IMPLEMENTING CYBER-PHYSICAL SYSTEMS IN MANUFACTURING

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ABSTRACT

Cyber-physical systems (CPS) are a new generation of systems that integrate computation and physical processes interacting with humans in different ways. Integrated networks of computers, sensors and similar technologies monitor and control the physical processes, reporting relevant data to planners and decision-makers, and vice versa.

By means of case research, this paper analyzes the implementation of cyber-physical systems aiming at lead-time reduction in two manufacturing contexts, namely footwear and natural cork stoppers. The results of this research contribute to literature and practice with a conceptual framework for the implementation of cyber-physical systems and the discussion of the challenges of implementing this technology.

Keywords: Cyber-Physical Systems, Technology Implementation Management, Case Research

1 INTRODUCTION

Developments in computer science, information and communication technologies, and manufacturing automation have enabled the application of sensors, wireless communication, and

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the Internet of Things to the manufacturing context. Cyber-Physical Systems (CPS) are automated systems that orchestrate operations from the physical world using communication and computing infrastructures, enabling the networking of several devices and equipment (Lee [1], Baheti & Gill [2]). In this context, CPS are seen as the backbone of ongoing digital transformation initiatives in the industry, the so called Industry 4.0 or Fourth Industrial Revolution (Jazdi [3], Wang et al. [4]).

Research on Cyber-Physical Systems has so far been focused on the development of technological solutions and hence, contributions on issues related to the management of implementing this technology have been scarce. This paper aims to fill this gap by studying the implementation process of cyber-physical systems in two contexts: footwear production and supply and production of natural cork stoppers.

The literature review in section 2 starts with the basic concepts of technology implementation management and presents a conceptual framework for the implementation of advanced manufacturing technologies. Afterwards, the definition and expected impact of cyber-physical systems are presented. Section 3 explains the case research method applied and section 4 details the within-case analysis. Finally, section 5 presents the implementation challenges deducted from the cross-case analysis and section 6 concludes the paper.

2 LITERATURE REVIEW

2.1 Implementation of technologies in operations

Technology implementation management has been a critical challenge in organizations due to frequent cost and schedule overruns (Plaza et al. [5]). Implementation includes activities ranging from the decision to adopt to the incorporation of the technology in the routines of the adopter, or its abandonment. Three main stages can be identified in the implementation process: adoption decision, implementation, and assimilation (Greenhalgh et al. [6], Rogers [7]). The implementation is initiated by an adoption decision that is frequently made by a restricted group of decision makers within the adopter's structure (Gallivan [8]). Then, during the implementation stage, efforts are initiated to include the technology in the routine operations of the adopter and to align the adopter and the technology to better fit the operations and the expected outcomes (Greenhalgh et al. [6], Rogers [7], Gallivan [8]). At this stage the technology is being gradually adopted by the users, with the assistance of training sessions and other efforts to promote the acceptance of the technology (Gallivan [8]). The implementation and assimilation stages are intermingled. In the assimilation stage, efforts to routinize and incorporate the technology continue, but the technology is already fully working within the adopter's operations and begins to lose its external identity by becoming an ongoing element of those operations (Rogers [7]).

Although the technology to implement is chosen according to a set of requirements defined by the adopters (Rogers [7], Leonard-Barton [9]), there are always challenges to overcome throughout the implementation process. Key challenges in the implementation of new technologies include: (1) integration of perspectives and needs of both developers and users, (2) serving a variety of internal business and functional requirements, (3) users' resistance to change, (4) the right degree of promotion (the faster the benefits of the new technology are realized by users, the more visible those benefits will be), (5) planning the implementation process (conducting a pilot operation before introducing the technology across the board in a large organization), and (6) the need for one person to take overall responsibility (Leonard-Barton & Kraus [10]).

Some authors have focused on describing the challenges of implementing technologies in operations, such as advanced manufacturing systems and Radio Frequency Identification (RFID), and identified the following: i) integration of the technology with the capabilities and constraints of people and organization (Yusuff et al. [11]); ii) privacy, massive data management, high cost, and technical reliability issues (Bhattacharya [12]); iii) increase of managerial uncertainty, due to implementation difficulties and possible failures (Zammuto & O'Connor [13]).

Implementation of a new technology is a strategic issue, and thus requires strategic planning both at the business and manufacturing levels. Table 1 synthesizes the implementation process of technologies in operations taking into account the literature on manufacturing technology and technology management.

Table 1: Conceptual framework for the implementation of Advanced Manufacturing Technologies (AMT)

Implementation Factors	Description	Questions to be answered by the implementation team	References
Implementation context and strategic alignment	Strategic planning of the implementation process, creating awareness of the technology, and analysing external drivers and alignment with business strategy.	- Why did the company decide to implement the AMT? - Where was the technology implemented?	Fraser et al. [14], Small, & Yasin [15]
Technology consistency	Matching capabilities of the technology and benefits expected by the organization, ensuring compatibility of the technology with existing systems	- What technology was implemented - How was it integrated with the existing systems?	Small, & Yasin [15]
Organizational change	Users preparation for technology adoption, implementation and assimilation	- How were users prepared for using the new technology (training type and duration, ergonomic studies, etc…)?	Yusuff et al. [11],Fraser et al. [14], Small, & Yasin [15], Adler & Shenhar, [16]
Adaptation effort	Functional integration: new process planning, systems integration, quality control, industrialization and supply chain development.	- How many functional areas have been involved in the implementation process? - How was the implementation process communicated to the company? - Did the implementation team experienced resistance to change? What strategies were used to mitigate it? - Which adaptations were	Yusuff et al. [11],Fraser et al. [14], Small, & Yasin [15],

		needed to align technology and organization?	
Assimilation and impact	Incorporate the technology in the routine operations of the organizations. Outcome of the implementation: change brought by the technology to the work performed and to the organization's structure or the interactions between its members; economic performance of the technology; and degree of improvement in the operations (operational effectiveness).	- How long did it take for the technology to be routinized in the organization's processes? - What was the operational impact of the technology implementation?	Rogers [7], Linton [20]

2.2 Cyber-physical systems in the context of Industry 4.0

Industry 4.0 is the term frequently used to characterize a strategic program promoted by the German federal government for the "Fourth Industrial Revolution" (Walendowski et al. [18]). In sum, Industry 4.0 is a manufacturing concept supported by the integration of a number of technologies for the purpose of creating ecosystems of intelligent, autonomous, decentralized factories and integrated product-services (Schmidt et al. [19]; Almada-Lobo [20]). The key technologies of Industry 4.0 include (Zhou et al. [21]): Cyber-Physical Systems (CPS), mobile internet and internet of things technologies, cloud computing, big data and machine learning techniques.

The impact of Industry 4.0 in the manufacturing sector is expected in many fronts. First, in improving information exchange, by enabling communications between humans, machines and products, and the real time access to product and production information. Second, in operations, by having fully autonomous work processes and seamless integration of value chains. Third, in the innovation processes, through the engagement of producers and consumers and the reduction of time-to-market (Brettel et al.[22], European Commission [23]). In terms of value creation, it is expected that the European manufacturing sector achieve a growth from 15% to 20% by 2030 if it digitizes their value chains (European Commission [23]).

In this regard, CPS play a central role, and some authors have argued that its proliferation is at the basis of Industry 4.0 (Jazdi 2014 [3] and Wang et al. [4]). CPS are automated systems that orchestrate operations from the physical world using communication and computing infrastructures, enabling the networking of several devices and equipment (Lee [1], Baheti and Gill [2]). CPS result from the convergence and advances from wide range of technological fields (including computing, sensing, informatics and process control), although a complex research and innovation field by itself (Schätz et al. [24]).

Concerning its definition, one may argue that CPS applications in manufacturing (known under the term Cyber-Physical Production Systems) have been in place for some time, however, the advancements in information and communication technologies (ICT) coupled with already existing technologies (e.g. embedded controllers, sensors, collaborative robots, etc.) is enabling increasing levels of interconnection and interoperability between production systems (Wang et al. 2015, [4]). Still, to realize its full expectations, CPS implementation require R&D investments in a number of research fields (Monostori [25]).

3 RESEARCH METHOD

The conceptual framework developed from the literature in section 2.1 was applied in an exploratory case research (Voss et al. [26], Yin [27]) in order to derive the main challenges of implementing cyber-physical systems in manufacturing contexts. The unit of analysis of the case research is the CPS implementation project. This study considers two cases of CPS implementation in two manufacturing contexts, namely footwear and natural cork stoppers. Both cases have as objective to reduce production lead-time and have implemented CPS technology to achieve this goal. Section 4 presents the within-case analysis based on the dimensions of the conceptual framework of Table 1.

4 WITHIN-CASE ANALYSIS

Table 2 describes the implementation of cyber-physical systems in two contexts, namely footwear production and supply and production of natural cork stoppers.

Table 2: Within-case analysis

Footwear production	Supply and production of natural cork stoppers
Implementation context and strategic alignment	
Company's goal is to reduce production lead-time by reducing machinery downtime and workstations' processing time. The technology was implemented in the production processes of cutting, pre-stitching, stitching, pre-assembly, and assembly.	Company's goal is to reduce natural cork stoppers' production leadtime. The technology was implemented in the supply and production processes, including cork oak purchase and harvesting, transportation of the cork oak bark from the forest to the intermediate stockyard and to cork stoppers manufacturer's stockyard, and cork stoppers production.
Technology consistency	
The company had previously implemented an internal logistics system composed by robotic manipulators and an automation system. In this project, data from the available sensors and actuators was retrieved and processed in order to collect information for production monitoring and predictive maintenance.	RFID tags and environmental sensors are used to provide relevant information about cork piles (e.g. temperature and humidity) to the software for cork inventory management, to the cork debarking machine for adjusting its settings to the cork physical conditions, and to the industrial controller for setting the conditions and duration of the stabilization process.
Organizational change	
Training was provided to the production line operators about the alarms given by the system and to the production line responsible about	The new software to support cork acquisition was easily adopted by the responsible for purchasing. On-the-job training of the operators

the information the system needs to operate and the feedback indicators given by the system.	was needed for placing the RFID tags in the cork planks and implementing readers across the production process. The production manager had difficulties in adopting the new monitoring process.
Adaptation effort	
The implementation involved top management, production planning managers, section responsible, maintenance team, managers of the companies providing the technology. Both the organization (more specifically the maintenance process) and the technology (mainly the alarm settings) had to be adapted during the implementation process to achieve project's goals.	The implementation involved the top management, the responsible for cork acquisitions and the responsible for production. The implementation followed a step-wise approach: first, environmental sensors were installed and integrated with the cork inventory management software. Second, RFID tags were installed to mark cork planks, as well as the necessary readers across the production process. Third, afunctional prototype of the new equipment for cork debarking and corks stoppers drying was built and assessed by the workers.
Assimilation and impact	
Timeline: five months for the implementation of access sensors on footwear production lines for gathering and propagation of field-level data to factory and cloud (enterprise) levels to enable real time view on the status of the production system. Two months for the implementation of a diagnostic and predictive maintenance system for real time detection of physical problems on working posts and robotic manipulators and estimation of their possible occurrence in the near/medium term future. Impact: Downtime reduced from 15 min/day to 10 min/day. Number of shoe pairs produced increased by 5.5%.	Time line: two years for development/ prototyping; one year for implementation; one month for routinization in companies' operation (1st step). Impact: 1st step: Better use of cork inventory. Simplify cork acquisition process and more grounded buying/investment decisions. Reduce cork waste and decay. 2nd step: cork traceability: improved process control. 3rd step: new equipment uptake: expected to reduce corkstoppers' production time from 48 to 40 hours through monitoring of corkstoppers' features before drying operation and update of the machine's control model.

5 CROSS-CASE ANALYSIS

Three main challenges in the implementation of cyber-physical systems were extracted from the case data as follows.

Assessing data: Sensor and actuator signals are read and produced by PLCs. Difficulties may arise to retrieve the corresponding data available in the PLC's internal memory, because there is a need to identify such memory segments and the logic behind their lifecycle so as to relate them to the readings/writings performed on each sensor/actuator. Once achieved, e.g. with the help of a PLC memory reader/writer software program, the use of the retrieved data enables the development of software applications (e.g. production management, maintenance management, performance management) intimately related with the physical manufacturing process, thus starting building a cyber-physical production system (CPPS).

Making sense of data: Data analytics services may cause problems when poorly configured, since the analysis of the different data streams generated by the sensors may create a high number of alarms, which therefore are meaningless to the operators. On the other hand, many of the alarms may also be generated due to operators that do not follow the expected working procedures.

Lack of off-the-shelf solutions: The current CPS technologies still need additional development in order to exploit them in a manufacturing context. Systems integration is key to achieve real time information that is propagated throughout the CPS system feeding the data analytics services.

6 CONCLUSION

Although Cyber-Physical Systems (CPS) is the cornerstone of Industry 4.0, very few studies have documented and discussed their implementation in the manufacturing context. This paper reviewed the literature on implementation of technologies in operations to synthesize a conceptual framework for the implementation of advanced manufacturing technologies, such as CPS. This framework was then used to describe and discuss two implementations of CPS in manufacturing. The results reveal three main challenges of CPS implementations, namely assessing data, making sense of data, and lack of off-the-shelf solutions. Future research should consolidate this results with further case studies also by applying the conceptual framework to the implementation of other operations technologies.

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