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Coordinating Knowledge Creation: A Systematic Literature Review on the Interplay Between Operational Excellence and Industry 4.0 Technologies

Toloue Miandar[1], Ambra Galeazzo and Andrea Furlan

Abstract In the process of creating new knowledge, literature has scarcely studied how bodies of knowledge arising from different sources should be coordinated to enhance performance. In particular, the present research focuses on two sources of newly created knowledge, i.e., operational excellence and Industry 4.0, to understand whether they should be implemented sequentially or simultaneously. Operational excellence refers to the implementation of practices such as just in time, total quality management and Six Sigma that help a firm to create knowledge that facilitates waste reduction and customer value improvement. Industry 4.0 refers to the implementation of new technologies such as artificial intelligence, Big Data, robotics, Internet of Things and laser cutting that help a firm to create knowledge to improve overall business performance. We identified and analysed 30 papers published in 13 peer-reviewed journals and conference proceedings in the field of operations management. Our findings based on the systematic literature review suggest that the interplay between operational excellence and Industry 4.0 can be categorized into four groups: (1) Industry 4.0 supports operational excellence; (2) operational excellence supports Industry 4.0; (3) complementary (4) no interdependence. Majority of the papers under study are in the first category, suggesting Industry 4.0 technologies as enabler of lean manufacturing.

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1 Introduction

Organizational knowledge has increasingly been recognized as a central element of competitive advantage (Nonaka and Takeuchi 1995). New knowledge is created as a result of a recursive interaction of tacit and explicit knowledge that continuously go through four steps: socialization (from tacit to tacit knowledge), externalization (from tacit to explicit knowledge), combination (from explicit to explicit knowledge) and internalization (from explicit to tacit knowledge). Past literature has widely investigated the theory of knowledge creation across different disciplines, such as marketing, operations management, strategy and innovation (Li et al. 2009; Linderman et al. 2004; Merx-Chermin and Nijhof 2005; Moreno-Luzon and Begona LLoria 2008). Most of them, however, have focused on the effects that new knowledge has on a range of organizational processes leading to competitive advantage (Tsai and Lee 2007; Li et al. 2009). However, some scholars call for a better understanding of the process, not only the effects, of new knowledge creation (Gourlay 2006).

Indeed, literature shows that the way activities are coordinated has profound implications on firm's performance (Barki and Pinsonneault 2005; Galeazzo et al. 2014) and can greatly impact the way these activities are managed as well as their potential success. This chapter aims at contributing to the knowledge management literature by shedding some light on how it is possible to combine together different sources of knowledge. In particular, we focus on two different sources of knowledge creation: operational excellence and Industry 4.0.

On the one hand, operational excellence creates new knowledge by using a series of practices to eliminate each form of waste along the value chain. These practices, also known as lean practices or quality-related practices, increase the stability of processes by reducing machine set-up times, guaranteeing overall equipment effectiveness and introducing standard work. They also promote ways to create flow by replacing the push-oriented manufacturing planning and control systems with the adoption of a pull logic (Demeter and Matyusz 2011) and to improve quality by eliminating scraps, defects and reworks. Finally, these practices involve employees and increase their responsibilities and competences to sustain continuous improvement over time (Furlan et al. 2018; Galeazzo et al. 2017). Some of these practices are, for example, just in time (JIT), total quality management (TQM), total productive maintenance (TPM), human resource management (HRM) and Six Sigma (Galeazzo and Furlan 2018; Furlan et al. 2011; Schroeder et al. 2008). Literature in operations management suggests that, as the implementation of these practices completely changes the way

operators perform their jobs (e.g., they have a more in-depth understanding of the production processes, they are more involved in process improvements and they collaborate more tightly with top management and colleagues), there is a strong relationship between operational excellence and the creation of new knowledge.

On the other hand, Industry 4.0 creates new knowledge because it represents a technological breakthrough for organizations and creates a paradigmatic change in the processes of value creation and competition rules. Industry 4.0 applied to manufacturing activities includes technologies such as additive manufacturing, advanced automation and advanced human-machine interface, Internet of Things - IoT, cloud manufacturing). These technologies have the potential to increase firms' efficiency and productivity, enabling them to strongly customize their products by flexibly adapting to the market demand (Holmström et al. 2016; Roblek et al. 2016). Overall, literature on operations management agrees that technology, including Industry 4.0, allows operators to have access and incorporate explicit knowledge as well implicit knowledge as a result of the man-machine interaction. This implies that the interaction of tacit knowledge and explicit knowledge fosters knowledge creation.

Although literature is clear about the benefits of new technologies and operational excellence programs in creating new knowledge, the risk for firms is to approach Industry 4.0 and operational excellence as two separate cycles of knowledge creation. Firms implementing the two sources of knowledge independently risk reducing Industry 4.0 technologies to a mere technological investment, introducing new complexities and digitalizing wastes. Moreover, they risk operational excellence-related practices underperform without an adequate technological support. Instead, it is important to combine the new knowledge created by Industry 4.0 and operational excellence in the most effective way. Thus, the idea that there are different ways to accrue the benefits of the combination between operational excellence and Industry 4.0 is very important.

The purpose of this chapter is to provide a clear understanding of the combination of Industry 4.0 and operational excellence drawing on Thompson (1967)'s research on task coordination. In particular, there are three possible ways to coordinate operational excellence and Industry 4.0. First, they may be implemented separately having in mind that both of them contribute to the process improvement. Second, the joint implementation may occur sequentially and the main issue is to understand whether operational excellence should be implemented before or after new technologies. Third, operational excellence and Industry 4.0 may be implemented together. Based on a systematic literature review, we found that only 30 papers deal with the purpose of this chapter, i.e., understanding

the combination of Industry 4.0 and operational excellence. This is mainly due to the fact that research on Industry 4.0 is still at its infancy. Most of these studies argue that the introduction of Industry 4.0 technologies helps firms to exploit the potential of operational excellence (Roy et al. 2015; Rüttimann and Stöckli 2016), thus implying that Industry 4.0 paves the way to the implementation of operational excellence. Some studies show that Industry 4.0 technologies need the support of operational excellence to maximize their potential in increasing performances (Khanchanapong et al. 2014; Tortorella and Fettermann 2018; Rossini et al. 2019) thus implying that operational excellence paves the way to the implementation of Industry 4.0. Although contradictory, this evidence would suggest that the implementation of Industry 4.0 and operational excellence is sequential. Finally, few studies found that Industry 4.0 and operational excellence should be implemented simultaneously. Overall, these findings result in two important contributions. First, this chapter contributes to the literature on knowledge creation by providing practical examples of the way two sources of knowledge may be combined together. Second, it contributes to the literature on operations management by giving a state-of-the-art overview of the relationship between operational excellence and Industry 4.0.

2 The process of knowledge creation

Though many researchers have been studying the process of creating knowledge, Dierkes et al. (2001) identified the theory proposed by Nonaka (1994) as the stemming reference in knowledge creation literature. According to Google Scholar index, this paper has been cited more than 23,476 times whereas Scopus counted 320 citations, proving that Nonaka's theory has received an increasing attention since its publication. It has been described as a "highly respected" theory (Easterby-Smith and Lyles 2003) and one of the most influential in knowledge management literature (Choo and Bontis 2002). This theory has been applied to several areas of research as diverse as operations management (Linderman et al. 2004; Galeazzo and Furlan 2019), innovation (Subramaniam et al. 2005; Esterhuizen et al. 2012), human resource management (Droege and Hoobler 2003) and internationalization strategies (Zahra et al. 2000).

Nonaka (Nonaka 1994; Nonaka and Takeuchi 1995; Nonaka et al. 2000) proposed that knowledge is created as the result of a continuous interaction of the epistemological and ontological dimensions of knowledge. The epistemological dimensions of knowledge comprise explicit and tacit knowledge. The former is easily accessible and codifiable because it refers to objective knowledge that is stored in such forms as documents,

spreadsheets, standardized operating procedures, scientific formulas and manuals. It is also easily shared among individuals within or outside the organization. The latter is difficult to classify, it resides in the know-hows of individuals and it is linked to personal experience (Nonaka 1994). The ontological dimensions of knowledge are classified as individual and social knowledge. Individual knowledge resides into individuals whereas social knowledge transcends individuals and it refers to knowledge that resides within groups, organizations and even between organizations. The ontological dimensions represent the way knowledge can be disseminated throughout the different strata of an organization and transcend progressively beyond the boundaries of the organization.

Nonaka and Takeuchi (1995) depicted the process through which organizational knowledge is created by using a matrix, sometimes called the SECI model, that involves four sequential key activities of interaction between tacit and explicit knowledge: socialization (from tacit to tacit knowledge), externalization (from tacit to explicit knowledge), combination (from explicit to explicit knowledge) and internalization (from explicit to tacit knowledge). Through an iterative, spiral-like process, tacit knowledge is converted into explicit knowledge that, combined with new explicit knowledge, is finally internalized by the organization. This process does not stop once the activity of internalization has been performed, but continues by starting a new knowledge-creating spiral (see Fig. 1).

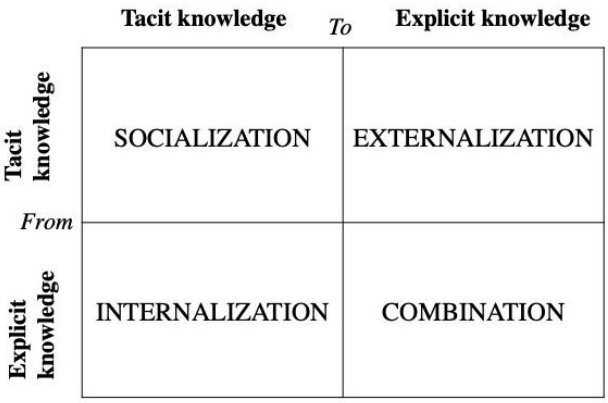


Fig. 1 The model of knowledge creation (adapted from Nonaka & Takeuchi 1995, pp. 57, 62, 71)

Socialization is the "process of sharing experiences and thereby creating tacit knowledge such as shared mental models and technical skills" (Nonaka and Takeuchi 1995). This activity of knowledge interaction requires that individuals share their experiences and knowledge without the use of language through imitation, observation and practice. Socialization is a

time-consuming process because individuals are supposed to spend time together, even through frequent physical proximity, and develop a relationship based on trust and empathy. Therefore, the core aspect of socialization is experience, as the mere transfer of information does not allow individuals to connect to each other to incorporate others' emotions and feelings and understand the specific context associated with the experience.

Externalization is the process of articulating tacit knowledge into explicit knowledge. "It is a quintessential knowledge creation process in that tacit knowledge becomes explicit, taking the shapes of metaphors, analogies, concepts, or models" (Nonaka and Takeuchi 1996: 837). This activity of knowledge interaction requires that individuals communicate with one another through dialogue or collective reflection. In comparison to socialization, where knowledge is shared through unstructured and loosely defined interactions, externalization is often supported by structured and formal organizational mechanisms such as meeting and collaborative work assignments (Nonaka et al. 2000). The core aspects of externalization are language and symbols because they enable individuals to create mutually understandable knowledge. Therefore, externalization allows "the individually held tacit knowledge concepts to be crystallized and shared with other members, creating new knowledge" (Byosiere and Luethge 2004: 246).

Combination is the process of combining different bulks of explicit knowledge. According to Nonaka and Takeuchi (1995), "reconfiguration of existing information through sorting, adding, combining, and categorizing of explicit knowledge can lead to new knowledge" (p. 67). Explicit knowledge is gathered from both inside and outside the organization and it is then disseminated among the employees of the organization. The use of technology can support the combination mode of knowledge creation as it facilitates the collection, synthesis and dissemination of knowledge from different sources and its transformation into outputs such as reports, documents and work rules that can be accessed from any part of the organization (Nonaka et al. 2000). Also the breakdown of knowledge can be considered a combination process. For example, breaking down corporate strategy into operational directions for the organization's functions is a way to create new explicit knowledge.

Internalization is the "process of embodying explicit knowledge into tacit knowledge" (Nonaka and Takeuchi 1995). Through internalization, explicit knowledge created at the organizational level is internalized by employees, thus becoming tacit knowledge. Learning by doing, exercises and training are different modes of knowledge internalization because they allow individuals to access newly created organizational knowledge and

identify the knowledge important for themselves. “In practice, internalization relies on two dimensions. First, explicit knowledge has to be embodied in action and practice. [...] Second, there is a process of embodying the explicit knowledge by using simulations or experiments to trigger learning by doing processes.” (Nonaka and Konno 1998: 45).

Past research proves that the process of new knowledge creation has a prominent role in affecting performance and, thus, contributing to develop or sustain the firm’s competitive advantage because knowledge is associated to innovative and difficult to imitate ways that enhance value creation for customers (Tsai and Lee 2007; Jiang and Li 2009; Chang et al. 2014). These studies mostly focused on assessing the effects of the combination of different sources of knowledge on performance. For example, Tsai and Lee (2007) demonstrated that the implementation of new venture strategies triggers the dynamic spiral of knowledge creation that facilitates the successful execution of these strategies to improve performance. Similarly, Chang et al. (2014) provided empirical evidence on the positive relationship between knowledge creation, innovation and creativity. Specifically, they found that knowledge creation enhances the ability of R&D personnel to develop products that include characteristics of novelty and that respond to customers ‘expectations, which in turn increases new product success. However, some scholars call for a better understanding of the process, not only the effects, of new knowledge creation (Gourlay 2006). To fill this gap, the present chapter investigates how knowledge is created by focusing on the context of operations management. In particular, the following sections will explore past literature to highlight the way two cycles of knowledge creation (new knowledge created by operational excellence and new knowledge created by Industry 4.0) are combined together.

3 Knowledge creation in operational excellence

Firms are increasingly implementing operational excellence techniques like JIT, TQM, Six Sigma and continuous improvement to reduce waste along the processes and enhance organizational performance. Literature highlights that knowledge creation and operational excellence are strongly connected. In fact, Deming (1994), one of the fathers of continuous improvement with his PDCA (Plan-Do-Check-Act) cycle, said that ‘‘best efforts and hard work, not guided by new knowledge, only dig deeper the pit we are already in’’ (p.1). Moreover, Linderman et al. (2004) argued “organizations can create more knowledge by deploying quality management practices that support each of the knowledge creation processes [i.e., socialization,

externalization, combination, internalization]. Since knowledge creation often leads to improvement, effective deployment of quality management should result in a set of practices that support each of the knowledge creation processes" (p. 601-602). Finally, Colurcio (2009) and Sin et al. (2015) reported that there is an iterative interaction between operational excellence and knowledge creation because, on the one hand, operational excellence implements practices that facilitate the conversion of tacit knowledge into explicit knowledge to create new knowledge and, on the other hand, knowledge creation develops mechanisms that facilitate the adoption of operational excellence.

There are at least two reasons in support of the argument that the use of operational excellence techniques is strongly associated with knowledge creation. First, operational excellence aims at developing employees' systematic problem solving behaviors to search for the root causes of problems and prevent errors to occur again. By adopting systematic problem solving behaviors, employees contribute to the change of organizational routines. A routine "is a repetitive, recognizable pattern of interdependent actions, involving multiple actors" (Feldman and Petland 2003: 96) that consists of an ostensive (the schematic form of the routine) and performative (the actual way the routine is performed by individuals in a specific place and time) aspect. Furlan et al. (2019) argued that when employees analyze the causes of a problem, compare different alternatives to identify the most adequate solution and, as a result, adopt actions, they modify the performative pattern of routines. These changes in organizational routines imply knowledge creation. Indeed, routines store knowledge that is embedded in organizational memory and, therefore, changes in routines modify, update or revise existing knowledge. Likewise, Linderman et al. (2010), drawing on the case study method, showed how Six Sigma enables knowledge creation. This study suggested that Six Sigma techniques enable employees to ask for the right questions and that, by getting the answers to the right questions, they created new knowledge. Moreover, newly created knowledge is shared among employees through organizational mechanisms such as meetings, teamwork and standardized practices that, in turn, positively affect systematic problem solving behaviors (Galeazzo and Furlan 2019). It is therefore confirmed that systematic problem solving behaviors, one of the most relevant micro-foundational elements of operational excellence, trigger activities of knowledge interaction and *vice versa*, thus reminding the knowledge creation process depicted by Nonaka and Takeuchi (1995).

Second, operational excellence fosters learning behaviors that, as an outcome, lead to the creation of new knowledge. Fine (1986) conducted one of the first researches on the relationship between quality improvement and

learning. He found that the quality-based learning curve decreases manufacturing costs over time. This finding suggests that quality-based experience creates a better understanding of cost reduction. The author also found that cost reductions only depend on quality-based learning and not on other types of learning (i.e., autonomous learning and induced learning). The importance of learning behaviors that arise from the adoption of operational excellence is confirmed by Choo et al. (2007). They showed that the adherence to structured methods linked to Six Sigma positively influences learning behaviors because structured methods define how to gather and process information in the most effective way. The development of learning behaviors, in turn, influences how information is interpreted and understood and it also shapes employees' thinking process, thus positively affecting knowledge creation. Moreover, Arumugam et al. (2013) empirically demonstrated that operational excellence provides technical support to leaders for coordinating activities that foster learning in teams through the coordination of activities that transform individual knowledge into team-level knowledge that, as a result, enhances performance improvements. Therefore, literature shows evidence on the importance of operational excellence in generating new knowledge by promoting learning at individual-, team- and organizational level that enables to reach the expected performance objectives, thus starting a new virtuous cycle of operational excellence, learning and knowledge creation.

4 Knowledge creation in Industry 4.0 technologies

Technology is crucial to the success of any organization. Past literature on knowledge management has shown evidence of the relationship between technology and knowledge creation. In their paper focusing on the model of knowledge creation, Nonaka et al. (1996) argued that "every business organization that wants to prosper in the knowledge society should fuse synergistically IT [i.e., technology] as knowledge-creation tools and human beings with collaborative knowledge creation capabilities to become a 'knowledge-creating company'" (p.217). Technology improves the efficacy of knowledge-based processes as it gives access to knowledge, fosters knowledge sharing, facilitates collaboration among employees, enables the articulation and codification of knowledge, speeds up innovation processes, creates opportunities to combine different competencies and capabilities (for example, using virtual environments), etc. (Arora and Gambardella 1994; Santos 2003; Vaccaro et al. 2009). Therefore, it is suggested that technology is a means through which knowledge creation flows.

The positive relationship between technology and knowledge creation is likely to be stronger in the era of Industry 4.0. The recent exponential development of Industry 4.0 technologies applied to manufacturing activities (i.e., additive manufacturing, advanced automation and advanced human-machine interface, Internet of Things - IoT, cloud manufacturing) leads technology to build a system of information and telecommunication technologies and industrial technologies that is more integrated and enables the operations function to become more information-led, digital and responsive to customers compared to the past (Lee et al., 2015). Industry 4.0 also changes the human-machine interaction because machines become increasingly autonomous and operators assume more responsibility, meaning their tasks are less related to mindless jobs. Instead, operators are asked to deal with a wide range of information that needs to be analyzed and take on the role of problem solvers to approach more complex problems (Gorecky et al. 2014). Therefore, Industry 4.0 develops highly intelligent and interconnected factories in which operate highly skilled workers, suggesting there is an increasing opportunity for implementing cycles of new knowledge creation.

For a better understanding of the positive relationship between Industry 4.0 and knowledge creation, examples on the use of Internet of Things and artificial intelligence are provided. Related to IoT, this technology enables objects to upload data previously sensed into a central processing facility that, in turn, instructs objects to take actions, responding intelligently to changes in the environment. Hence, it provides information on productive assets and enables workers to quickly make adjustments in the most effective way in order to optimize production performance (Freedman 2017). Compared to traditional factories in which sensors and devices have limited intelligence, the use of IoT ensures a more tight connection between physical and digital elements, a better communication and knowledge sharing and decentralized decision-making processes. Thus, IoT enables two activities related to new knowledge creation: on the one hand, the transformation of tacit knowledge, embedded in objects, into explicit knowledge, embedded in information processing facilities and, on the other hand, the internalization of explicit knowledge into tacit knowledge because workers, not their supervisors, have responsibility to make decisions based on the knowledge arisen from IoT technologies. Related to AR, this is a set of technologies that overlays digital data and images on the physical world, transforming volumes of data and analytics into images or animations. For example, wearable AR devices such as head-mounted displays or smart glasses allow workers to overlay digital information on real objects or environments (Porter and Heppelmann 2017). Using wearable AR, they can have easy access to instructions and detailed content about specific objects,

materials, machines or problems and, at the same time, they can capture information and store them in the company's servers. This means that AR allows workers to process the physical and digital world simultaneously, rapidly and accurately absorbing information, making decisions, and executing required tasks quickly and efficiently. Thus, AR enables three activities of knowledge creation: first, it supports the externalization of tacit knowledge into explicit knowledge by allowing workers to integrate their personal knowledge with knowledge coming from digital data; second, it facilitates the combination of different chunks of explicit knowledge encompassed in the physical and digital world; third, it promotes the internalization of explicit knowledge into tacit knowledge because workers, not their supervisors, have responsibility to make decisions.

5 The coordination of knowledge creation

The implementation of operational excellence-related practices requires a coordinated set of work activities eventually performed by operators with the use of some tools and/or machineries. The implementation of digital technologies also requires that a coordinated set of work activities are performed. As seen in previous sections, both operational excellence and digital technologies use knowledge and generate additional knowledge. A main objective for the firm is to manage the work flows related to operational excellence and Industry 4.0 in order to assimilate and possibly combine the knowledge created by these two work flows in the most effective way to improve performance. In order to reach this objective, how to coordinate knowledge management emerges as a central topic that needs investigation. Knowledge coordination is defined as the management of interdependencies among work activities (Holsapple and Joshi 2000). Therefore, it is important to understand the types of interdependencies between work activities.

Organizational literature and, in particular, theories on organization design, have defined task interdependence in different ways (Thompson 1967; Hickson et al. 1969; Van de Ven et al. 1976; Galbraith 1977; Shea and Guzzo 1989). For example, Johnson and Johnson (1989) have distinguished task interdependence from resource interdependence, which is defined as the extent to which operators have to share the necessary resources. Shea and Guzzo (1989) argued that operators exercise discretion over task interdependencies that are viewed as an attribute of the operator. Other scholars (e.g., Van der Vegt et al. 2000, 2001) distinguished between goal interdependence and task interdependence. They stated that task

interdependence depends on the way organizations design jobs and roles, thus affecting the division of information, materials, or expertise among operators. The degree of task interdependence typically increases as jobs become more complex and operators require others in order to reach the desired outcomes. For example, sales representatives operate almost independently from one another, whereas surgeons need great assistance from others to perform surgical operations. However, only Thompson (1967) explained how tasks can be designed to be executed at different levels of interdependence.

Thompson (1967) identified three patterns of task interdependence, each corresponding to a different degree of coordination between parts. Pooled interdependence is defined as a situation in which there is absence of workflow between parts. Each part acquires independent inputs and produces independent outputs that contribute to the whole organization. This implies that "each part renders a discrete contribution to the whole and each is supported by the whole"(p.54). In this case, each part performs activities separately and in any order, without any exchange between parts. The second form of interdependence is defined as sequential interdependence, representing the situation in which each part's outputs are the inputs of another part and similarly, the inputs that one part uses are the outputs from another part. This type of interdependence requires that parts perform activities in a specified sequence, implying there is an asymmetric exchange between parts. Finally, reciprocal interdependence represents a bidirectional exchange of inputs and outputs between parts, meaning that the activities performed by each part poses "contingency for the other" (p.55).

The greater the interdependence, the more organizational decision-making is constrained through commitments, rules and obligations, thus requiring higher coordination. With pooled interdependence, tasks are performed autonomously and coordination is achieved by standardization. This requires the implementation of routines and rules that define how and when each task should be performed and resources should be shared, thus minimizing the need for communication and decision-making among operators. With sequential interdependence, tasks are performed in sequence and coordination is achieved by plan. This implies the adoption of schedules for governing the workflow among operators. With reciprocal interdependence, multiple tasks are performed simultaneously and are strongly interconnected. In this case, coordination is achieved by mutual adjustment. Operators must continuously communicate to each other and give feedback in order to make adjustment whenever the expected objective becomes difficult to achieve.

Some scholars provided evidence of the existence of these types of task

interdependencies in different areas of research. For example, Galeazzo et al. (2014) drew on case studies on pollution prevention to demonstrate that lean practices and environmental practices can be implemented either sequentially or reciprocally. Compared to a sequential interdependence, a reciprocal interdependence of lean and green practices leads to higher operational performance. Krishnan et al. (2006) used a survey on international strategic alliances operating in India in order to investigate the relationship between inter-organizational trust and performance when partners share tasks at different levels. They found that alliances benefit more from trust when partners show reciprocal interdependence rather than pooled or sequential interdependence. Gully et al. (2002) studied the moderating effect of task interdependence on the relationship between team-efficacy (i.e., a team's belief on its ability to successfully perform a specific task), potency (i.e., a team's belief on its ability to successfully perform any type of task) and performance. Their results indicated that team-efficacy is more related to performance if task interdependence is high (reciprocal interdependence) whereas task interdependence did not moderate the relationship between potency and performance. Finally, Baumler (1971) provided evidence of the need to combine each type of interdependence with the respective coordination mode. For example, he showed that impersonal methods such as rules and routines were more frequently used with low task interdependence, and less frequently with high interdependence.

However, most areas of research have not highlighted the nature of task interdependencies between work flows related to different cycles of knowledge creation. To address this theoretical gap, the present chapter focuses on the knowledge created by operational excellence and Industry 4.0 technologies. Understanding task interdependence in this context is particularly important because it is not clear whether firms implementing the two sources of knowledge independently may accrue higher or lower benefits than firms implementing operational excellence and Industry 4.0 simultaneously. Therefore, the purpose of this chapter is to review past studies related to both operational excellence and Industry 4.0 and examine them using the theoretical lens of Thompson (1967)'s research on task coordination.

6 Methodology

We have adopted a structured approach to the literature search and analysis in order to synthesise the results from previous research in the field. Given the large number of papers published about Industry 4.0 in the last years, we deemed necessary to adopt a systematic approach to identify and analyse the

contributions that focused explicitly on operational excellence. Despite the large number of papers published on the emerging topic of Industry 4.0 there are few papers and specifically literature reviews addressing the interplay between operational excellence and Industry 4.0 technologies. Following Tranfield *et al.* (2003), the key steps in a systematic review include the planning phase, the undertaking of the review, and reporting and dissemination. In order to address our research question we conduct a systematic literature review identifying current state of academic research and contributions of the field. (e.g. Tranfield *et al.* 2003; Schulze and Bals 2018). This literature review systematically analyses existing literature, examining publications on Industry 4.0 and operational excellence published in English, peer-reviewed journals and conference papers listed in the Scopus database. There is a lot of information in conferences especially on such emerging topics that are not published in journals yet; therefore we included conference papers in our systematic literature review. The Scopus database was used because of its broader coverage. The literature review has been conducted in business, management and accounting journals. The keywords that were used for searching in article title, abstract and keywords fields were categorized into three groups:

- industry 4.0/intelligent manufacturing/smart manufacturing;
- internet of things/IoT/big data/artificial intelligence/AI/additive manufacturing/3D printing/cloud computing/collaborative robotics/augmented reality/virtual reality
- lean management/lean manufacturing/lean thinking/operational excellence/six sigma/quality improvement/just in time/JIT/continuous improvement/total quality management/TQM/Kaizen

Different combinations of these three groups were used to search for in the past literature in order to ensure that as many relevant articles as possible would be included. We tracked the papers until June 2019 when we conducted the search process.

The first stage of the search process generated 374 papers. The titles and abstracts of the papers within this initial sample were then checked manually for overall relevance. We removed duplicates and papers that were purely technical (e.g. about operational techniques in manufacturing) resulting in 60 potentially relevant papers. The relevance screening process of content of the papers, within the scope of relationship between operational excellence and Industry 4.0 technologies, further reduced the list to 30 relevant papers. We ended up (Fig. 2) with the 30 relevant papers from journals and conferences (Table 1) in the field that form the basis of our

systematic literature review.

Fig. 2 Systematic literature review process

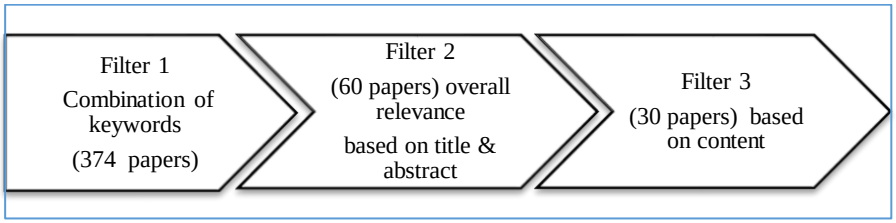


Table 1 shows the journals in which we identified relevant research papers and number of relevant papers in every journal. Highest number of papers is published in International Journal of Production Research, which is mainly reporting production and manufacturing research. Papers from conference proceedings are from International Conference of Industrial Engineering & Engineering Management, International Conference on Industrial Technology and Management, International Conference of Business Informatics Research, etc.

Table 1 Journals and number of papers identified for the final inclusion stage

International Journal of Production Research	10
Conference paper	8
Business Process Management Journal	1
Central European Business Review	1
IEEE Engineering Management Review	1
International Journal of Product Development	1
International Journal of Quality and Service Sciences	1
Journal of Cleaner Production	1
Journal of Industrial Engineering and Management	1
Journal of Manufacturing Technology Management	1
Journal of the Operational Research Society	1
Systems Research and Behavioral Science	1
Technovation	1
Total Quality Management and Business Excellence	1

6.1 Data analysis and coding

We built an Excel database that contains data for all 30 papers. This step was the starting point in conducting the analysis presented in the next section. Regular meetings of three researchers to evaluate and finalize the analysis followed the coding. We commenced the analysis of the papers by examining methodology and year of publication.

We categorized the papers based on their focus into 4 groups: (1) Industry 4.0 supports lean manufacturing; (2) lean manufacturing supports Industry 4.0; (3) complementary (4) no interdependence. Overall, our aim was to explore the relationship between Industry 4.0 and operational excellence.

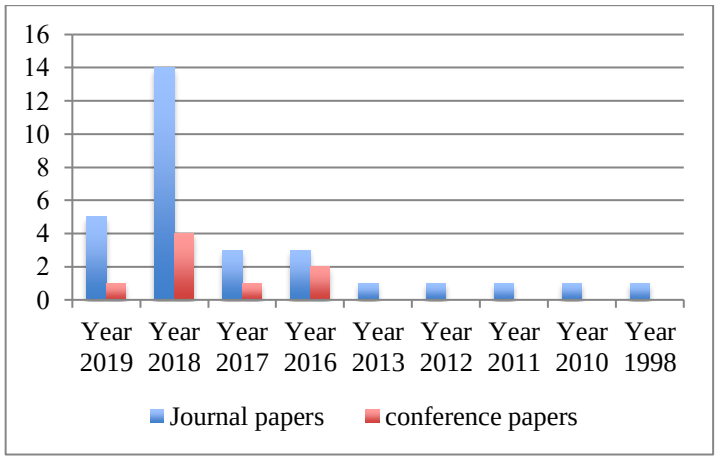
7 Findings

In the following section, we provide a general overview of the results of the analysis as a basis for understanding the research approaches that have been applied in the field.

7.1 Number of papers by publication year

Fig. 3 shows that there is an increase in the number of papers regarding this topic, especially in the last years. It is an emerging topic and together with published papers there are 8 relevant conference papers in the last years. In our list there are a couple of papers published before the emergence of industry 4.0 in literature, which were focused on specific technologies such as artificial intelligence (AI) and RFID (Proudlove *et al.* 1998; Brintrup *et al.* 2010).

Fig. 3 Number of papers by publication year



7.2 Relationship between lean manufacturing and Industry 4.0

Based on the focus of every paper we tried to extract any kind of relationship they have addressed between Industry 4.0 and lean manufacturing. Accordingly we allocated the papers under study into 4 categories; first category refers to Industry 4.0 technologies as enabler of lean manufacturing, second category refers to lean manufacturing lessons as enabler of Industry 4.0 improvement, third category refers to simultaneous implementation of Industry 4.0 and lean manufacturing and fourth category where importance of both Industry 4.0 technologies and lean manufacturing in order to achieve operational excellence has been acknowledged however there is no interdependence between the two. Table 2 shows the number of papers addressing each category.

Table 2 Number of papers addressing each category of relationship between Industry 4.0 and lean manufacturing

Category	Papers
Industry 4.0 supports lean manufacturing	14
Complementary	8
No interdependence	5
Lean manufacturing supports industry 4.0	3

We find the following for each of the four categories of papers; all papers under study in every category have been listed in Table 3.

1. *Industry 4.0 supports lean manufacturing* category is mainly regarding Industry 4.0 technologies that are supporting lean manufacturing. For example RFID-enabled real-time traceability enhance the implementation of advanced strategies such as just-in-time (JIT) lean (Huang *et al.* 2012). RFID technology is viewed as a vehicle to achieve leaner manufacturing through automated data collection, assurance of data dependencies, and improvements in production and inventory visibility (Brintrup *et al.* 2010). AI technology based on Big Data is expected to promote the widespread use of quality management (Hyun Park *et al.* 2017). Table 3 below shows the list of journal and conference papers included in this category.
2. *Lean manufacturing supports Industry 4.0* category refers to papers such as; Martinez (2019) stating Industry 4.0 is the next step after lean or other process improvement approaches. According to Beard-Gunter *et al.* (2019) there are positive implications merging good games design and TQM in socio-technic systems, which could improve engagement and quality in companies implementing in Industry 4.0.
3. *Complementary* meaning both lean management and Industry 4.0 support the objectives of operational excellence and they are stronger when being implemented together. Lean production practices are positively associated with Industry 4.0 technologies and their concurrent implementation leads to larger performance improvements (Tortorella *et al.* 2018). Not only can Industry 4.0 and lean thinking coexist but their integration can also provide benefits and opportunities (Demartini and Tonelli 2018). Industry 4.0 needs to be understood as digitally enabled lean. Industry 4.0 solutions can enhance operational excellence but they can also improve eco-efficiency (Szalvatez 2017). The interaction between Industry 4.0 and lean manufacturing needs to be considered as two sides of operational excellence because the former's purpose is speeding up flows of information and the latter's goal is eliminating waste to accelerate physical flows (Moeuf *et al.* 2018).
4. *No interdependence* category of papers is mainly literature reviews of the field, which don't necessarily focus on the relationship between Industry 4.0 and operational excellence, however they touch upon both topics. For example Yin *et al.* (2018) presented potential applications of lean principles for Industry 4.0 in the evolution of production systems from Industry 2.0 through Industry 4.0. Leyh *et al.* (2017) analyzes Industry 4.0 models with focus on lean production aspects.

Table 3 List of papers included in each of the four categories of relationship between lean manufacturing and Industry 4.0

Category	Author(s)	Focus
Industry 4.0 supports lean manufacturing	Urbinati et al. 2019	Quality management can be facilitated thanks to the quality records collected from the manufacturing processes.
	Makhanya et al. 2019 – Conference paper	In benchmarking QM maturity traditional approach has reached the end of its lifespan, Big data & impact of Industry 4.0 to be further investigated.
	Bertoncel et al. 2018	Digitalization helps to detect early warning systems at smart-factory, which is relevant to lean manufacturing.
	Trotta and Garengo 2018 – Conference paper	"Committing into Industry 4.0 makes a factory lean besides being smart", while Industry 4.0 is being seen as the possibility to implement the Lean Automation in the factories.
	Vogelsang et al. 2018 – Conference paper	Industry 4.0 became part of the strategic orientation. Digital integration eases quality management and leads to higher demands.
	Lugert et al. 2018	In general users appreciate a combination of Lean methods and solutions of Industry 4.0. This paper provides a current evaluation of the VSM from an exploratory perspective.
	Hyun Park et al. 2017	AI supports the development and production of a high-quality product. AI technology based on Big Data is expected to promote the widespread use of QM.
	Foidl and Felderer 2016 – Conference paper	Industry 4.0 provides promising opportunities for quality management. Explore research challenges of Industry 4.0 for providing promising opportunities for QM.
	Sanders et al. 2016	Industry 4.0 is indeed capable of implementing lean, committing into Industry 4.0 makes a factory lean besides being smart.
	Liu et al. 2013	A knowledge system for lean supply chain management (KSLSCM) has been developed using artificial intelligence system shells VisiRule and Flex.

	Huang et al. 2012	RFID-enabled real-time traceability enhance the implementation of advanced strategies such as just-in-time (JIT) lean.
	Zhang et al. 2011	RFID in augmented reality environment-Aiming at providing just-in-time information rendering.
	Brintrup et al. 2010	RFID technology is viewed as a vehicle to achieve leaner manufacturing through automated data collection, assurance of data dependencies, and improvements in production and inventory visibility.
	Proudlove et al. 1998	As a part of the LR: contribution of AI techniques to both product or service quality management issues, and maintenance management.
Lean manufacturing supports Industry 4.0	Beard-Gunter et al. 2019	There are positive implications merging good games design and TQM in socio-technic systems which could improve engagement and quality in companies implementing in Industy 4.0.
	Martinez 2019	Industry 4.0 is the next step after lean or other process improvement approaches. It is about having the system coordinated.
	Basios and Loucopoulos 2017 – Conference paper	The large amounts of data, especially in light of Industry 4.0, need to be organised so that organisation can understand what insights they need in order to take strategic and operational decisions. In order to achieve that Six Sigma DMAIC Enhanced with Capability Modelling approach has been introduced.
Complementary	Ren et al. 2019	It has been estimated that the combination of big data analytics and lean management could be worth tens of billions of dollars, in improved profits for large manufacturers.
	Tortorella and Fettermann 2019	Lean production practices are positively associated with Industry 4.0 technologies and their concurrent implementation leads to larger performance improvements
	Buer et al. 2018	Industry 4.0 supports lean manufacturing through 'Hard' practices, which refers to the technical and analytical practices used in lean like value stream mapping (VSM) and 3D printing.

	Demartini and Tonelli 2018 – Conference paper	Not only can Industry 4.0 and lean thinking coexist but their integration can also provide benefits and opportunities.
	Dallasega 2018	Reorganization is required, preferably through lean management principles. Industry 4.0 concepts can support and foster the reorganization of processes. Variety of Industry 4.0 concepts to address these problems. For example RFID technology allows gathering information about the construction supply chain (CSC) process in real time allowing for rapid response to unpredictable events.
	Szalavetz 2017	Industry 4.0 needs to be understood as digitally enabled lean. Industry 4.0 solutions can enhance operational excellence but they can also improve eco-efficiency, namely in the field of quality management (through smart production control, data analytics and predictive modelling solutions); process optimization (through capacity planning and production scheduling solutions); and product and process engineering (through advanced virtual technologies).
	Eleftheriadis and Myklebust 2016 – Conference paper	Understanding best practices through TQM methods towards zero defect manufacturing. Then, thanks to the implemented sensors and monitoring systems it is possible to provide a detailed documentation of any event occurred during the process named as Industry 4.0 or CPS.
No interdependence	Hannola et al. 2018	This paper proposes a conceptual framework for empowering workers in industrial production environments with digitally facilitated knowledge management processes.
	Yin et al. 2018	The evolution of production systems from Industry 2.0 through Industry 4.0. Potential applications of lean principles for Industry 4.0 are presented.
	Melnyk et al. 2018	The best of times and the worst of times in operations and supply chain management (OSM).
	Chang and Yeh 2018	About Industry 4.0 and the need for talent companies need talent in the areas of lean management, the Internet of Things (IoT), cloud computing, and big data.

	Leyh et al. 2018 – Conference paper	Lean management/lean production principles are not often addressed in Industry 4.0 models. Despite the fact that those aspects are often seen as a basis for Industry 4.0 implementation this is not integrated in the respective models nor is it discussed in connection with these models.

7.3 Research method

Fig. 4 shows that the most frequent methods are literature review (LR), systematic literature review (SLR) and conceptual studies (with 16 papers). For example the study by Hannola *et al.* (2018) identify logical conclusions on empowering production workers with digitally facilitated knowledge processes in the form of a conceptual framework. More specifically, the study links current concepts, presenting new perceptions and expansion of the existing view (Hannola *et al.* 2018; Gilson and Goldberg 2015). Followed by case studies (with 8 papers). For example Dallasega (2018) has collaborated with different engineer to order supplier companies to optimize their processes using Industry 4.0 concepts, some of the practices are outlined in the study.

Studies such as Szalvatez (2017) demonstrate the beneficial impact of advanced manufacturing technologies on firm's environmental performance, drawing on interviews conducted with 16 Hungarian manufacturing subsidiaries. Tortorella and Fettermann (2018) used data from a survey carried out with 110 Brazilian companies to examine the relationship between lean production practices and the implementation of Industry 4.0. As for the modelling methodology, Basios and Loucopoulos (2017) propose an approach referred to as Six Sigma DMAIC Enabled with Capability Modelling approach, by which requirements' can be considered from an operational and strategic perspective.

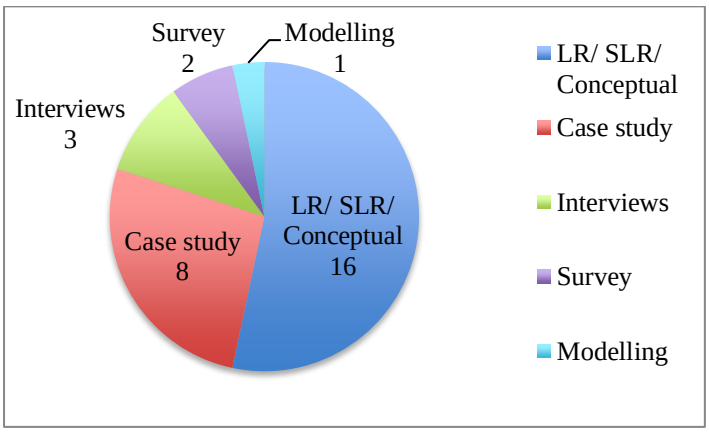
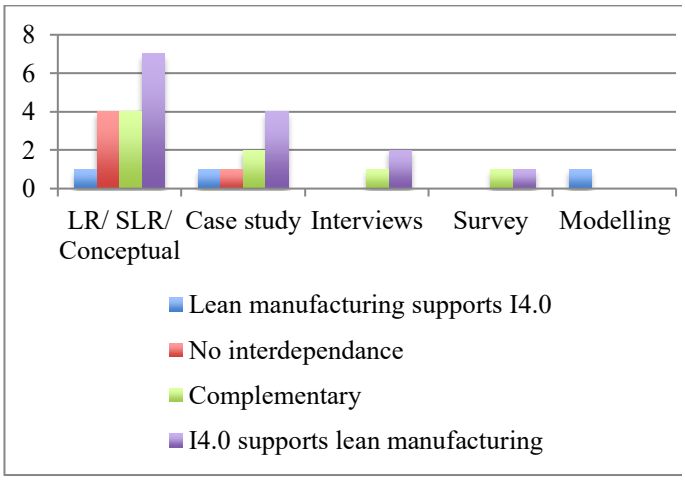


Fig. 4 Number of papers based on the method of research

Furthermore, we analyze how studies have used different methods. Fig. 5 shows the relations between categories of studies and applied

methodologies. It is clear from our SLR that the most common methodology used in the papers under study is LR/ SLR or conceptual method.

Fig. 5 Categories of papers and applied methodologies



8 Conclusion

The present chapter links together literature on knowledge creation (Nonaka 1994) and task coordination (Thompson 1967) to examine how the new knowledge stemming from Industry 4.0 and operational excellence is coordinated. According to the literature, new knowledge is created as a result of the recursive interaction of tacit and explicit knowledge that move through the steps of socialization, externalization, combination and internalization. When the recursive interaction of tacit and explicit knowledge involves multiple sources of knowledge such as Industry 4.0 and operational excellence, it is also important to take into consideration how these different sources of knowledge are coordinated. In particular, based on Thompson (1967), there are three possible ways of coordinating Industry 4.0 and operational excellence. First, they may be implemented separately. Second, Industry 4.0 and operational excellence may be implemented sequentially and the main issue is to understand whether operational excellence should be implemented before or after new technologies. Third, operational excellence and Industry 4.0 may be implemented together. Literature shows that the way activities are coordinated has profound implications on firm's performance (Barki and Pinsonneault 2005; Galeazzo et al. 2014) and can greatly impact the way these activities are managed as

well as their potential success. To investigate how operational excellence and Industry 4.0 are coordinated, we collect information on past studies focusing on both Industry 4.0 and operational excellence and approach them using the theoretical lens of knowledge creation (Nonaka 1994) and task coordination (Thompson 1967).

Our findings draw on a systematic literature review on 374 papers. After an accurate screening of these papers, only 30 were identified as relevant. We can assume that very few studies have focused on both operational excellence and Industry 4.0 literature, thus suggesting a lack of knowledge on this topic. Almost one third of the papers under study are conference papers, we believe this is due to the emergance and increasing demand of Industry 4.0 topic in academia. Also as shown in Figure 2 we observe increasing number of publications throughout the past years, which shows that the interplay between operational excellence and Industry 4.0 is an emergig area. Majority of the papers under study are LR/ SLR and conceptual, this finding calls for more empirical research in order to investigate different types of relationship between operational excellence and Industry 4.0.

The main finding of the present SLR shows that operational excellence and Industry 4.0 can be coordinated in different ways. Based on Thompson (1967)'s categorization of task coordination, we identified four categories.The first category includes papers arguing that Industry 4.0 supports operational excellence; implying Industry 4.0 technologies enable operational excellence. The second category includes papers arguing that operational excellence supports Industry 4.0; implying operational excellence enables the implementation of Industry 4.0 technologies. Both these categories suggest that Industry 4.0 and operational excellence should be coordinated sequentially because, as Thompson (1967) highlights, tasks have a sequential interdependence, representing the situation in which each part's outputs are the inputs of another part and similarly, the inputs that one part uses are the outputs from another part. This type of interdependence requires that parts perform activities in a specified sequence, implying there is an asymmetric exchange between parts. The third category includes papers arguing that Industry 4.0 and operational excellence complement each other, thus implying their coordination occurs simultaneously. This is in line with Thompson (1967) maintaining that the simultaneous coordination is associated with reciprocal interdependence between tasks. Reciprocal interdependence represents a bidirectional exchange of inputs and outputs between parts, meaning that the activities performed by each part poses "contingency for the other" (p.55). The fourth category includes papers arguing that, though their relevance is well acknowledged, there is no interdependence between Industry 4.0 and operational excellence. This

category is closer to pooled interdependence. Pooled interdependence is defined as a situation in which there is absence of workflow between parts. Each part acquires independent inputs and produces independent outputs that contribute to the whole organization. This implies that "each part renders a discrete contribution to the whole and each is supported by the whole"(p.54). In this case, each part performs activities separately and in any order, without any exchange between parts. Among the four categories, our literature review shows that most of the papers are in the first cateogy, i.e. Industry 4.0 supports operational excellence, suggesting there is a sequential interdependence between operational excellence and Industry 4.0. However, based on these findings, we can not rule out that the other three categories are not appropriate to describe the way knowledge created by operational excellence and Industry 4.0 is coordinated because of the few papers in our sample.

Finally, our findings highlight that not all Industry 4.0 technologies would support all operational excellence practices and *vice versa*. For example, Huang *et al.* (2012) and Zhang *et al.* (2011) view RFID technology as enabler in providing just-in-time information rendering and real-time traceability. In a study by Brintrup *et al.* (2010) RFID technology is viewed as a vehicle to achive operational excellence through automated data collection, assurance of data dependancies, and improvements in production and inventory visibility. Lugert *et al.* (2018) state that users appreciate a combination of operational excellence-related practices and solutions of Industry 4.0 and that experts request further development of the value stream mapping (VSM), the paper provides a current evaluation of the VSM from an exploratory perspective. Hyun Park *et al.* (2017) state that artificial intelligence (AI) supports the devolement and production of high-quality products and that AI technology based on big data is expected to promote the widespread use of quality management.

Future studies should further investigated the relationship between operational excellence and Industry 4.0 in future studies to provide support to our main findings. Another future avenue of reserach is to investigate the circumstances in which these interdependences work.

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