Impacts of Industry 4.0 on Operations Management: Challenges for Operations Strategy

Marcelo GASPAR
School of Management and Technology, Polytechnic Institute of Leiria, Leiria, Portugal

Jorge Julião*
Católica Porto Business School, Universidade Católica Portuguesa, Porto, Portugal

ABSTRACT

The digital transformation of business positively contributes to the creation of new opportunities and challenges for Operations Management. New technologies have made it possible for managers to access, store and process large amounts of data, collected from different complementary sources, both internal and externally to processes. Nonetheless, even though such data availability may be of great contribution for management at the operational level, its potential for value creation at the operations strategy level remains unclear. The purpose of this paper is to explore the impacts of recent trends and features related to the digital transformation in the operations management field, namely to further understand how such digital transformation is going to impact the operations strategy definition.

CCS CONCEPTS

• **Applied Computing**; • **Operations Research**; • **Industry and Manufacturing**;

KEYWORDS

industry 4.0, digital transformation, operations management, smart factories, operations strategy

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1 INTRODUCTION

Industry 4.0 is based on the integration of innovative information and communication technologies into the value chain by means of inter-connection and computerization of traditional processes [1, 2]. This new and disruptive paradigm aims at fostering an intelligent networking of products and processes in order to reduce the complexity of operations while increasing efficiency and effectiveness with long-term cost reduction and processes improvement [3].

While digitization is a key driver of the fourth industrial revolution [4], the continued integration of the Internet of Everything (IoE) into industrial operations allows organizations to design different approaches and to explore opportunities and challenges concerning this digital transformation. Furthermore, an ever-increasing competitiveness between companies lead to pressure business processes for an effective increase in efficiency. To this end, the convergence of innovative means of production with digital information and communication technologies promises substantially increased operational effectiveness [5].

The field of operations management provides a rich ground for research with the Industry 4.0 developments as it allows setting operations strategies suited to the market. Based on complex scenarios it allows establishing more efficient resource-based models. Considering that these strategies are implemented through processes that define how things are done, it is important to guarantee that such processes will be executed efficiently whilst meeting operational goals and requirements. Thus, implementing Industry 4.0 raises issues not only locally at the shop floor, but also has implications widespread into the global supply chain. To such end, even though Operations Management implications of globalization are important for practice, it is widely recognized that it is a topic still under-researched by scholars [6].

In order to contribute to a better understanding of the impacts resulting from the implementation of Industry 4.0 scenarios in current and future organizations, this paper aims at contributing to close this gap in research related to such trends and challenges on the operations management field.

2 INDUSTRY 4.0: A NEW MANUFACTURING AND ORGANISATIONAL PARADIGM

It is referred that the term Industry 4.0 was coined in 2011 as part of a strategic manufacturing roadmap designed by a German association of representatives from business, politics, and academia to strengthen the manufacturing industry competitiveness through a digitization of processes [3]. Nonetheless, even though the terms «Industry 4.0»or «fourth industrial revolution»may not be fully accepted by academia and/or industry alike [2, 5], there is no doubt that a disruptive change of processes and operations is on the verge of taking place on a global scale due to such digital transformation.

These changes result on a new trend of operations based on the integration of a set of technologies that enable ecosystems of innovation in smart factories and organizations to interconnect in real-time at a global scale. It is such global interconnectivity and exchange of data and information that is enabling organizations to adapt or create new business models and concepts within their area of operation [6] to become more competitive, or just simply

*Corresponding Author. E-mail: marcelo.gaspar@ipleiria.pt.

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to survive in an increasingly complex global landscape. Considering the Industry 4.0 paradigm, four key design principles and technology trends [5] related to current digital transformation of operations can be identified, namely: interconnection, information, decentralization and flexibility.

2.1 Cyber-Physical Interconnectivity of Systems

Considering the wide scope of digital interconnectivity, the IoE results from the combination of both IoT (Internet of Things) and IoP (Internet of People). It is a key principle of the new digital paradigm that the cyber-physical interconnectivity takes place between systems of people, devices and/or machines [7]. This real-time digital communication can only take place due to the broadband wireless communication characteristic of current ubiquitous internet access. Via the IoE interconnected objects and people are able to share information by means of three types of collaboration, namely, human-human collaboration, human-machine collaboration and machine-machine collaboration [8].

2.2 Information Transparency and the use of Digital Twins of Real-World Systems

The above mentioned cyber-physical interconnectivity of systems enables a new form of information transparency [9]. Digital twins resulting from the virtual copy of real-world systems allow for process simulation and optimization (supporting real-time decision making), as well as for systems monitoring and control. Context-aware information is indispensable to support appropriate decision making [5], as context-aware systems allow combining information coming both from physical systems and their digital twins. In order to create transparency, the data analytics' results need to be collected and processed by adequate software solutions [10], allowing real-time information provision of critical operation information [11].

2.3 Decentralized Decision Making

Both interconnection of systems and transparency on information lead to the ability to produce decentralized decision making [5]. Such decentralization, supported with local and global information, allow for more robust decision models and software solution, thus increasing overall productivity and efficiency. Real-time fed context information also allows for automated decision making and autonomous monitoring and control of real-world systems.

2.4 Increased Autonomy and Flexibility of Cyber-Physical Systems

Real-time context-aware information and communication enable smart machines and/or devices to flexibly adapt to dynamic real-world data (flexibility of machines or devices). The same concept applies to smart factories and real-time fluctuating market demands, or personalized orders (flexibility of production). Also, for the human aspect, automation and decentralized decision making allows for a change of role of current and future workforce. Thus, from a mere machine operator position, people can act as system supervisors or strategic decision-makers and flexible problem solvers, thus resulting in human flexibility and increased process interaction and engagement. Thus, an overall cyber-physical interconnectivity of people, devices and machines may contribute to the agility and flexibility of production systems, increasing the efficiency of future smart factories.

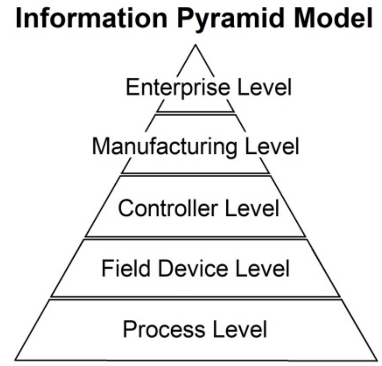

Figure 1: Information pyramid model, based on [12]

3 CONVERTING CURRENT MANUFACTURING SYSTEMS INTO SMART FACTORIES

Considering all features and attributes envisaged for smart factories, it can be observed that most existing production systems are not yet Industry 4.0-ready. According to Kagerman et al. [9], future factories need to be developed considering the need for agile customization and flexible individualization.

Future interconnectivity of Cyber-Physical Production Systems will be the base of the Smart Factories [7], allowing for combined data management from the overall system, as well as from each of their integrated components. This data can be effectively managed by the smart production systems to adapt for every single piece requirements and attributes, influencing future workload of the system whilst being adjusted through a live feed of data directly from the customer.

Currently, from the data management point of view, most factories are structured hierarchically from the shop floor level up to the enterprise resource planning level according to the information pyramid of automation [12] presented in Fig. 1. This architecture shows that in such arrangement, only members of adjoining segments can exchange information, leading to a decrease of cycle time of data from top to bottom, accordingly to the amount of information transferred.

However, considering that in an Industry 4.0 paradigm all members of the value chain are able to connect and exchange information with each other, numerous intermediate contacting nodes are required for the flow of such data to occur in real-time. Vogel-Heuser et al. [13] propose a communication model for the new digital manufacturing paradigm based on a mesh architecture. In this model, the communication pyramid (Fig. 1) will be transformed to integrate intermediate nodes and mechanisms to detect and connect persons, products and devices to exchange data and information.

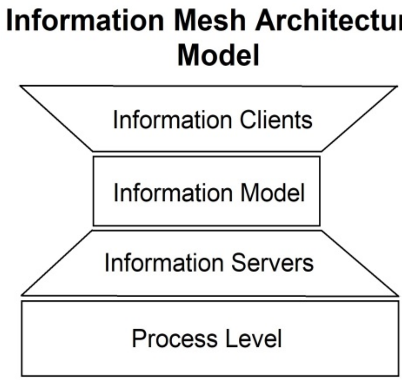

Figure 2: Information mesh architecture model, based on [14].

In such information model (Fig. 2), intermediate communication interfaces allow for the communication and processing of data in a dedicated mesh architecture.

In a mesh architecture model, production systems need dedicated communication interfaces to acquire and exchange data with all connected Cyber-Physical users and devices. External interfaces are used in production sites allowing for user interaction as human-machine interfaces (HMI), whilst internal interfaces are generally used for process and control functionalities [13].

The Industry 4.0 model requires for Production Systems to have dedicated functionalities to manage and control all manufacturing-related processes and resources. The template for each functionality in the new production paradigm needs to be pre-defined to assure a standardized semantic [13]. This shows to be key for the effective Operations Management of Smart Factories to take place in a new digitized global production environment.

4 IMPACTS OF INDUSTRY 4.0 ON OPERATIONS MANAGEMENT

Operations are a major function within any type of organization that is responsible to create and deliver goods or/and provide services to clients. Operations management (OM) is the activity of managing these processes and associated resources. Operations is, therefore, a key element for companies to gain competitive advantage and improve growth [15]. Considering a business model as a transformation process that takes resources and transform them into goods or services, OM is the set of activities of value creation. According to Slack et al. [16], these activities can be clustered under four broad categories: Direct, Design, Deliver and Develop. The purpose of this research is to explore the impacts of Industry 4.0 developments in these four OM categories and identify related challenges and opportunities for both research and practice.

4.1 Steering Operations and Processes

The operations function has a strategic dimension, directing the overall strategy that govern the direction of the operation and impact all other operations decisions. Directing includes setting an operations strategy, defining performance objectives, taking decision about product and service design and innovation, and managing the scope of the operation. These strategic decisions are strongly influenced by the marketplace, particularly by customers and competitors, which change very rapidly. Thus, companies need to establish a process that allows quick reaction to these market changes, makes strategy adaptation agile and speeds operation modifications [16]. Therefore, interconnecting all activities in this process and improving information flows will be essential. Considering the Industry 4.0 principles and technology trends, it is important to study the potential of OM on the quest for the organizations' most effective strategy definition. This is particularly relevant in current market scenarios considering that it is key to have quick and agile operation modifications as they are strongly influenced by the fast pace changing market demands and competitors' pressure.

4.2 Shaping Operations and Processes

Designing the transformation process is the activity of determining the physical form, shape and composition of operations and processes, together with the resources they contain, responsible for creating products and services. Design includes process design, layout definition, and selection of technology and people. Each of these activities is defined according to the organization strategy i.e., the operation type and performance objectives, and typically includes structural changes and significant investments. Thus, modifications in operations and processes design, resulting from changes in the marketplace, tend to be slow and sometimes impossible. Therefore, companies could gain competitive advantage by having a flexible, dynamic [17] and decentralized transformation process, and the possibility of testing the designs before implementation. To this end, Industry 4.0 principles can give a great contribution, since they promote decentralization and allow for the flexibility of real-world systems. On the other hand, digital transformation allows for context-aware real-time information provision of critical operation variables. The question remains about the suitability of current OM models to encompass the Industry 4.0 paradigm.

4.3 Planning and Controlling Operations

Once operations and processes are designed, products and services must be created and delivered to customers. In order to assure the effectiveness of this process, all activities from the supply chain operation must be planned and controlled. The efficiency of the process is guaranteed by managing the capacity (optimizing the reaction to demand fluctuation), the supply chain (analyzing the impact of all supply chain decisions on profitability), and the inventories (applying models to balance costs). The delivery activities are supported by methods and techniques that need process data and information. These data and information are, commonly collected with a time delay and sometimes in different contexts, in relation to the decision point, and based on statistical analysis. This process may compromise the precision and reliability of the decisions. Thus, companies could improve delivery if real-time data were collected and fed to the decision process. However, current OM models still need to be tested for their capacity to receive real-time data.

4.4 Improving Operations

The role of operations management does not finish with delivery. It is a dynamic process with opportunities for development and improvement. The chain of value process cannot perform always with the same standards because conditions change, like customer´s needs and competitors supply. Thus, companies should set a strategy for improvement, radical or incremental, that could be supported with methods like quality management (preventing errors) and project management (improving project activities). Like delivery activities, performance improvement activities depend on accurate and up-to-date process data. As for above, current OM models need to be studied for their suitability to such type of demands.

5 CHALLENGES FOR OPERATIONS STRATEGY

The digital transformation of business is creating new opportunities and challenges for management. New technologies have made it possible for managers to access, store and process a large amount of data, collected from different sources, internal and externally (Fig. 2). These data are of great contribution for management at the operational level. For example, using these technologies, manufacturing companies can gain access to individualized customer data that allow to customize the sales process, product design and service. Moreover, they can provide real time data that enhance both demand forecasting and market product accuracy, and helps predicting consumer behavior [18].

While the data made available throughout the digital transformation technologies has enabled these benefits, its potential for value creation at the operations strategy level remains unclear. The implement and utilization of these data at the strategic level bring a few challenges to management. One of the key challenges is knowing how to automate extracting knowledge from data. Another challenge is balancing the explicit knowledge (resulting from the collected data), with tacit knowledge (from manager´s experience), when taking strategic decisions. Current research did not yet provide an answer to the question, how digital transformation is going to impact the operations strategy definition.

Companies, even before the digital transformation, considered day-to-day experience when using a 'bottom-up' approach to define its operations strategy. The new digital technologies allow this process to be more agile and generate more volumes of data. Since some authors argue that managers should be detached from distractions of day-to-day activities when defining the operations strategy [19], these high volumes of data may have a negative effect when defining a strategy. On the other hand, considering that markets are intrinsically unstable in the long term, it may be more important to keep close to what is happening in the market and adapt to whatever circumstances develop [17] Notwithstanding the complexities and disturbance that real data may cause in the decision process, it is believed that a model that consider these data, can help most managers to understand what they believe they should be doing. The purpose of these data in not to change strategy, but to introduce a continual and incremental improvement [19].

Defining operations strategy is essential to produce and deliver products and services efficiently, and gain competitive advantage [20]. Therefore, setting business objectives that direct an enterprise towards its overall goal, is a crucial for companies to define their transformations process and the way manage operations. These strategic objectives define the competitive priorities and are used to implement the operations strategy. On the other hand, the strategy is defined according to the purpose of business, that could be technology-driven, marketing-intensive, low-cost, among others [21], and are influenced by competitors, market and technology. This raises another question that is to know how digital transformation technologies are going to impact the definition of the strategic objectives of a company since they promote a continuous feed of real data from market and competitors. Would companies in future need a flexibility that allow them to adapt and change strategic objectives accordingly to data that is being fed from digital transformation technologies? For example, a company that seeks to offer products and services at a competitive price, its strategic objective would be cost reduction and process efficiency. If this company receives market and competitor data that indicates a trend for quality products, would that change its strategic objective? It is believed that the answer is yes. Firms are required to continuously configure their operations strategy with respect to continuous changes in the market, in order to sustain competitive advantage [22]. On the other hand, the definition of the strategic objectives of a firm, as cost, quality, delivery, and flexibility are influenced by specific organizational knowledge [23]. Thus, continuous knowledge acquisition about internal and external business environment through digital transformation technologies (e.g. competitors, customers, and suppliers) is essential to a firm's overall competitive performance [24]. Moreover, firms that offer competitive products and services that match customer' needs and wants are in a superior position to create a sustainable competitive advantage [25]. Still, while firms may acquire, share, and apply knowledge to improve operations strategy, they may need to possess a conceptual model to ensure effective outcomes of such integration.

Although it is suggested that the new technologies from digital transformation may impact positively the definition of operations strategy, empirical evidence to demonstrate it is still missing. From a managerial perspective, firms should carefully contemplate how data from digital transformation technologies can be used successfully. Managers need to stimulate data acquisition, sharing and application, and assuring its alignment with business strategy. They also need to recognize its importance to the definition of operations strategy. Moreover, they need to ensure a dynamic conversion between tacit and explicit knowledge, so the values top managers hold from their experience and practice, can be integrated in the decision process. This is a key issue, since research demonstrated that managers when making a decision on a firm's competitive priorities of strategy, considered if it fits their specific organizational culture [26]. But still, there is little evidence to conclude how top managers would react to the digital transformation integration.

6 SUMMARY AND FUTURE DEVELOPMENTS

The paper discusses the Industry 4.0 impacts on OM field, providing evidence of gains from exploring this new paradigm, and stresses for an alternative lenses and framework. It also argues that the trends and challenges related to Industry 4.0 have to be tested and adapted on the OM field. Finally, it allows suggesting the following research question: «Are current Operations Management models and approaches suited for the Industry 4.0 paradigms, trends and challenges? ».

It was shown that Industry 4.0 is based on the integration of information and communication technologies into the value chain of innovative products and services through the interconnectivity of people, products and processes. Nonetheless, such new operational paradigm requires having dedicated functionalities to manage and control all production-related processes and resources by means of a dedicated model. This shows to be key for the effective Operations Management to take place in a new digitized global production environment.

Even though current digital transformation makes it possible for managers to access, store and analyze large amounts of process-related data, its potential for value creation at the operations strategy level remains unclear. Challenges arise at the operations strategy level, like the need to balance explicit knowledge with tacit knowledge. Thus, even though current research may not yet provide an answer to such demand, further research is needed to fully comprehend the implications of the Industry 4.0 paradigm on OM, and, more specifically, to further understand how such digital transformation is going to impact the operations strategy definition.

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