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# What does operational excellence mean in the Fourth Industrial Revolution era?

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**ABSTRACT**

Although the term Operational Excellence (OE) has been widely applied over the past few decades, its meaning is still ill-defined. This issue may be especially aggravated after the advent of the Industry 4.0 (I4.0), which introduces disruptive digital technologies that may help to overcome traditional barriers in operations management. This paper examines the concept of OE in the Fourth Industrial Revolution. For that, we conducted semi-structured interviews with experts from both academia and manufacturing companies, focusing on the shifts in OE's concepts implied by the I4.0 with regards to four key aspects (*people*, *partnerships*, *processes*, and *products and services*). Experts' responses had their content analysed through the lens of General Systems Theory, which allowed the formulation of propositions towards the conceptualization of OE in the digital transformation era. Our findings indicated that, although some attributes may remain the same, the emphasis of OE in the Fourth Industrial Revolution is likely to change. The extensive integration of digital technologies into manufacturing companies tends to entail different expectations in terms of excellence in *people*, *partnerships*, *processes*, and *products and services*. As interconnectivity and cyber-physical systems gain prominence, a more integrative and systemic perspective of OE is facilitated, expanding its meaning and understanding.

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## 1. Introduction

Industry 4.0 (I4.0) – or smart manufacturing (Kusiak 2018) – is the new paradigm for factories of the future, inducing remarkable improvements due to changing operative framework conditions (Lasi et al. 2014). I4.0 contributes to decentralized and simple structures over large and complex systems, while aiming for small and easily integrated modules with lower levels of complexity (Züehlke 2010; Tortorella et al. 2018). From a business perspective, I4.0 has been claimed as an approach for significantly improving performance through automation and digitalization. This performance improvement is enabled by higher levels of interconnectivity among people, products, processes, services and equipment, big data analytics, as well as both horizontal and vertical integration of value chains (Ghobakhloo 2018; Fatorachian and Kazemi 2018). Complementarily, researchers have envisioned I4.0 as a strategic framework that provides competitive advantages through the enhancement of operational performance, such as cost reduction, quality improvement, higher customer satisfaction, and shorter lead times (Bibby and Dehe 2018; Schroeder et al. 2019).

Such performance improvement corroborates the achievement of Operational Excellence (OE) (Chiarini and Kumar 2020). According to Asif et al. (2010) and Carvalho et al. (2019), OE is the execution of the business strategy more consistently and reliably than the competition. OE's scope goes beyond the traditional event-based model of improvement; it encompasses a long-term change in organizational culture. There are two main aspects that characterize companies in pursuit of OE: (i) systematic management of business and operational processes, and (ii) development of an organizational culture that supports the continuous improvement initiatives (Bigelow 2002; Sony 2019). OE is also denoted by an integrated performance across revenue, cost, and risk (Gólcher-Barguil, Nadeem, and Garza-Reyes 2019), focusing on meeting customer expectation through the continuous improvement of the operational processes and the culture of the organization (Burton and Pennotti 2003).

Significative efforts towards I4.0 have been observed in companies from a wide variety of sectors, such as manufacturing (Dalenogare et al. 2018), supply chain (Zekhnini et al. 2020; Núñez-Merino et al. 2020), healthcare (Tortorella et al. 2019a), public services (Gerrikagoitia et al. 2019), among others. Those efforts are motivated by the expectation that digitalization may lead

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companies to superior levels of OE (Drath and Horch 2014). Nevertheless, despite those initiatives, academics and practitioners still lack consistent knowledge about how the digital transformation implied by I4.0 is going to affect industries in the future (Fettermann et al. 2018). Furthermore, the integration of I4.0 disruptive technologies (e.g. cloud computing, Internet of Things – IoT, machine learning, etc.) may imply changes on the concept of OE, as it helps to overcome traditional barriers in operations management (e.g. data collection and management, end-to-end integration, among others). As highlighted by Found et al. (2018), although the term OE is widely applied, its meaning is ill-defined. This issue may be especially aggravated after the advent of I4.0. Previous studies on OE and I4.0 are not profuse. Some authors related those concepts in context of sustainable development goals (Quezada et al. 2017), circular economy (Dev, Shankar, and Qaiser 2020); knowledge creation (Miandar, Galeazzo, and Furlan 2020) and management (Bettiol, Di Maria, and Micelli 2020), Lean Six Sigma (Chiarini and Kumar 2020), and World Class Manufacturing (D'Orazio, Messina, and Schiraldi 2020). Nevertheless, the interplay between OE and I4.0 is still inconclusive. Based on these arguments, a research question arises:

> RQ. What does OE mean in the Fourth Industrial Revolution era?

To address this question, we performed an empirical research based on semi-structured interviews with senior managers from manufacturing companies and academics involved in this research topic. Because I4.0 is a contemporary phenomenon whose implications are still under investigation (Tortorella, Giglio, and Van Dun 2019b), a qualitative methodological approach was conducted, following Barratt et al.'s (2011) recommendations. The exploratory approach provided a better understanding of the investigated problem but did not necessarily lead to conclusive results. We focused on the shifts in OE's concepts implied by the I4.0 with regards to four key aspects (*people*, *partnerships*, *processes*, and *products and services*) (Dahlgaard and Dahlgaard-Park 1999). Data collected from the interviews was consolidated and analysed with respect to those aspects, and how their interrelationship has been changing with the increasing digitalization in manufacturing companies.

It is also worth emphasizing that this study was grounded on concepts from General Systems Theory – GST (Kast and Rosenzweig 1972; Skyttner 2005), which assume that a system is a cohesive conglomeration of interrelated and interdependent elements (product, process, service and people) influenced by its environment (i.e. industry digital transformation era). Using GST to frame this research allows a more holistic understanding of OE's concept in the Fourth Industrial Revolution era, avoiding biased or narrow definitions that could lead to misguided or myopic views. Such theoretical ground also contributes to comprehend the intricacies associated with the achievement of OE and its elements in organizations undergoing their digital transformation. GST also states that a goal (i.e. OE) can be achieved in many ways, and the proper understanding of system's elements elucidates the most effective means for achieving such goal. In this sense, our research led to propositions on the conceptualization of OE in the Fourth Industrial Revolution era, and how companies may pursue it in the upcoming years through the lens of GST. Such theoretical framing allowed the proper breadth that was needed to investigate our research problem.

The remainder of this paper is structured as follows. Section 2 establishes the background on the main concepts related to our study, i.e. the Fourth Industrial Revolution and OE. Section 3 describes the proposed research method, whose results are shown in Section 4 and further discussed in Section 5. Practical and theoretical implications of our research are drawn in Section 6, along with work limitations and future research opportunities.

## 2. Conceptual background

### 2.1. Fourth Industrial Revolution

An Industrial Revolution may be defined as a turning point in which there was a significant transition to new manufacturing processes supported by advances in science and technology, shifting their methods, organization and resources (Belvedere, Grando, and Bielli 2013). The First Industrial revolution is deemed as one of the most important advancements in humanity, starting in 1760 (Liao et al. 2018). It was underpinned by the utilization of water and steam-powered mechanical manufacturing facilities that enabled the large-scale production of goods and products, such as textiles (Allen 2009). In the late 1800s, the Second Industrial Revolution emerged with the application of electrically powered mass production technologies, which also implied the division of labour and rapid economic growth (Horn, Rosenband, and Smith 2010). Later, in the late 1960s, triggered by a more extensive use of electronics and information technology in manufacturing, the Third Industrial Revolution began. This industrial revolution was characterized by the automation of production processes and utilization of computers to support manufacturing management (Yin, Stecke, and Li 2018). More recently, in the Hannover Fair in 2011, the term I4.0 was firstly introduced to symbolize the beginning of the Fourth Industrial Revolution (Liao et al. 2017; Tortorella and Fettermann 2018; Rossit, Tohmé, and Frutos 2019). I4.0 usually consists of many complex components applied in a wide range of industries. It represents the current automation and digitalization trend that has evolved from embedded systems to cyber-physical systems, resulting in higher modularity and flexibility for mass customized production contexts (Landscheidt and Kans 2016; Tortorella et al. 2020a; Ciano et al. 2021). I4.0 has been claimed a promising technology-driven approach that integrates people, processes, products and services at both intra – and inter-organizational levels (Xu, Xu, and Li 2018; Rosin et al. 2020).

The feasibility of an effective digital transformation across a wide variety of manufacturing sectors and socioeconomic contexts has motivated discussions among researchers, government, institutions and organizations (Kipper et al. 2020). I4.0 encompasses disruptive information and communication technologies whose full adoption requires certain elements, such as a highly skilled labour (Tortorella et al. 2018; Ivanov et al. 2020) and intensive levels of capital expenditure (Raj et al. 2020). These elements may impair a broader digitalization of manufacturers, limiting I4.0's pervasiveness. In opposition, recent developments and technological advances have been enabling a viable array of solutions (e.g. digital workplace cyber security, and end-to-end digital transformation services) to the growing needs of digitalization in manufacturing industries (Xu, Xu, and Li 2018; Buer, Strandhagen, and Chan 2018). These can facilitate the emergence of new improvement opportunities for organizations (Hecklau et al. 2016; Pagliosa, Tortorella, and Ferreira 2019; Gupta, Modgil, and Gunasekaran 2020).

According to Frank, Dalenogare, and Ayala (2019), digitalization implied by I4.0 has followed a pattern based on the integration of a few base-technologies (e.g. cloud computing, Internet of Things, big data and machine learning) into products, processes and services. This is leading companies to new business models (Weking et al. 2020; Stentoft and Rajkumar 2020) supported by innovative value chain management practices (Tortorella et al. 2020b), which, supposedly, increase organizational performance to superior levels. Complementarily, as the I4.0 readiness level may vary among companies (Moeuf et al. 2018), industry digital transformation must be seen as a transformational process in which individuals, teams and organizations continuously learn from it as they advance (Belinski et al. 2020; Tortorella et al. 2020c). We argue that the conceptualization and, hence, achievement of OE in this evolving digitalization scenario may shift, which has motivated this investigation.

### 2.2. Operational excellence and GST

According to Soto (2017), although usually overlooked, the appropriate definition of OE is the first step in an organization's journey to industry-leading performance. A key reason why industries fail to attain OE is due to a lack of its full understanding (Fok-Yew and Ahmad 2014; Kulkarni, Verma, and Mukundan 2019). In this sense, a measurable and actionable conceptualization of OE is important to align the organization around a new way of doing business and focus it on results achievement (Roth, Deuse, and Biedermann 2020). In their seminal text, Treacy and Wiersema (1995) defined OE as the strategy for organizations endeavouring to concurrently deliver quality, price and ease of purchase, and service, at levels which competitors cannot match. Later, Dahlgaard and Dahlgaard-Park (1999) proposed an OE definition based on 'the 4Ps': (i) people, which emphasizes that excellence cannot be achieved without employees' buy-in; (ii) partnerships, which refer to both internal (departments) and external (customers, suppliers and society) collaboration; (iii) processes, which relate to the key business and management processes to deliver value to customers; and (iv) products (and services), which are able to exceed customer expectations.

OE reinforces a set of interrelated principles and practices that facilitate the continuous improvement of an organization, adapting and managing them in search of sustainable organizational results (Carvalho et al. 2019; Henrique et al. 2020). However, according to Found, Samuel, and Lyons (2017), there is a lack of clarity on the critical interdependence of those principles and practices of OE. Such gap is somewhat aligned with indications from GST of mutuality (Caws 2015), which suggests that there may not be a universal roadmap to achieve OE. OE relies on consistently and reliably implementing actions, and not on making strategic decisions (Gólcher-Barguil, Nadeem, and Garza-Reyes 2019). Nevertheless, the proper combination between an effective strategy and OE results in industry-leading performance (Soto 2017).

Different improvement approaches have been associated with OE. Concepts derived from Lean Manufacturing, Total Quality Management, Reengineering, Supply Chain Management, Six Sigma, and Statistical Process Control were traditionally applied to achieve OE (Bigelow 2002; Basu 2004; Oakland 2014; Mangla et al. 2020). The adoption of practices inherent to those approaches has extensively contributed to the enhancement of organizations in the last decades, being acknowledged as 'requirements' for OE (Asif et al. 2010; Found et al. 2018; Buer et al. 2020). More recently, those continuous improvement practices have been complemented or supported by the integration of new digital technologies, which tend to lead organizations to superior patterns of performance (Tortorella and Fettermann 2018; Bittencourt, Alves, and Leão 2021). Nevertheless, most digitally enabled improvement practices are tailored solutions owned by private companies (Kolberg, Knobloch, and Zühlke 2017), resulting in a shallow view of how this digitalization can impact OE (Kamble, Gunasekaran, and Dhone 2020).

Previous studies (e.g. Bigelow 2002; Burton and Pennotti 2003; Carvalho et al. 2019) indicated that OE may be catalyzed by a few enablers, favouring a successful journey. Theadore, Jr, and Anderson (2010), for instance, listed four critical success factors to pursue operational excellence; they are: (*i*) the vision of the organization must reflect its desired future state; (*ii*) people must be fully involved; (*iii*) the processes performance should operate in order to fulfil the stakeholders' requirements, and (*iv*) the technology is the enabler that allows people to accomplish systematic processes efficiently and effectively. Although there are commonalities among researchers in terms of those critical success factors for OE, Found et al. (2018) and Gólcher-Barguil, Nadeem, and Garza-Reyes (2019) highlighted that their interrelationship might impose nontrivial implementation challenges, and research on this regard has not yet received adequate attention. Therefore, attaining OE implies the actual execution of broadly applicable and interdependent practices and principles, as opposed to concepts and principles specific to one domain of knowledge, building on GST's concept of equifinality (Caws 2015).

Besides the definition of measurable aspects of OE, it is relevant to highlight other characteristics. The understanding of excellence is relative and can change over time (Found et al. 2018). Attributes and performance results that once stood for excellence may not represent it today. As management practices, technologies and market requirements evolve, operational standards tend to shift the perception on those attributes and performance results (Shingo 2014; Sartal and Vázquez 2017). Schonberger (2015) reinforces this by arguing that management terms have a lifecycle of approximately 20 years, presenting an 'S curve' shape. Such transient nature of OE is aligned with GST's principle of boundaries, which indicates that for systems that learn and adapt, the growth and the degree of adaptation depend upon how well the system is engaged with its environment (Skyttner 2005; Luhmann, Baecker, and Gilgen 2013). In other words, organizations that seek OE must evolve their understanding of OE so that they can adapt and lead in the current digitalization era. Furthermore, OE is truly observed when there is an integrated performance improvement among different indicators (Moktadir et al. 2020). The path to OE is less about balancing the potential tradeoffs between performance indicators, and more about a systematic approach that leads to gains across all of them (Bigelow 2002; Burton and Pennotti 2003; Soto 2017). This integrative view of OE is somewhat underpinned by the GST assumption of holism, which state that changing one part of a system may affect other parts or the whole system (Hammond 2010). Based on these arguments the pathway to OE achievement and its intrinsic characteristics can be highly related to GST's principles (Von Bertalanffy 1993), e.g. holism, boundaries, hierarchy, mutuality, equilibrium, equifinality and entropy, providing a solid theoretical foundation on which we can build our study analyses and propositions.

## 3. Research method

As impacts of I4.0 on OE conceptualization are still unknown, a qualitative approach was carried out corroborating to the exploratory and descriptive nature of our study (Voss, Tsikriktsis, and Frohlich 2002; Barratt, Choi, and Li 2011). Following Ketokivi and Choi (2014), the study used *a priori* theorization to frame the research design; findings are therefore not statistically generalizable. That offered an in-depth understanding of the conceptualization of OE in the Fourth Industrial Revolution era, producing novel insights to the field.

The methodological design consisted of three main steps: (i) definition of selection criteria; (ii) interviews with experts; and (iii) content analysis and propositions. These steps are detailed next.

### *3.1. Definition of selection criteria*

The following criteria were established to select interviewees. First, because we wanted to confront theoretical and practical perceptions on the subject, we involved both academics who have investigated OE for at least 10 years, and experienced practitioners (i.e. minimum of 15 years of experience) who have played key leadership roles (e.g. manager or director) in large-sized manufacturing companies. The combination of different perspectives would enable a wider understanding of our research problem. Second, specifically for practitioners' selection, they should work for manufacturing companies that have consistent digitalization initiatives, either on shop floor or supporting processes. Third, since we aimed to conceive a generalizable understanding of OE, regardless the contextual factors that may influence experts' perceptions, we sought academics and practitioners from different nationalities. As digitalization may entail different challenges (e.g. high capital

**Table 1.** Interviewees' profiles.

| Expert | | Experience | Country | Role | Organization characteristics [a,b] |
|---|---|---|---|---|---|
| Academics | $E_1$ | 10 years | Chile | Associate Professor in Industrial Engineering | Large private university ranked among the top two hundred in the world |
| | $E_2$ | 26 years | Brazil | Associate Professor in Industrial Engineering | Large private university ranked among the top seven hundred in the world |
| | $E_3$ | 14 years | U.S.A. | Associate Professor in Operations and Supply Chain Management | Large public university ranked among the top five hundred in the world |
| | $E_4$ | 16 years | Italy | Associate Professor in Systems Engineering | Large private university ranked among the top two hundred in the world |
| | $E_5$ | 22 years | Argentina | Full Professor in Operations Management | Large private university ranked among the top four hundred in the world |
| | $E_6$ | 11 years | China | Full Professor in Industrial Engineering | Large public university ranked among the top six hundred in the world |
| Practitioners | $E_7$ | 22 years | Mexico | Continuous Improvement Manager | Large multinational metal-mechanics manufacturer |
| | $E_8$ | 25 years | Brazil | Facility and Maintenance Manager | Large multinational automotive manufacturer |
| | $E_9$ | 24 years | U.S.A. | Supply Chain Manager | Large multinational electronics manufacturer |
| | $E_{10}$ | 18 years | U.K. | Manufacturing Director | Large multinational food manufacturer |
| | $E_{11}$ | 15 years | Uruguay | Plant Manager | Large multinational auto parts manufacturer |
| | $E_{12}$ | 12 years | Germany | Continuous Improvement Manager | Large multinational tobacco manufacturer |

Note: [a]University with more than 15,000 students.
[b]Manufacturer with more than 500 employees.

expenditure and skilled labour) for companies located in either emerging or developed economies (Tortorella et al. 2019c), our expectation was to identify certain variation in interviewees' opinions. To mitigate the potential bias existing in interviewees' responses, we cross compared their opinions based on their respective socioeconomic contexts (emerging or developed economies). We considered arguments that were equally mentioned by experts and avoided utilizing the ones that were clearly associated with the socioeconomic context in which the expert is inserted. Two of the authors individually analysed interviews' transcripts in order to increase the reliability and mitigate biased findings.

Finally, by using authors' network, 12 experts (six academics and six practitioners) were identified and invited to participate in the research. Their profiles are summarized in Table 1. Experts presented fairly well-balanced characteristics in terms of experience, socioeconomic context (emerging and developed economies), and roles, meeting the pre-determined selection criteria and ensuring the quality and legitimacy of their opinions, as recommended by Shetty (2020).

The data collection method that helped to achieve the shape of interviewees in Table 1 was also based on theoretical sampling. According to Corbin and Strauss (2008, 143), its purpose is to 'collect data from places, people, and events that will maximize opportunities to develop concepts in terms of their properties and dimensions, uncover variations, and identify relationship between concepts'. The difference of theoretical sampling from conventional methods of sampling is that it is responsive to the data rather than established before the research begins, i.e. it is about discovering relevant concepts and their properties and dimensions.

Additionally, previous qualitative studies (e.g. Guest, Bunce, and Johnson 2006; Fugard and Potts 2015; Braun and Clarke 2016; Boddy 2016) have recommended a minimum sample size of at least twelve to reach data saturation among a relatively homogeneous population, which matches with our sample size. Other studies used an even lower number of experts to collect data. Agarwal, Shankar, and Tiwari (2006) compared the performance of lean, agile, and 'leagile' supply chains based on interviews with five experts. Tortorella and Fogliatto (2014) used the opinion of six experts to indicate the relationship intensity between Lean Production implementation phases and Organizational Learning problems. Sant'Anna et al. (2017) used 10 experts to score the relationship between lean and green practices at a supply chain level. Thus, we claim that our sample size was large enough to describe the phenomenon of interest and address the research question at hand, avoiding repetitive data, and attaining theoretical saturation (Vasileiou et al. 2018). Experts accepted to join the interviews after receiving a consent form and a plain language statement, in which they were informed that their participation was voluntary, and any information provided would be kept anonymous.

### 3.2. Interviews with experts

Data was collected through online interviews during the first half of October 2020. Individual interviews followed a semi-structured protocol of questions (see Appendix) that allowed open answers. Questions were grouped into three parts. The first part comprised the professional background of interviewees. The second part sought information on their understanding of OE concepts previous to the formal advent of I4.0. More specifically, this part focused on OE's conceptualization in manufacturing companies during the period of the Third Industrial Revolution (i.e. between 1970 and 2010 approximately). The last part encompassed questions on how they perceived that those OE concepts would evolve during the Fourth Industrial Revolution (i.e. after 2011).

Data analysis was completed during the second half of October 2020. Interview coding, cross-interview analysis, and fact checking were adopted to interpret data. All interviews were audio-recorded and followed the same sequence of questions, lasting from 45 to 75 min. No ideas from earlier interviews were introduced into subsequent ones, as recommended by Guest et al. (2017). Interviews were attended by at least two of the authors, thus increasing the ability to handle contextual information confidently (Dubé and Paré 2003).

Information was transcribed and subsequently analysed and discussed by the authors; summaries were then merged after reaching consensus on the main findings (Miles and Huberman 1994). To code our findings, we used excerpts from the transcripts and interpreted the information obtained from interviews. This produced a narrative made up of the transcriptions plus ideas and insights. Idiosyncratic responses were disregarded in the interest of focusing on dominant patterns among interviewees. All aspects of those research design choices were made to reduce the subjectivity.

### 3.3. Content analysis and propositions

In this step, we performed a content analysis of information gathered in interviews to develop a chain of evidence (Carter et al. 2014) that supported the formulation of propositions for theory testing in future studies. Information was grouped into four broad categories: (i) *people*, (ii) *partnerships*, (iii) *processes*, and (iv) *products and services*. The propositions stressed the OE concepts in the Fourth Industrial Revolution era according to seven principles of GST (Von Bertalanffy 1993), namely:

(a) Holism: which states that the whole is greater than the sum of its parts;
(b) Boundaries: which indicates that systems regulate what may pass between them and the environment;
(c) Hierarchy: which says that every part must obey the rules of any whole to which it belongs;
(d) Mutuality: since parts are interdependent, it is impossible to know what causes something;
(e) Equilibrium: systems tend to seek a steady state between forces that are strongly opposed to one another;
(f) Equifinality: there is more than one way to get from here to there; and,
(g) Entropy: unless checked, systems tend to fall into disrepair.

Having described the research methods and procedures, attention is turned to the core results provided in the following section.

## 4. Results

This section reports the insights on OE's aspects derived from the interviews, whose main perspectives and viewpoints are displayed in Table 2. Regarding *people*, experts emphasized that during 1970 and 2010 most manufacturing companies have sought the implementation of people-oriented continuous improvement approaches, such as Total Quality Management and Lean Production. Those approaches encompassed the implementation of principles and practices that were supposed to change the way processes were performed. Nevertheless, a long-term, successful implementation depended on employees demonstrating behaviours and mindsets that corroborated to its sustainability, which was emphasized by $E_4$ and $E_{12}$. To achieve people excellence, experts indicated that previously to I4.0 companies almost exclusively relied on employees' training and development to entail behavioural changes that would support processes improvement. With the advent of I4.0, large amounts of data are now available, and people are still learning how to manage them. Regardless the role within the company, data will be prolific and the issue becomes what people do with it. In other words, experts suggested that people's behavioural change should not be the focal point anymore, but the consequence of how data is perceived and managed. As stated by $E_1$

> Now, it is about making people understand how to perceive the reality through data, and what they can do with it. People must learn how to use data to support their decisions and, hence, behaviors.

Another comment that came up consistently in the interviews was related to roles, responsibilities and work relationships. Before I4.0, roles and responsibilities

**Table 2.** Experts' main comments on the OE's aspects before and after the advent of I4.0

| Aspect | Before I4.0 (1970-2010) | After I4.0 (post 2011) |
|---|---|---|
| People | 'There has been a great focus on people development and training. People should demonstrate the expected behaviors to support processes. Continuous improvement approaches, such as lean production and total quality management, were very much people-oriented, and companies have invested a lot in training their employees in such practices and concepts'.'We have fostered a clear division in roles and responsibilities among people and departments, so that people could become experts in what they did. Although there were some initiatives to integrate them (i.e. people from different departments), we were aware about the existence of silos. Very few people in the company had a clear idea of the actual implications of their activities upstream or downstream the flow of value. In other words, people were used to neglect the value of such horizontal integration'. | 'Leaders may need to adapt their style to achieve people excellence in the Fourth Industrial Revolution, as employees tend to require more flexibility and be multi-taskers. This will be particularly noticed as new generations of employees (e.g. millennials and post-millennials) become the majority of the labour force. They are the 'children of technology' and may set their working expectations accordingly'.'Regardless the digitalization level, people still remain important. However, the integration of disruptive technologies (e.g. machine learning and collaborative robots) will allow working remotely and avoid repetitive tasks. As such, people's role and responsibilities are going to change. They will be more frequently required to think and solve complex problems. For that, skills such as creativity and systems thinking will be highly valued'. |
| Partnerships | 'There were some truly collaborative initiatives. However, partnerships were mainly established based on commercial agreements and negotiations where price and cost were the language. This raised a trade-off between cost reduction and other criteria for partnership establishment, such as quality, logistics, environmental impact and local communities' development'.'Commercial contracts explicitly established businesses boundaries and responsibilities. Every agent from the supply chain had very clear roles and should know exactly what was expected from them. However, it was still very difficult to understand the implications of one's decision to the whole supply chain'. | 'Although the financial side is still an important element, partnerships are more likely to be developed to complement the value delivery to the end customer. As supply chains become more complex and diversified, digitalization will allow the entrance of new partners that can shortcut some tiers by providing innovative win-win solutions'.'The extensive utilization of omni-channels supported by information and communication technologies, such as augmented reality and mobile applications, are going to drive better relationships between customers and suppliers. Since customers' experience is enhanced, this may lead to competitive advantages, changing the traditional structure of supply chains while challenging for more pervasive and customized distribution channels'. |
| Processes | 'Manufacturing processes were aimed to be linear, so that flow management would be enhanced, and problems/deviations easily identified. Explicit flow standards were in place, setting clear expectations with regards to where parts should be'.'Computer integrated manufacturing allowed processes to be more automatized and productive. This automation would mitigate ergonomics issues and allow employees to watch more than one machine. However, information and data collection mostly relied on employees' ability to precisely collect and share with their teammates and leadership'.'Technologies integrated into manufacturing processes (e.g. robots, sensors, automatic quality inspections, etc.) were mainly oriented to the material flow. We have seen companies investing heavily in the physical automation of their production lines, to the point that a 'best-in-class manufacturing process' should work independently'. | 'Due to higher customization levels, manufacturing processes are less likely to be linear. Instead, to meet customers' requirements, manufacturers will shift to fuzzy material flows (i.e. there may be different productive routes), whose scheduling, control and inventory management will occur in real-time supported by technologies such as Internet-of-Things, cloud computing and big data analytics'.'In the Fourth Industrial Revolution era, we may see process excellence not only from a material flow perspective. The focus of digital technologies integration into manufacturing processes is likely to be on information flow as much as on the material. Excellent processes will be the ones that are reliable and flexible in terms of both the material and information flows'.'Highly interconnected processes will contribute to a more proactive production management. To support that, the working procedures and routine of administrative processes (e.g. scheduling, logistics, commercial, finance, etc.) must be changed so that decisions can be taken more frequently. Otherwise, we will be collecting information in the Fourth Industrial Revolution but managing processes like we used to do in the Third one'. |
| Products and Services | 'There was a clear distinction between what a company offered as a product and the services provided. One was not necessarily related to the other, and improvement initiatives on those were addressed separately'.'Although servitization was already known, manufacturers heavily relied that their competitive differentiation was mostly on the products they offered. In general, little attention has been given to services integration into products, and the existing technologies at that time would not favor this either'.'Products were engineered and properly designed to become more appealing to customers, so that they felt they had to own/consume it'. | 'The incorporation of novel digital technologies into products facilitates the establishment of new services that increase product's attractivity to customers. Take fridges, for example. They are now capable of collecting data on their utilization so that maintenance checks could be performed remotely. This is more appealing to customers'.'Now, customers perceive products as an experience and services integration has a key role for that. Innovative information and communication technologies will enable the digital integration between them, raising customers' expectations and developing new markets'. |

were supposed to be clearly established, avoiding functional overlaps and aligned with the department's scope. Although experts $E_1$, $E_6$, $E_8$, and $E_{11}$ acknowledged that some integrative and collaborative initiatives were conducted, the division of labour, which is a legacy of the Second Industrial Revolution, was still very prominent in many companies and somewhat implicitly fostered. In the Fourth Industrial Revolution, such labour division is expected to be less pervasive, as the integration of novel information and communication technologies (e.g. IoT, machine learning and cloud computing) becomes more extensive. Employees are more likely to be multi-taskers focusing their attention on non-repetitive activities, since machines are going to oversee the repetitive ones. In such scenario, departmental boundaries and steady role scopes will make less sense, giving rise to new working environments (e.g. working remotely and leadership style) and relationships (e.g. legal requirements and flexible hours). This is also aligned with the values and beliefs of the upcoming workforce generation denoted as post-millennials, who understand digital technologies as part of the *modus operandi* (Okros 2019). Experts $E_2$ and $E_{10}$ highlighted that leaders of this generation must learn how to cope with these generational characteristics to successfully achieve OE, which was not an evident concern in leadership that preceded I4.0.

In terms of *partnerships*, two points were commented on by most of the interviewees. The first one referred to the way supply chains were developed. Until the Third Industrial Revolution, most customer-supplier relationships were framed on commercial agreements, whose decision criterion was almost exclusively related to price. As argued by $E_9$

> In the last two decades, we have witnessed a strong movement within companies in relation to choosing their suppliers and partners from low-cost countries, despite other negative effects those decisions may imply.

With the digitalization of manufacturing companies, experts understand that those partnerships may transcend the purely commercial interests. As the complexity level of supply chains increase, digitalization may enable the rise of new partners that can co-deliver value to customers by providing solutions that can mitigate such complexity. An example is the role of retailers in supply chains. Customers are more frequently buying products and goods through mobile applications or websites that are managed by third parties, reducing the importance of retailers and, hence, simplifying the value chain. Similar to what was observed for *people*, the second point on *partnerships* concerned the roles of partners in supply chains. Before I4.0, when the available information and communication technologies did not provide enough support for higher levels of interconnectivity and vertical integration throughout the supply chain, suppliers, customers and stakeholders were forced to establish clear boundaries and responsibilities. This was necessary to properly controls and ensures that value would be delivered according to end customers' expectations in an efficient way, as highlighted by $E_5$. As those technologies become more inexpensive and advanced, true supply chain integration is more likely to occur and the previously rigid roles may become meaningless. Furthermore, the extensive utilization of technology-driven omni-channels would enhance such partnership trend, as indicated by $E_3$ and transcribed in Table 2.

With respect to *processes*, experts claimed that flow linearity has been an attribute widely valued in manufacturing processes. This facilitated production management and improvement, since the identification of abnormalities and deviations would be much easier. In this sense, shop floors were mostly designed according to this concept, minimizing alternative routes. Such flow characteristic also favoured higher levels of physical automation (e.g. robots, automatic conveyors, etc.), which supposedly increased productivity and mitigated ergonomics issues. With the introduction of new information and communication technologies, some of those concepts are envisioned to change, so that manufacturing processes can meet the upcoming trends in customers' requirements. For instance, content analysis from experts $E_2$, $E_{9,}$ and $E_{10}$ suggests that higher levels of product and service customization are expected. Meeting such expectations requires even more flexibility from manufacturing processes, implying more variety of production routes and process flows. This trend may lead to fuzzy material flows whose scheduling, control, and inventory management will only be effective with the proper support of disruptive information and communication technologies (e.g. IoT, machine learning, big data, and cloud computing). Moreover, a concern was observed regarding not only the productive processes, but also the administrative ones that support manufacturing (e.g. logistics, finance, and sales). As I4.0 enables real-time data collection, manufacturing companies can more easily and proactively identify and address issues (Dalenogare et al. 2018). For that, the way administrative processes are managed must also be changed so that the decision-making can keep up with the speed with which information is collected, as suggested by $E_4$ and $E_8$.

Finally, concerning *products and services*, experts indicated that, although some servitization initiatives were already evidenced, most companies used to address improvement opportunities separately. In other words, the benefits from integrating products and services were not fully acknowledged. Most manufacturers solely relied on their products to obtain competitive differentiation, neglecting the importance of services. With the I4.0 technologies, services may be embedded into products so that new market opportunities may arise. Moreover, until the Third Industrial Revolution, products were designed primarily to increase their attractiveness and functionality to the point that customers wished to own them. In the Fourth Industrial Revolution, customers see products as an experience. For this, pre- and after-sales services play a fundamental role to ensure customers' expectations are met. Indeed, digital technologies will support the integration between products and services, enhancing such customer experience. Emerging digital technologies

**Table 3.** Summary of the perceived OE's aspects before and after I4.0.

| Aspect | Before I4.0 (1970-2010) | After I4.0 (post 2011) |
|---|---|---|
| People | - Focus on people development<br>- Behaviours support processes<br>- People-oriented approaches<br>- Clear division in roles and responsibilities<br>- Neglect of horizontal integration | - People remain important<br>- Employees are multi-taskers<br>- Requirement of more flexibility and remote work<br>- Aversion to repetitive tasks<br>- Contingent roles and responsibilities |
| Partnerships | - Established based on commercial agreements<br>- Price and cost are the priorities<br>- Trade-off between cost reduction and quality, logistics, environmental impact and local communities' development<br>- Clear businesses boundaries and responsibilities<br>- Every agent from the supply chain has a clear role | - Finance is still important<br>- Partnerships complement the value delivery to the end customer<br>- Digitalization allows the entrance of new partners short-cutting tiers<br>- Extensive utilization of omni-channels supported by technologies<br>- Enhanced customers' experience<br>- More pervasive and customized distribution channels |
| Processes | - Linear manufacturing processes<br>- Explicit flow standards and expectations<br>- Search for automatized and productive processes<br>- Information and data collection relied on employees<br>- Technologies oriented to the material flow | - Fuzzy manufacturing processes<br>- Scheduling, control and inventory management occurs in real-time<br>- Process excellence seen beyond material flow perspective<br>- Technologies equally oriented to both information and material flows<br>- Proactive production management |
| Products and Services | - Clear distinction between products and services<br>- Improvement initiatives individually addressed<br>- Competitive differentiation based on the offered products<br>- Poor emphasis of technologies on service integration<br>- Products designed to customers own/consume them | - New services emerged from technologies integration into products<br>- Products are an experience<br>- Services intrinsically offered with products<br>- Higher customers' expectations and new markets development |

Note: Constructed by the authors based on data analysis.

become increasingly dominant in the service environment (De Keyser et al. 2019; Kunz, Heinonen, and Lemmink 2019). This new scenario accelerates the offer of integrated product and service to generate new value and grow relationships with customers in the era of Fourth Industrial Revolution (Pirola et al. 2020). In this context, the whole customer experience may be derived from the combination of products and services collaboratively provided by different companies. As $E_7$ argued

> A product or service that a company offers is no longer sufficient on its own. It must be capable of integration with other products and services provided by other companies at different levels of the value chain. A company's product/service is only part of a larger solution for customers' experience.

Finally, Table 3 summarizes the perceptions on the main OE's aspects and compares them before and after the introduction of I4.0.

**Table 4.** OE emphasis according to GST's principles.

| | OE's aspects | | | |
|---|---|---|---|---|
| GST's principles | People | Partnerships | Processes | Products and Services |
| Holism | ++ | ++ | ++ | ++ |
| Boundaries | ++ | ++ | + | ++ |
| Hierarchy | + | + | ++ | ++ |
| Mutuality | ++ | ++ | ++ | ++ |
| Equilibrium | N | N | N | N |
| Equifinality | + | ++ | ++ | ++ |
| Entropy | ++ | N | ++ | N |

Notes: N: 'not explicitly referred'; +: 'briefly referred'; ++: 'emphatically referred'.

## 5. Discussion and propositions

The main insights derived from interviews are now reported and framed according to the seven principles of GST: (i) holism, (ii) boundaries, (iii) hierarchy, (iv) mutuality, (v) equilibrium, (vi) equifinality, and (vii) entropy. The emphasis on each principle varied among OE's aspects (i.e. *people*, *partnerships*, *processes*, and *products and services*). Nevertheless, there were some communalities, indicated in Table 4, that allowed the formulation of general propositions for further theory testing and validation. Additional evidence of OE conceptualization was sought in interviewees' statements (e.g. details in the examples provided, arguments used to justify answers, similarity in responses). For example, $E_{11}$ illustrated his opinion about *partnerships* after I4.0 with the introduction of new mobile applications that eliminate the need for visiting grocery stores to buy supplies (and potentially reducing the need for a grocery store itself), since one can choose everything from his/her home.

From this content and latent analysis, the OE emphasis on each GST principle was classified into three classes: 'not explicitly referred to', 'briefly referred to' and 'emphatically referred to'. All principles were reasonably mentioned by experts, with the exception of *equilibrium* whose association was not explicitly mentioned with anyone of the OE's aspects. Therefore, the research propositions discussed here only encompassed principles that were either briefly or emphatically mentioned in at least one of the OE's aspects.

With respect to the principle of *holism*, information collected from the interviews emphatically indicated that OE in the I4.0 must carefully consider a system-wide perspective to address the improvement initiatives. Although the need for systematic integration of all continuous improvement initiatives is a concept that precedes I4.0, experts pointed out that most companies still adopt unilateral solutions and strategies to improve their processes, products, and services. Such solutions tend to lead to marginal benefits, frustrating managers and disbelieving the validity of those techniques (McLean and Antony 2014). With the introduction of I4.0, there may be a frenzy regarding the digital transformation of companies, even though companies still struggle to understand its benefits (Dalenogare et al. 2018). This may generate overestimated expectations on the effects of digitalization, leading managers to mainly focus their improvements efforts on the adoption of a set of new technologies. Nevertheless, as highlighted by Tortorella and Fettermann (2018), the incorporation of new digital technologies into ill-structured process will not result in significant performance improvements. The effective fusion between the physical and cyber world proposed by the I4.0 requires an enhanced horizontal and vertical integration of the organization (Pérez-Lara et al. 2018). Within this context, systemic thinking becomes a crucial ability whose importance is aggravated by the fact that implications of managerial decisions may be continuously perceived in real-time by the whole value chain. Such aspect was clearly indicated by experts, who suggested that the interconnectivity and cyber-physical systems derived from I4.0 technologies are going to allow a more integrated and collaborative relationship among *people*, *partners*, *processes*, and *products and services*. This assumption is aligned with indications from Tortorella et al. (2020c) and Chiarini and Kumar (2020), which stated that the proper incorporation of I4.0 technologies into current operations management practices may lead to systemic benefits that can overcome individual and isolated improvement initiatives. Thus, based on Table 3 outcomes, we infer that the understanding on OE's aspects in the Fourth Industrial Revolution is likely to positively reinforce *holism*, giving rise to the following proposition

> *Proposition 1*: The pursuit of OE in the Fourth Industrial Revolution era, particularly in terms of people, partnerships, processes, and products and services, infers that manufacturing companies must systematically integrate novel digital technologies as a support to their continuous improvement initiatives, rather than simply focusing on the adoption of individual technologies.

Regarding the principle of *boundaries*, its pervasiveness was evidenced across all OE's aspects, with a shallower mention in relation to processes. As already suggested by Netland (2016) and Beraldin, Danese, and Romano (2020), the improvement approach a company is going to adopt must consider the contingencies that surround it. Based on experts' statements, such indication seems to be also valid to pursue OE in the Fourth Industrial Revolution. However, experts highlighted that, due to digitalization, the contextual elements to be considered may shift; e.g. generational changes in the case of *people*, and the increasing complexity of supply chains in terms of *partnerships*. This somewhat corroborates to the findings from Szász et al. (2020), which evidenced the contextual relevance for the digitalization level of manufacturers. Thus, based on the common indications from experts with respect to OE's aspects in the I4.0 and the principle of *boundaries*, the following proposition is formulated:

> *Proposition 2*: The pursuit of OE in the Fourth Industrial Revolution era, particularly in terms of people, partnerships, processes, and products and services, infers that manufacturing companies must consider the environment in which digital technologies will be incorporated to properly support the continuous improvement initiatives.

The *hierarchy* principle states that the whole dictates the individual behaviours of parts (Hammond 2010). In the content analysis of interviewees' comments, references to this principle were observed in all OE's aspects, with special attention to *processes* and *products and services*. Experts suggested that the development of *processes*, *products* and *services* supported by I4.0 technologies is prone to be more vertically and horizontally integrated. This entails that their characteristics and roles must be designed in a way that they favour the whole organizational value chain, being subordinated to the delivery of value for the end consumer. It is not just a matter of systemically integrating technologies into processes, products and services as indicated by holism; but also ensuring that their scopes are planned according to a larger value view, providing a better solution for customers. This finding converges to indications from Hahn

(2020) and Tortorella et al. (2020a), which reinforced the need for the proper coordination of each organizational element (i.e. *processes*, and *products and services*) towards the effective delivery of a broader outcome that meets customers' expectations. Therefore, the following proposition is developed:

> *Proposition* 3: The pursuit of OE in the Fourth Industrial Revolution era, particularly in terms of people, partnerships, processes, and products and services, infers that manufacturing companies must vertically and horizontally align and coordinate the technology-integrated continuous improvement initiatives so that larger value-added solutions are provided to customers.

*Mutuality* in the conceptualization of OE indicates that aspects are interrelated, leading to superior performance levels. Among the attributes of I4.0, interoperability is the one that assumes that *people*, *partners*, *processes*, *products and services* can communicate through the Internet of Things (Xu, Xu, and Li 2018; Ghobakhloo 2018), contributing to a closer interdependency. This was emphatically suggested by all interviewees in relation to all OE's aspects. Unlike the previous industrial revolutions, the advances in terms of information and communication technologies achieved in the Fourth Industrial Revolution significantly enhance the interaction among OE's aspects (Fettermann et al. 2018; Golan, Cohen, and Singer 2020). If the interrelationship among *people*, *partners*, *processes*, *products and services* was already fundamental to achieve OE in the Third Industrial Revolution, in I4.0 its importance may become even higher fuelled by the disruptive I4.0 technologies. These arguments give rise to the following proposition:

> *Proposition* 4: The pursuit of OE in the Fourth Industrial Revolution era, particularly in terms of people, partnerships, processes, and products and services, infers that manufacturing companies must incorporate digital technologies into continuous improvement initiatives to support their interaction so that higher performance results can be achieved.

The principle of *equifinality* was clearly identified in the interviewees' comments for all OE's aspects. In terms of *processes*, for instance, those are claimed to have more diversified flows in the I4.0, following fuzzier productive routes until being ready for customer delivery. Moreover, partnerships are also likely to be less rigid, being differently established based on each company's needs and partners' contributions. The versatility implicit in the Fourth Industrial Revolution derives from the modularity and flexibility implied by technologies such as additive manufacturing, augmented reality, and supervisory control and data acquisition (Züehlke 2010; Liao et al. 2017; Barata, Cunha, and Coyle 2019). Furthermore, our findings suggest that OE in the I4.0 also heavily relies on customization, which results in the fuzzification of interactions among *people*, *partnerships*, *processes*, and *products and services*. In other words, I4.0 technologies contribute to the development of multiple solutions to the achievement of similar outcomes. To better investigate this, we formulate the following proposition:

> *Proposition* 5: The pursuit of OE in the Fourth Industrial Revolution era, particularly in terms of people, partnerships, processes, and products and services, infers that manufacturing companies must incorporate digital technologies into continuous improvement initiatives so that solutions can be properly adapted according to the issues in each company, avoiding one-size-fits-all solutions.

The GST principle denoted as *entropy* states that systems must be checked so that the expected performance is sustained (Skyttner 2005). I4.0 digital technologies support more effective sensing and communication of data throughout the company, collecting it in real-time and enabling to store and analyse large amounts of data (Dalenogare et al. 2018; Frank, Dalenogare, and Ayala 2019). Experts argued that such capability will be particularly useful to monitor the performance of *people* and *processes* within the company, enhancing the company's ability to identify abnormalities and more rapidly implement countermeasures. According to Spear (2008; 2010), one of the key features that distinguishes a company from its competitors is the capacity to thoroughly designing processes so that, whenever deviations (problems) occur, anyone can easily identify them and trigger an immediate corrective action. Results reported in Table 3 corroborate this indication, suggesting that OE in the I4.0 favours a faster identification and solution of problems, which gives rise to the following proposition:

> *Proposition* 6: The pursuit of OE in the Fourth Industrial Revolution era, particularly in terms of people and processes, infers that manufacturing companies must be able to check in real-time their working systems so that abnormalities are easily identified, and improvements timely addressed.

*Equilibrium* in an organizational environment is observed when opposite forces, which may be represented by contradictory policies, strategies, practices, performance indicators, values, among others, continuously push each other towards a steady state (Caws 2015). None of the experts mentioned it, nor associated their responses to its concept in the interviews, thus, no proposition was formulated considering this principle. This result was surprising in light of the continuous improvement concept that permeates OE, in which organizations must permanently seek better and more efficient ways to provide value to their customers and society (Li, Papadopoulos, and Zhang 2016; Ciano et al. 2019). The search for *equilibrium* is intrinsic to the achievement of OE, as the systematic conduction of problem-solving activities foster the reestablishment of flow whenever abnormalities are identified (Spear 2008; 2010), promoting learning and developing people, processes, products, services and partners. Nevertheless, one of the reasons that might explain this counterintuitive absence of evidence relies on the fact that OE is more likely to be achieved when organizations have their improvement strategies vertically and horizontally aligned (Giordani da Silveira et al. 2017). According to Tortorella, Cauchick-Miguel, and Gaiardelli (2019d), if the guidelines that compose an organization's strategic planning are properly deployed, variation on the understanding of priorities is minimized. In this sense, the true achievement of OE supposedly requires that all change agents (e.g. senior and middle managers, team leaders and operators) have clear and convergent goals, mitigating any managerial conflicts of improvement initiatives and reducing the need for *equilibrium* when operationalizing them. This outcome corroborates the view of *equilibrium* as a balance between organizational interests, originally suggested by Fayol (1956), in which *equilibrium* is seen as resulting from a dynamic process (Gazendam and Simons 1998). Therefore, our finding does not neglect the relevance of *equilibrium* to OE. Instead, we understand it may highlight the prominence of *equilibrium* at the strategic planning stage, which must precede the operationalization of improvement initiatives. This may be valid regardless the digitalization level of the organization.

Finally, it is worth emphasizing that the pursuit of OE is a multi-dimensional endless job whose concept may transit over time and highly depends on the existing abstraction level in the organization. Hence, to properly facilitate such conceptualization, we established a theoretical ground that would allow us to build on in a more concrete and assertive way. Although the propositions may emphasize the points of vigilance or interest between OE and I4.0, they also help to set an expectation about what OE looks like in the Fourth Industrial Revolution. In other words, by identifying those points of vigilance in each proposition, we were able to materialize a concept of OE in the I4.0 to which academics and practitioners can refer in future investigations.

## 6. Conclusions

This work aimed at investigating the concept of OE in the Fourth Industrial Revolution through the lens of GST, which led to the formulation of six research propositions. Interviews with experts identified the shifts in OE's concepts implied by the I4.0, whose insights are worth for both theory and practice.

In theoretical terms, our study sheds light on OE's meaning after the acknowledgement of the Fourth Industrial Revolution. OE has been traditionally ill-defined either in academia or companies, and its conceptualization usually lacks a solid theoretical ground. As I4.0 enables significant changes on how companies will work, a proper definition of OE's meaning becomes even more relevant. Our findings support such definition according to GST's principles, indicating that the conceptualization of OE in the I4.0 is likely to encompass a more integrative and systemic perspective of *people*, *partnerships*, *processes*, and *products and services*. Hence, our propositions were intentionally formulated to be wider, so that future studies could deepen this topic and provide more specific findings on the OE's concept after the I4.0 advent. We argue that the main theoretical contribution of those propositions is not for the knowledge on I4.0 itself but for a broader understanding of OE, whose concept has been transitioning as new technologies are incorporated into organizations changing the way people, processes, products and services, and partners interact. To the best of our knowledge, there is no similar research on this topic. Hence, we provide initial evidence towards the establishment of a common understanding of OE in the industry digital transformation era.

From a practical standpoint, our study provides managers and practitioners arguments to better understand the definition of OE in face of I4.0. With the transition from the Third to the Fourth Industrial Revolution, manufacturers will be compelled to adapt their continuous improvement initiatives to the digital transformation. Although some concepts from the previous industrial revolutions remain important, the introduction of disruptive digital technologies is likely to affect the way *people*, *partnerships*, *processes*, and *products and services* are seen. Our findings may help companies to anticipate those changes, so that the ones who embrace them earlier may obtain competitive advantage. Therefore, this study allows a redirection of manufacturing companies' continuous improvement approaches towards the achievement of OE in a highly digitized world.

As all research, this work does suffer from limitations that may motivate further studies. First, in terms of the applied empirical methods, further research could encompass other data collection approach (e.g. survey). The use of large datasets would allow the application of sophisticated multivariate data analysis techniques, allowing the test of the propositions developed here. Second, we exclusively focused on OE's concepts based on four aspects (*people*, *partnerships*, *processes*, and *products and services*). However, true business excellence results from the combination between an effective strategy and a consistent OE. Although our study provided arguments to better understand OE's meaning in the Fourth Industrial Revolution, it only addresses part of what is required for a company to be successful. In this sense, further research could build on our findings by integrating the strategic planning and its deployment to tactics and operational levels. Finally, as I4.0 is a relatively recent phenomenon, many of its benefits are still unknown. Since most companies that initiated their digital transformation have applied it to specific processes, a system-wide perspective (i.e. integrating *people*, *partnerships*, *processes*, and *products and services*) of I4.0 is scarce, and short-term perceptions are prevalent in the information collected. Thus, longitudinal studies that examine how OE's concepts will actually be affected by the I4.0 in the long run are recommended.

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## Appendix – Interview semi-structured protocol

(1). What is your professional background? Please, provide a brief description of your professional experience.

(2). Considering the period between the third and fourth industrial revolutions (i.e. from 1970 to 2010), please, tell us how you think Operational Excellence in manufacturing companies was understood (or perceived) according to the following aspects:
(a). People
(b). Partnerships (e.g. suppliers, customers, stakeholders)
(c). Processes
(d). Products and services

Please, justify your answer and give examples.

(3). With emergence of the Fourth Industrial Revolution (also denoted as Industry 4.0) in 2011, how do you think the understanding (or perception) of Operational Excellence in manufacturing companies will change in terms of:
(a). People
(b). Partnerships (e.g. suppliers, customers, stakeholders)
(c). Processes
(d). Products and services

Please, justify your answer and give examples.