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MES/MOM systems for Manufacturing Networks: An exploratory study from operations in India

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Abstract

The purpose of this paper is to explore the role of information systems (in smart factories) to support the coordination practices in the international manufacturing networks (IMN). The paper attempts to study the usefulness of manufacturing IT tools to enable IMN coordination for optimization of physical distribution. Theoretical propositions made on manufacturing operations management (MOM) systems for IMN coordination (based on the literature study) were empirically examined using two case studies of companies with international manufacturing networks. Based on the qualitative analysis of propositions and empirical findings, the paper identified manufacturing execution systems (MES) to have the potential for achieving IMN coordination goals. As a result, the priorities for developing research agenda in this area to design factories of the future and to achieve Industry 4.0 vision were established. It is the first attempt to analyse the concepts of MES/MOM systems to empirically investigate their application in IMN coordination.

Keywords: Smart manufacturing; Factory networks; Enterprise information systems; Manufacturing operations; Emerging countries

1. Introduction

To achieve the competitive advantage, multinational companies have been following two important approaches. First one is by shifting the focus from a factory to that of the international manufacturing networks (IMN) by coordinated aggregation (network) of intra-firm factories located at various locations in the world (Feldmann et al. 2013). Second one is by increasing the investment in technology-enabled initiatives to face future volatile markets (Westerman et al. 2012) with digital transformation strategies by exploiting digital technologies (Hess et al. 2016). The later approach necessitates the manufacturing enterprises to achieve better IT competencies using various manufacturing IT tools such as manufacturing operations management (MOM) systems, including manufacturing execution systems (MES). '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 (Lasi et al. 2014). 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).

IMN coordination aims to achieve company's strategic objectives on effective planning of physical and non-physical flows in the networked factories (Pontrandolfo and Okogbaa 1999) through degree of centralization, policies, incentives, measures, and controls etc. Capacity planning, product allocation (among factories) and product distribution (between factories) are popular research topics in IMN coordination, where physical (product) distribution is a delivery issue that pertains to the logistics management, materials management, demand management and order fulfilment etc. (Lambert and Cooper 2000). However, more research is needed on the tools and methods for IMN optimization (Cheng, Farooq, and Johansen 2011), specifically addressing the IMN performance issue of 'delivery'.

Motivated by this need, the paper explores the question of how information systems (henceforth, referred as IS in this paper) of smart factories (such as MES) can improve IMN performance. It highlights the importance of manufacturing IS in the digital transformation era, for facilitating an effective international operations strategy.

The next section introduces manufacturing IS as the enabling technology for IMN coordination to present the key constructs. After that, research methodology is discussed, then the findings (from the literature study and case study) are presented which includes exploring the IMN issues in the factories operating in emerging countries. Findings are discussed in the section 5 to draw the conclusions in section 6.

2. Manufacturing information systems for IMN coordination

2.1. *Practices related to IMN coordination*

IMN coordination is associated to the management of factory networks of various locations and refers to the question of how to link or integrate the production and distribution facilities to achieve the strategic objectives of the manufacturing enterprise. A proficient IMN coordination will result in achieving efficient and effective planning of the physical and non-physical flows among the network's factories. It involves tactical decisions in different business areas and within several processes (Pontrandolfo and Okogbaa 1999).

Through a literature survey, Cheng (Cheng et al. 2011) identified the following as popular research streams in IMN coordination:

1) Best practices from the companies: Many companies that have operated their IMNs for years have accumulated much experience on IMN coordination and gradually formed their own practices in terms of structured tools, processes and methods. Some of these practices have been introduced through specific case studies (Mascarenhas 1980)

2) Transfer of production technologies and knowledge: This topic deals with the transfer and diffusion of production technologies and knowledge among plants (Ferdows 2009). Detailed reviews on the transfer of production technologies and knowledge can be seen in Waehrens et al. (Vejrum Wæhrens, Cheng, and Skov Madsen 2012)

3) Optimization of physical distribution: Multiple plants that cooperate in sequence or in parallel, with a vertically or horizontally focused network, need to be optimised in order

for the IMN to reach its true competitive potential, e.g. to be fully productive. This topic deals with the questions on allocation of products and volumes to plants, and the production and distribution of products and orders within the network (Rudberg and Olhager 2003). As a result, capacity planning and product allocation among plants and product distribution between plants and distribution centers or even customers have gradually emerged as a popular topic in the field of IMN coordination and, therefore, have attracted the attention of many studies, e.g. (Chan, Chung, and Wadhwa 2005), (Tsiakis and Papageorgiou 2008), and (Yuan, Low, and Yeo 2012).

This paper falls under the third research stream in the above list, where the IMN coordination issue of optimization of physical distribution is explored. Most of these studies tend not to distinguish between intra-firm IMN and inter-firm supply network. Instead, they attempt to consider node characteristics (such as plant location, the allocation of the production capacity, work-load and production cost) and link characteristics (such as transportation costs and duties for material flows) holistically, mostly in the mathematical models.

In summary, the research on the coordination of IMN generally concerns both knowledge transfer and physical allocation among plants in the same network. However, few studies have been conducted to examine how the coordination of IMN can be supported by IT tools and systems, although a number of mathematical models have been developed to optimise capacity planning and product allocation among plants and product distribution between plants and distribution centers or even customers. Several commercial tools such as Supply Chain Guru (http://www.supplychainguru.com/) are also available in the today's market, claiming to provide users with capabilities to model, analyse, optimise, and simulate their supply chain network operations. Moreover, IMN coordination is a much more complex task beyond merely modelling, optimising and simulating. Its implementation is usually a long-term, slow, iterative, and progressive process (Cheng et al. 2011) and needs complicated interactions with almost all the functions of a company. Therefore, even if the competitive position has been established, and tools and methods have been crafted to manage and optimise the IMN, the issue of coordination remains and can be an area for further research. On that account, it is essential to explore the question of how industrial software systems of the digital era can enhance IMN coordination.

2.2. Smart factories for IMN coordination

Smart factories are key components of Industry 4.0 and are context-aware to assist people and machines in the execution of their tasks. Smart factories are empowered by real-time systems such as MES, empowering them. 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. Figure 1 illustrates the scope of smart factories where the focus area for this paper is highlighted.

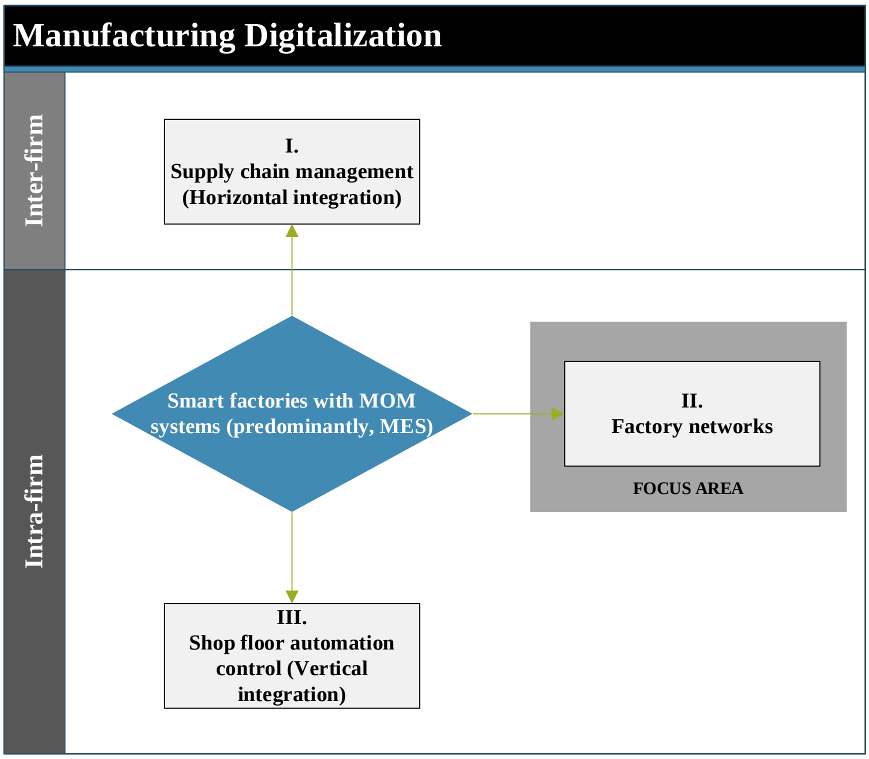

Figure 1 Scope of smart factories to achieve information transparency

MES was developed in the 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 IS tool, MES too has evolved with time to integrate several extensions to perform various manufacturing activities using the sophistication of the computer technology advancements.

For a manufacturing enterprise, logistics costs are estimated to account to 13 to 15% of sales revenues in India and 16 to 20% in China. This share is significantly higher than the European counterparts, which is only 5 to 10% (Rodrigues, Bowersox, and Calantone 2011). The logistics costs in emerging countries are high due to the regulatory framework of the governments as well as the poor logistics infrastructure. Hence, companies that wish to achieve economies of scale by establishing production networks in emerging countries like India must formalise their communication channels to combat these challenges through effective tactical (capacity) planning. Even though planning process and execution in a manufacturing enterprise is supported electronically, using real-time compliant software such as MES can result in increased profit margins by further improving the global production planning. Lack of documented cases of best practices in IMNs (Rudberg and Martin West 2008) support the need to investigate the research question on IMN performance using MES.

3. Methodology

First, a selective literature review was done on the topics such as - IMN performance, issues related to IMN coordination, MOM systems (of smart factories) in relation to international manufacturing operations etc. The review results contributed to the knowledge on MES functionalities and its usefulness for IMN coordination to make theoretical propositions. Research gap during this process was identified as lack of studies on MES/MOM support for manufacturing coordination.

Second, to empirically explore the gap, an in-depth exploratory case study approach was followed (Voss 2002); (Yin 2014) and MOM systems of a multinational Danish manufacturing company were studied. The case company is a large player in the renewable energy industry and has a global presence, including India. A case of operations in India was considered because it is the most competitive country in South Asia (as per world economic forum) and an emerging market. The case company was chosen based on the criteria of it having IMN as well as its involvement in sales, marketing and production operations in India. Selecting the cases with operations in India also helped in understanding the dynamics of operational issues and complexities in production planning in the emerging markets. The case study follows Flynn, et al. (Flynn et al. 1990) six-stage framework and data collection was primarily done via interviews and field studies (in Denmark and India) through multiple factory visits.

To ensure the validity, theoretical replication across another company was examined. For this purpose, a large multinational manufacturing company (in the aerospace industry) with production facilities in India was chosen. Due to commercial confidentiality, the primary case company is called Company A and secondary case company is called Company B throughout this article. Data on manufacturing IS at the case companies was collected through various sources. First author and third author conducted a semi-structured interview with a manufacturing IT architect at company A. The interview duration was 90 minutes, which was electronically recorded and transcribed. Data from company B was gathered through field study and interaction with the plant operations manager.

To ensure reliability, data triangulation was done using results from the literature review, interviews and archival documentation. This paper was written based on the preliminary analysis of the case and its empirical study. Case study results contributed to developing a hypothesis.

4. Findings

Findings from the literature: Literature suggests IMN dependency on the technology for smoothly running the manufacturing operations. Findings also confirmed that manufacturing firms must acquire better IT competencies, by extending their IS by intra-firm integration. The phenomenon of smart factories for IMN coordination was studied and it was observed that the software systems of factories (level 3 of ISA 95 standard) of MOM layer consists MES, which was identified as the technology enabler for IMN coordination. ERP systems operate at Level

4 and deal with enterprise level operations and do not provide real-time production information (tracking production conditions etc.).

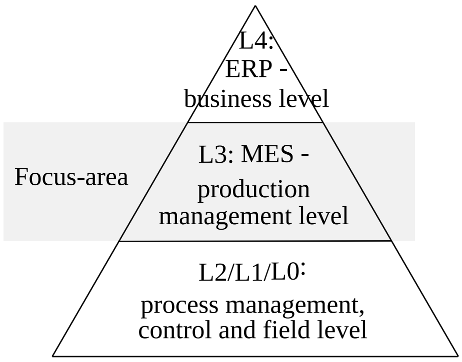

Figure 2 ISA 95 levels of functional hierarchy in a manufacturing enterprise (Scholten 2007)

The paper identified that further research in this area (MES as a real-time compliant software) can promote coordination of supply networks by achieving the strategic objectives of the manufacturing enterprise. Collaboration within the supply networks through informational cooperation (Adams et al. 2014); relating to either planning, replenishment or forecasting, can be explored better through research on real-time information support (Mcclellan 2003) via manufacturing execution systems. IMN coordination issue of 'optimization of physical distribution' can be addressed through the MES functionality of detailed production scheduling where production can be monitored in real-time. Hence, assigning the orders to multi-plants can be effectively done using MES.

Findings from the case study: Based on the exploratory case study, research gap and theoretical propositions were verified. Case study findings also emphasize the importance of manufacturing IT tools to achieve IMN coordination.

Table 1 Summary of collected qualitative data

Company	**A**	**B** *(to ensure validity)*
Size (employees)	>10,000	>10,000
Industry	Electrical equipment	Aerospace
Interviewee	AA	BB
Observation 1	The company has a global presence with manufacturing footprint in 9 countries, which	Manufacturing footprint in more than 10 countries with the production facilities in India

Manufacturing footprint of the enterprise, particularly in emerging countries of Asia?	includes Asia (India and China)	
Observation 2 Vision for Industry 4.0	Market development by leveraging data processing and analytics expertise to enhance its digital capabilities	Aims to embrace Industry 4.0 by accessing the available data for traceability, real-time monitoring and analysis to predict future disruptions
Observation 3 What is the role of an IT platform to achieve the company's IMN coordination goals of 'physical distribution'?	The company has been relying on ERP layer to coordinate with other factories in the network and started exploring MES functionalities	Individual plants correspond only with the corporate head quarter regarding order fulfillment and do not communicate with the other factories in the network
Observation 4 Company's vision for MES	Rolled out a MES platform globally and aims to achieve interoperability	Already using MES and rely on it for effective production execution at the shop floor level

The findings also explored the role of MES in tactical (capacity) planning or production program planning for order scheduling to various plant locations. The qualitative data gathered from the empirical study also recognizes the importance of IT tools (particularly, MES) to support the IMN coordination needs on capacity planning. However it can be perceived from the findings that the manner in which the enterprise utilises MES varies across the industries and aerospace industry has less requirement to use MES for IMN coordination.

The first iteration of results from the in-depth exploratory case study is discussed in the section 5, below.

5. Discussion

The study was done with an expectation to identify the potential areas for future research in enabling technologies for IMN coordination (in the digital transformation era) and to explore the role of smart factories for it. Since the MES software is identified to improve IMN performance by tracking multi-plant production activities using real-time information analysis, the expanded version of this study could identify the key functionalities of MES that have links with IMN and map them into key groups of IMN coordination practices. The scope of this paper is limited to the issue of physical distribution, however the future research can include the study on MES for another IMN coordination practice of 'knowledge transfer'. It is well established that supply chain management (SCM) is crucial for the manufacturing enterprises that have globalized factory networks, however the role of MOM systems to enhance the supply chain performance for effective intra-firm SCM needs further study. Hence, the intra-firm supply networks are to be empirically examined to conceptualise the best practices for managing IMN. On the other hand, manufacturing enterprises must formalize their information sharing channels in IMN by systems integration and explore the usage of real-time systems such as MES to achieve company's internal transparency. Effective planning using such systems can be particularly beneficial in minimizing the logistics costs for companies operating in emerging markets like India.

6. Conclusion and Future Research

The paper guides the practitioners in utilizing manufacturing IS to design the factories of the future to improve IMN performance. Furthermore, it recommends the manufacturing companies (with international footprint) to focusing on the suitable resources to achieve their digitalization goals. Through the optimization of physical distribution using MES, the paper proves that the operations management perspective is to be merged with that of the supply chain management to design international operations strategy to face emerging business challenges.

It is the first attempt to analyse the concepts behind next generation MES/MOM systems for IMN coordination. For theoreticians, research gaps were identified through this paper as lack of studies on the next-generation IT tools that can support IMN coordination issues of knowledge transfer and physical distribution. Accordingly, the study concludes that:

- MES/MOM systems might have the potential to improve IMN coordination and this topic needs further research.
- There is a need to investigate the IMN coordination issue of capacity planning solely from the perspective of intra-firm supply networks (excluding the inter-firm supply networks) to contribute to the theory of IMN coordination.
- Smart factories are important for IMN coordination due to their ability for intelligent manufacturing using MOM systems (Level 3 as per ISA 95).

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