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Production Management and Smart Manufacturing from a Systems Perspective

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Abstract. The traditional view of production systems relies on the organization of physical and information flows enabling customer satisfaction with products or services, following inputs from strategy, policies, rules and principles, supported by tools, systems and methods, and improved through performance management systems. Moving forward to new levels of industrialization, smart manufacturing represents systems integration and automation supported by Cyber-Physical-Systems (CPS) to enable more autonomous, agile and sustainable production processes, which can at the same time be influenced by, as well as influencing the organizational system in real time. As a new managerial topic, this research paper intends to study and systematically organize the literature related to smart manufacturing and production systems design in order to identify whether smart manufacturing can be implemented through the production systems approach and, if so, what are the requirements for implementation and integration of different management systems (e.g. quality, and environment systems).

Keywords. Smart manufacturing, Production systems, Management systems.

1. Introduction

Manufacturing plays an important role globally, contributing to countries' wealth, development, and competitiveness [1, 2]. Besides some paradoxes, certain countries in the European Union (EU) are achieving better results through accelerating technological changes, in general following guidelines provided by programmes such as 'High Tech Strategy 2020' and 'Industry 4.0', Factories of the Future' and 'Horizon 2020'; 'Smart Industry' and 'Produktion 2030' [3-6]. The Swedish government emphasizes that digitalization is very important for future industrial competitiveness with positive impacts on sustainability [5].

In this context, the 'Smart Manufacturing System' (SMS) emerges, defined as a manufacturing system fully integrated, collaborative and able to respond in real time to new conditions and demands in the factory, in the supply network and also concerning customer needs. To achieve this end, a smart factory requires "real-time information technologies", across all manufacturing resources (e.g. sensors, machines, robots,

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humans) that transform factories in an intelligent system, enabling a predictive operational position with a higher level of control for the entire factory system, moving from a centralized to a decentralized decision-system [2, 4, 7]. This new set-up represents a complex system with different sub-systems that challenge the traditional production system models, which are not flexible enough [8, 9].

During the Industry 1.0 period, the physical system design was probably considered everything and there was no consideration of digital management or control system design apart from designing the physical system (machine) to achieve the desired output. Under Industry 2.0 (mass production/assembly lines), physical system design still took priority, but control system design started to become a consideration because of the need for materials scheduling and for achieving efficient operation of the physical system (e.g. line balancing). With Industry 3.0 (computers & automation, CNC etc.), physical and control system design are both important but undertaken separately, with the control system supporting the physical system and designed afterwards. However, Industry 4.0 (smart manufacturing/cyber physical systems) involves "state of the art" technology that is sufficiently advanced for the physical system and control system to be designed together in an integrated fashion.

In this context, the key research question arises: Can a completely integrated approach to production system design be taken with SMS, in contrast to the modular approach where designing the physical system precedes control system design? This paper intends to systematically consider the literature related to smart manufacturing in order to identify the SMS requirements for implementation and integration with different management systems. Some studies are dedicating efforts to set requirements for a production system in the context of smart factories (e.g. Srouf et al. [10] and Wang et al. [8]), but in general they are more focused on the technological aspects. Qin et al. [10 p.177] say the relevance of these studies is because the production system "(…) is the core section of the industry, including the entire product's value chain from product design to services".

The contribution of this paper derives from considering whether the traditional elements of production systems design are sufficient to support the smart factories' integration demands and, if not, by exploring which are the necessary elements to configure a Smart Production System.

2. Method

The smart manufacturing literature originating from academic research, consultant companies and government guidelines was organized using a lean production system approach [11]. In manufacturing, many operations management (OM) approaches involve introducing a company X Production System (XPS – where "X" stands for the company, with the most famous being the Toyota Production System), often with a Lean production focus [12]. To Kurdve et al. [13], a XPS is a conceptual model of the physical production system (containing all functions and resources required to design, manufacture, distribute, and service a product). As a Lean System, a Smart XPS model (SXPS) (Figure 1) needs to include some key elements on different management levels, i.e.

- **Vision and Values** – the company's core values, long-term vision, policies, and regulatory elements, regarded as essential for every company.
- **Principles -** or rules that are often visualized as a temple, supporting a holistic

system view and maintenance of the XPS [14].

- **Tools, methods and techniques** - used to implement the system driving towards best practice, often focusing on continuous improvement (CI), activities and behavior (e.g. operational procedures, technologies).
- **Business Performance Management System (BPMS)** - used to manage and control operations often given as a balanced scorecard signalling values and principles importance (e.g. prioritization, goal/targets, monitoring).
- **Organization –** the management of roles and responsibilities establishing the patterns of behaviour and intercommunication between people, systems and machines, internally and externally.
- **Auditing -** and revision, being used to improve the content of the elements in the model and incorporating organizational learning.

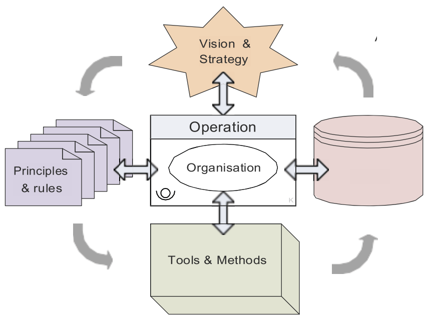

Figure 1. XPS key elements, Source: [13]

From one perspective, OM involves both daily operations and systems design and, taking the Lean System as an example, lean vision and values need to be translated into principles that support the vision/values in the management of operations and guide a set of tools, methods and techniques necessary to sustain the operations. People, machines and systems need to be organized internally and externally, and finally, the performance of the production system needs to be monitored and improved [13].

Several factors influence the manufacturing system and, considering SMS, for the smart topic, focusing on technology alone is not enough to understand the effectiveness of a solution, since it encompasses not only the production system, but also the factory, customers, logistics, and resource systems. By incorporating topic specific management systems, e.g. environmental (EMS) or quality management systems (QMS), it has been shown that these include much of the same key elements as XPS and that there are advantages of combining these systems together in coherent or symbiotic integration into general operations management systems [2, 15].

According to Qin et al. [2], the production system is the core section of the SMS and can evolve from a hardware connection to intelligent production in a sequence of developments based on (1) control, (2) integration, and (3) intelligence, applied in three engineering levels starting with machines, process and the factory system.

3. Smart Manufacturing

A Smart Factory can be considered as a representation of a Cyber-Physical-System (CPS) supported by data, predictive maintenance, sustainability, resource sharing and networking, manufacturing technologies and processes, and materials [3, 16]. It is perceived as being a convergence of the desirable features related to a manufacturing system that has the ability to be flexible and reconfigurable, low cost, adaptive or transformable, agile and lean [17, 18].

A smart factory demands a comprehensive system and planning and control tools enabling the integration of *"(...) planning, simulation, operation and even MES and ERP functions supporting the complete product lifecycle"* [18 p.136]. This also implies that issues in plant engineering can be caused by planning methods commonly associated with a top-down approach (defining structures, components, production methods and products' parameters), followed by bottom-up planning (machine parts/components, schemes, hardware and software controls). Factory planners need to embrace the vision where smart objects will interact based on semantic services, with no hierarchy (in the traditional sense) and objects capable of self-organizing for a specific task, supported by principles of IoT or "Internet of Things" [18].

An infrastructure is also needed, and Wang et al. [8] presented four layers, which can contribute to a closed-loop system: (1) a resource layer (self-organized and autonomous manufacturing system based on industrial network and intelligent negotiation mechanism); (2) an industrial network layer (infrastructure enabling inter-artifact communication) and which connects the physical resource layer with the cloud layer; (3) a cloud layer (network of servers providing layered services); and (4) supervision and control terminal layer (linking people to the smart factory). In addition, Monostori [20] states that cyber-physical production systems do not follow the traditional automation model since higher levels of the hierarchy are decentralized.

Burke et al. [17] claim that manufacturers can take small steps towards a SMS, starting from a single asset (e.g. improving performance on machinery, inventory, etc.), extending to the production line, to the factory, and finally to the factory networking.

4. XPS elements for a Smart Manufacturing System

Based on the literature, the aim of this paper is to identify whether a SMS presents the key elements of a production system. The results from various previous papers can be classified into the elements that are listed on Table 1. Thus, it is possible to identify the elements related to an XPS, allowing us to infer that it can be integrated with other management systems. As mentioned in Section 2, the vision and principles represent the strategic and operational management to develop and run the SXPS, while tools/methods/techniques represent the practices that need to be adopted by the organization, and finally, the BPMS and the auditing support response and improvement.

In this matter, the SXPS fits with the findings from Kurdve et al. [13] which means that the SXPS is based simultaneously on a top-down approach driven by values and on a bottom-up approach driven by the operations intelligence, thus answering the challenge stated by Zuehlke [19]. The architecture developed by Wang et al. [8] and the framework presented by Qin et al. [2] can be cited as examples. However, in most of the reviewed papers the implementation of SMS is technology driven and adapting the XPS, i.e. implementing the technology *ad hoc* rather than implementing it as an answer to the development needs of the XPS. One digitalization/automation risk is to institutionalize waste/losses in a rigid non-flexible system. Even if the development is made in small steps it is important that the technology being implemented follows the same principles as the rest of the system, e.g. it should be easy to do continuous improvement, and teamwork etc. [17].

Thus, the technology needs flexibility to be built-in and should be reconfigurable to maximize its usefulness. Consequently, there is a need for further operation management research on SMS implementation and management support, considering the organization of the elements in decentralized hierarchy network.

Table 1. Key elements of a production system of a Smart Production System

XPS	Smart XPS	Reference *
Vision	Interoperable, Conscious, Transparent, Intelligent, Efficient, Flexible, Agile, Collaborative, Responsive, and Sustainable	[2][3][5][7][8][9] [17][18][19][20] [21][22]
Principles and rules	Horizontal integration through value networks (company, its suppliers and partners creating an efficient ecosystem); Vertical integration connecting physical and informational subsystems inside a factory to create flexible and reconfigurable manufacturing systems (the "smart factory" connecting marketing, design, engineering, production, and sales); End-to-end engineering integration across the entire value chain (machine-to-machine integration, intelligent products enabling to obtain feedback from customers, product-to-service integration, and recycling, remanufacturing or reuse).	[8][3][19]
Tools, methods and techniques	Industrial Internet (IoT), and cyber-physical systems (CPSs), three-dimensional (3D) printing or additive manufacturing, autonomous robots, advanced materials, virtual or augmented reality, big data analytics, cloud computing, mobile devices, advance statistics analysis; modelling and computer simulation, service-oriented technology.	[16][17][20][22] [24]
BPMS	Real-time, multi-level, integrated (overall planning and operational systems) and dynamic performance measures (control level, integration level, and intelligence level considering process, machines, and facility); performance objectives (agility, customization, flexibility, responsiveness, resource efficiency (energy, water materials, labour, time, overall equipment effectiveness, environmental health & safe); ISA-95 standard; ISO 22400 standard; data protocols, interfaces and communication standards	[7][23][24]
Organization	Digital supply network (interconnected, open system of supply operations); multiple talent-related (Enhance education and training, investing in their own talent); closed-loop control strategy; collaborative and no hierarchical leadership; digital culture; cross-functional teams; integrate product and manufacturing process models; cybersecurity systems; integration of PLM/ MES/ERP/SCM/CRM.	[17][20][23]
Auditing	Real-time Analytics - sensors, identifiable components, and processors which carry information and knowledge to convey transmitting the uses feedback to the manufacturing system; simulation validation also supports feedback control mechanisms.	[19][23][25]

* A complete list of references used to compile the elements is available from the authors

5. XPS elements for a Smart Manufacturing System

Based on this conceptual review of literature it is possible to have a management system or XPS perspective on SMS, however many initiatives seem to be technology driven rather than strategy driven, when better results can be reach by a combined approach. Further empirical and literature studies are needed on how management in a strategic and systematic way can incorporate SMS in the overall management of operations.

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