)	Driven by the need to use enterprise systems to achieve Industrial IoT ecosystem in the company	Driven by the need to improve competitiveness through streamlining processes	Driven by the demand from manufacturing projects to obtain manufacturing intelligence
<b>Observation 3</b> Vision for process improvement (HOW)	Use MES to own real-time production data to analyze, improve and change vendors. Also have shop-floor dashboards using MES to give flexibility and visibility to the operators	Use MES to influence production processes to lower production costs and gain flexibility. Also use timely available production information to react to supply/demand problems	Use MES for – Real-time monitoring and control (ISA-88/95 compliance Level 1-2), cross business-unit coordination, business analysis

Observation 1, observation 2 and observation 3, contributed to testing the H1, H2 and H3 respectively. The results indicate the similarities where all the case companies have been approaching industry 4.0 vision by investing in digital technologies with a special focus on MES. The companies also believe that MES/MOM will aid the achievement of information transparency in the operations. These results align with the hypotheses.

## 5. Discussion

This study was done with an expectation to find the links between MES tool and Industry 4.0 to highlight its importance for future factories, while presenting the references from scientific literature. It gave an understanding on the challenges and opportunities of next-generation MES. The practical challenges of MES, identified through the case studies are – cybersecurity; information security and skepticism in cloud manufacturing; additional costs for buying MES software and no direct/tangible gains; vertical integration issues; high cost of deployment of smart manufacturing systems (devices) etc. However, the opportunities indicate that MES can indeed be used as a digital twin of a manufacturing process.

Demartini [40] introduces ‘enabling technologies’ of smart factories with respect to their applications and practical implementation at MES/MOM levels. They are listed as – cyber physical production systems, industrial internet of things (IIoT), cloud manufacturing, data analysis, augmented and virtual reality, additive manufacturing, simulation techniques –digital twin. To reinforce the understanding on next-generation MES as a digital twin to support smart factories, future research could be an empirical study to investigate the influence of MES on an organization; as the purpose of a digital twin is to also optimize business performance. Such a study is expected to demonstrate how MES can promote competitive advantage to businesses in a setup of ‘connected (integrated) enterprises’.

To realize MES as a digital twin, manufacturing firms must acquire better IT competencies, by extending their information systems to integrate with other supply chain partners [41]. As ERP systems at enterprise level are not equipped to provide real-time product-centric information (tracking production conditions etc.) to allow traceability on the unit level, a thorough understanding on the manufacturing software systems of smart factories (level 3 of ISA 95) is an essential step. It promotes supply chain collaboration by bringing competitive advantage to all the stages. The external collaboration [42], especially through informational cooperation [43]; relating to either planning, replenishment or forecasting, can be explored better through research on real-time information support [44] via manufacturing information systems. Hence, a study on coordination of MES with digital supply chains is identified as a potential area for future research and a next iteration of the case study analyses is envisaged for it. For Industry 4.0, MES is already identified as an enabling technology to enhance supply chain performance, (for both internal and external supply networks) as it shares product-centric data in real-time [45] [46].

## 6. Conclusion

Every section of this paper is written based on the qualitative methodology of literature review and the findings help in concluding that:

- MES is important for Industry 4.0

Replacing older information systems software in the level 3 (level as per ISA 95 hierarchy) with a single advanced MES software has the potential to help the manufacturing enterprises achieve greater degree of operational visibility and traceability. MES is believed to play a central role in the company's (manufacturing enterprise) path towards Industry 4.0 because flexibility and transparency in the processes are the key objectives of Industry 4.0. However, the manner in which an enterprise utilizes MES features will determine whether the enterprise is able to achieve its Industry 4.0 goals.

- MES has not been a widely used concept in academic research

Lack of academic studies on impact of MES on organizations suggests that, MES has not been used as a popular concept in the academic research.

- Concept behind the term next-generation MES

In this paper, next-generation MES is presented as a digital twin of future factories due to its ability to connect in real-time and provide digital image of manufacturing process. This feature of MES as a digital twin can aid in optimizing the overall business performance. The traceability feature might have the potential to involve customers in the production design phase and lead to supply chain transformation through enterprise integration.

For theoreticians, the paper presents the potential of MES as a digital manufacturing tool through academic literature. It gives insights into the requirements of smart factories to reveal the future research directions in the field of industrial automation and manufacturing information systems. Practitioners can read about the recent research in the field of MES and use it as a guide to design smart factories.

The future research could be to investigate how MES can enhance the process performance (engineering, execution and quality), resulting in optimizing manufacturing operations. Given that, software is an integral part of the manufacturing hardware systems, we argue that there is a need to research MES/MOM systems from the shop-floor perspective (beyond manufacturing IT) to effectively conceive intelligent 'cyber physical production systems'. Driven by the companies' need to improve business performance using advanced manufacturing techniques, we believe that the future research on such topic will render innovative software enabled solutions to the manufacturing industry.

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