

Performance Measurement for Supply Chains in the Industry 4.0 Era: A Balanced Scorecard Approach

Abstract

Purpose – The purpose of this paper is to present a theoretical approach based on the Balanced Scorecard (BSC) with regards to Performance Measurement (PM) in supply chains for the Industry 4.0 era.

Design, methodology/ approach – This paper combines the literature on PM and specifically the BSC related to the dimensions of supply chain in the context of Industry 4.0.

Findings – Dimensions extracted from the literature based on supply chains within the context of Industry 4.0 showed a strong alignment with the four perspectives of the BSC, which make it suitable to be considered as a Performance Measurement System (PMS) for supply chains in this new context.

Research limitations/Implications – From theoretical perspective, this study contributes to the limited literature on PM for supply chains in industry 4.0 era. The study proposes a supply chain 4.0 scorecard and strongly support researchers to conduct future empirical researches in order to get a deeper understanding about PM in supply chains in the Industry 4.0 era. As limitations, the theoretical framework proposed needs further empirical research in order to validate it and obtain new insights over the investigation conducted and presented into this paper.

Practical implications – Practitioners can use this study as a guide to develop more effective Performance Measurement Systems (PMSs) in their organizations.

Originality/value – This research is unique as it addresses a significant knowledge gap related to PM in Supply Chains in the Industry 4.0 era. It brings a significant contribution in terms of understanding how to measure performance in supply chains in this new era.

Keywords: Industry 4.0, Supply Chain, Performance Measurement, Balanced Scorecard, Theoretical Framework

Paper Type: Conceptual Paper

1. Introduction

Industry 4.0 is currently attracting high focus from researches and practitioners in the operations management area. The Industry 4.0's subject, also known as the fourth industrial revolution, was launched in the Hannover Fair which took place in Germany in 2011 (Ghobakhloo, 2018). Nonetheless, in this same year, Industry 4.0 was also part of the German government's agenda (Ghobakhloo, 2018; Lu, 2017; Hofmann and R uch, 2017; Pereira and Romero, 2017). Nowadays, Industry 4.0 is being discussed globally and it has been a relevant topic considered as part of the 2016 World Economic Forum's agenda (Hofmann and R uch, 2017; Lu, 2017) and others country's government strategy, e.g. United States, French, Japan, Singapore, United Kingdom and China (Liao et al., 2017). This is because only nations committed to Industry 4.0's initiatives will remain strong in a global competitive market perspective (Kagermann, Wahlster and Helbig, 2013). Moreover, this new approach will change the way in how companies compete with each other and how the value is created for their customers (Porter and Heppelmann, 2014).

In recent years several studies have been conducted with the aim of obtaining more clarification and discussion with regards to this subject (Oztemel and Gursev, 2018). Liao et al. (2017) emphasize that in the period between 2013 and 2015 the number of publications in journals and conferences has considerably increased and is still growing fast. For instance, some researches have focused on understanding the relationship amongst the Industry 4.0's phenomenon and other areas of knowledge that include Sustainability (Hazen, et al. (2016), Kamble, Gunasekaran and Gawankar, 2018; Branger and Pang, 2015; Stock and Seliger, 2016, Jabbour et al., 2018), Organizational Structure (Wilkesmann and Wildesmann, 2018; Schuh et al., 2015), Lean Manufacturing (Sanders, Elangeswaran and Wulfsberg, 2016; Rüttimann and Stöckli, 2016; Kolberg and Zühlke, 2015; Mrugalska and Wyrwicka, 2017), Product Development (Santos et al., 2017), Small and Medium Enterprises - SMEs (Moeuf, 2017), Production Planning and Control (Rossit, Tohmé and Frutos, 2018; Dolgui, et al., 2018) and Strategic Management (Lin et al., 2018).

Even though some papers related to Industry 4.0 have been recently published, research approaching this from the context of supply chains is still demanding more efforts from the research community. Büyüközkan and Göçer (2018) emphasize that scholarly research on Industry 4.0 with a focus on supply chains is still embryonic, as it has currently been more widely discussed among practitioners. In addition, according to these authors, Industry 4.0 has a significant potential of value creation, transforming the traditional supply chains schemes. Notwithstanding, this phenomenon is still unclear throughout the academic community.

The main focus of Industry 4.0 is on disruptive technologies that will cause significant impacts on supply chains (Tjabjono et al., 2017; Mathusami and Srinivsan, 2017, Stevens and Johnson, 2016). These technologies include: Virtual Reality, Simulation, 3D-printing, Big Data Analytics – BDA, Cloud Technologies, Cyber Security, Internet of Things – IoT, Radio Frequency Identification – RFID, Machine to Machine Communication – M2M, Automatic Identification and Data Collection – AIDC, Robotics, Drones, Nanotechnology and Business Intelligence – BI (Tjabjono, Esplugues and Pelaez, 2017; Oztemel and Gursev, 2018). According to Iddris (2018), these new technologies will radically change supply chain operations and they need to be aligned to customer demands. Moreover, these new technologies, especially IoT and Cyber-Physical Systems (CPS), will generate impacts on products and services, business models, markets, economy, work environment and people, and organizational skills, deeply changing supply chains (Pereira and Romero, 2017).

Although disruptive technologies play the most important role in the Industry 4.0 scenario, Bienhaus and Haddud (2018) also consider relevant development of new methods and concepts related to the Digitization era. Additionally, Wu (2016) states that besides technical aspects, non-technical challenges and obstacles will also have to be overcome in a Supply Chain 4.0 context. One of the most important subjects from a managerial standpoint is related to PM. Implementation of disruptive technologies will require many efforts from the members of supply chains in terms of collaboration, coordination, and people and infrastructure capabilities. Also, these technologies will generate expectations in terms of efficiency, integration, transparency and agility over the supply chain process as well as on the improvement of customer's satisfaction and financial improvements. Therefore, in order to guarantee that Industry 4.0's programs in supply chains will pursue those aspects, PM plays an important role in this management. However, the Industry 4.0 in supply chains area is still largely scarce.

Performance Measurement has been deeply discussed since the 1990s, when Eccles (1991) highlighted the importance of more comprehensive frameworks for Performance Measurement Systems (PMSs). From this moment forward, the theory of PM started to be consolidated, and significant contributions were made, including the concepts of performance measurement, performance measures and performance measurement systems (Neely, Gregory and Platts, 1995), the difference between performance management and performance measurement (Lebas, 1995 and Bititci, Carrie and Mcdevitt, 1997) and the proposal of the Balanced Scorecard framework (Kaplan and Norton, 1996).

Some PMSs for supply chains have been proposed in the literature (e.g. Van Hoek (1998), Beamon (1999), Holmberg (2000), Gunasekaran, Patel and Tirtiroglu (2001). In a recent study by Reddy, Rao and Krishnanand (2019), the SCOR model and BSC are identified as the most used PMS frameworks to measure performance in supply chains. Being largely used by practitioners as the management model for supply chains, the SCOR model (APICS, 2019) has also been considered to measure performance of supply chain's processes (e.g. Theeranuphattana and Tang, 2008; and Li, Su and Chen, 2011; Sellitto et al., 2015). BSC has been broadly used in management area, not only focused on supply chains. In the case of supply chain management, some frameworks have been published based on BSC e.g. Brewer and Speh (2000), Park, Lee and Yoo (2005), Bhagwat and Sharma (2007), Reefke and Trocchi (2013) and Nouri, Nikabadi and Olfat (2019).

Although these studies have made significant contribution to the supply chain management field, they are not aligned with the phenomenon of fourth industrial revolution that is transforming the environmental and strategic positions of supply chains, a gap which this article aims to address. In this regard, PMS for supply chains must consider the environmental and strategic changes (Shepherd and Günter, 2006 and Gopal and Thakkar, 2012). Mishra et al. (2018) argue that it is crucial for managers involved in supply chains to adapt PMSs according to the organizational context and stakeholders' requirements. Yet, supply chain performance measurement must respect the context and its dynamics in which the supply chain is operating (Cuthbertson and Piotrowicz, 2011). In this sense, BSC seems to be more suitable to be considered to measure supply chains in the Industry 4.0 era, taking into consideration that this phenomenon is more than only measuring processes performance which is more related to the SCOR approach.

In a systematic literature review research, Frederico et al. (2019) have pointed out the gap and the needs in having more studies approaching PM in supply chains from the changes to be caused by Industry 4.0 era. In a search on main scientific databases such as Web of Science, Scopus and Google Scholar, it was possible to identify that few papers have been published with regards to performance measurement within the context of Industry 4.0. These include the works of Shin et al. (2018), Miragliotta et al. (2018), Balters et.al. (2018), Ante et al. (2018) and Emmer et al. (2018). Although these proposals consider Industry 4.0 within their scope, they are more focused on technical than managerial aspects. Also, they are not closely aligned to supply chains in a holistic view as they focus more specifically on manufacturing and technical areas. Therefore, it is possible to notice a significant knowledge gap regarding to performance measurement on supply chains within the context of Industry 4.0, considering strategic and managerial with broad perspectives as should be the scope of modern PMSs.

Accordingly, taking into consideration that performance measurement is a relevant topic related to managerial issues on the Industry 4.0 phenomenon, this paper aims to bring a

theoretical approach with regards to how to measure performance in supply chains in an Industry 4.0 context. This is relevant considering that the approach proposed fills a gap in the literature and that it can significantly contribute to the practitioners involved in Industry 4.0 initiatives as well as to researchers who need deeper theoretical insights in order to develop future empirical studies.

The proposal is built based on the theoretical background of performance measurement, and specifically on the Balanced Scorecard, and the dimensions of supply chains 4.0. This proposal aims to answer the following research question;

How can the performance of supply chains within the context of Industry 4.0 be measured by the Balanced Scorecard?

Figure 1 presents the rationale of this paper approach based on the research question and motivation.

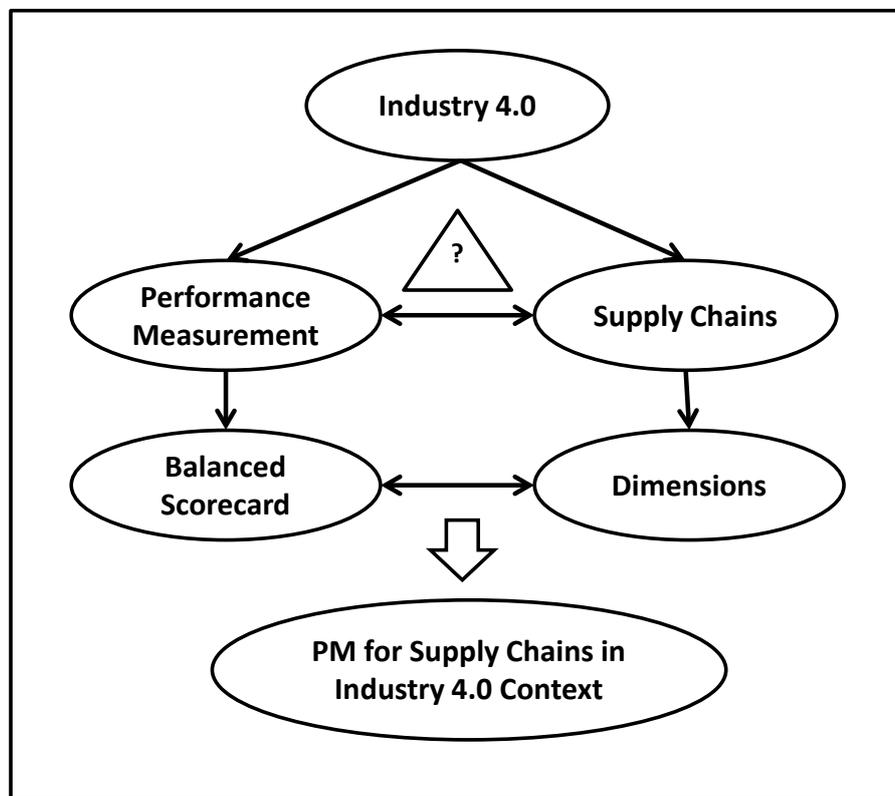


Figure 1. Paper proposal based on the research question and motivation

This paper is structured as follows: this section contextualized and introduced the research gap, question and motivation of the present paper. The second section reviews the theoretical background of PM, Balanced Scorecard and dimensions of Supply Chain within the Industry 4.0 context. The third section presents the proposed theoretical framework for the measurement of performance of Supply Chains in the 4.0 Industry era by aligning the Balanced Scorecard perspectives and dimensions of Supply Chains 4.0. Finally, in the fourth section, conclusions with future research directions, theoretical and practical implications as well as limitations are discussed.

2. Theoretical Background

2.1 Performance Measurement

Performance measurement has been one of the most researched topics in the last decades since Eccles (1991) defined PM as having a broader organizational scope. According to Eccles (1991), there was a need to stop considering only financial indicators as the basis for the measure of performance. A comprehensive range of indicators became crucial faced with the new competitive environment in 1990s.

Neely, Gregory and Platts (1995) define PM as “the process of quantification of the action, where measurement is the process of quantification and the action is what leads to the performance”. Neely, Gregory and Platts (1995) state that a PMS must contain individual measures interrelated among each other pertaining to certain environment. According to these authors, a PMS must consider and address the following questions: Which measurements of performance are used?, Why are they being used?, How much will they cost? and What benefits can they offer?

Lebas (1995) states that performance measurement and performance management are not separated. According to this author, there is an interactive process between these two issues. Actually, a PMS is an information system that is at the heart of the performance management process (Bititci, Carrie and Mcdevitt, 1997). Furthermore, PMS must have a dynamic process considering the external and internal changes (Bititci Turner and Begemann, 2000) and be aligned with the changes on the business environment (Kennerley and Neely, 2003)

Thus, organizations need to take into consideration PM and take it beyond the financial focus. Qualitative factors of processes and stakeholders’ satisfaction in the organization, like customers, employees and others, are included in new models of performance measurement, being linked to issues such as markets, new technologies and economy, with necessarily, a connection with the strategic scope modern organizations. Also, performance measurement must be part of the process control involving the strategic, tactical and operational levels, assessing through a continual way the planning and the actions implemented under others views beyond the financial. Considering the holistic view of Industry 4.0’ initiatives in supply chains, performance measurement becomes crucial for the success of these initiatives.

As the central element of measuring performance process, PMS plays an important role giving support to the process of performance management, which has a broader approach. In the development of a PMS it is important to understand the reasons, costs and utilizations of measures. It does not make sense to have many measures without a link with corporate and operations strategies. Also, it cannot require a huge effort to obtain the data to measure performance, costing lots of money and taking so much time from people who are responsible for the measure of performance.

Also, PMSs should pay attention in terms of its evolution and stages of development. Authors such as Wettstein and Kueng (2002), Van Aken et.al. (2005), Frederico and Martins (2012) and Frederico and Martins (2015) have proposed on the literature maturity frameworks in order to assess the evolutions of Performance Measurement Systems.

Modern Performance Measurement Systems such as the Performance Prism (Neely, Adams and Crowe, 2001) and Balanced Scorecard (BSC) (Kaplan and Norton, 1996) take into

consideration a balanced structure in order to have a more effective performance measurement process. Although some authors (e.g. Voepel, Leibold and Eckhoff, 2006) have strongly criticized the use of BSC, it has been successfully used by a wide range of world-class companies and it is certainly one of the most used PMSs.

2.2 Balanced Scorecard

Balanced Scorecard was initially proposed in 1990 by a work group from the Nolan Norton Institute, which assisted the KPMG in research and development of new management models. The objective of the group was to create a model to measure performance in organizations of the future, considering that existing models at that time were already obsolete. The leader of this study was David Norton, CEO of Nolan Norton Institute. By his side, Robert Kaplan acted as an academic consultant. Along the year of 1990, representatives of twelve companies from different sectors that included manufacturing, services, heavy industry and high technology were brought together in order to develop a new model for performance evaluation.

Kaplan and Norton (1996) considered that organizations were acting in complex environments where the understanding of their goals and methods to reach them was a crucial aspect to their own survival. According to the model proposed by Kaplan and Norton (1996), the Balanced Scorecard measures operational performance through four perspectives: 1) **Financial**, 2) **Customers**, 3) **Business Processes**, and 4) **Learning and Growth**.

The perspective of **Learning and Growth** is the basis for the **Business Processes** perspective. It is related to how companies will support changes and improvement in order to achieve their corporate mission and vision. The perspective of **Business Processes** is related to initiatives with regards to achieving excellence in business processes, aiming to satisfy customers and consequently shareholders. The perspective of **Customers** is linked to initiatives about customer relationship and satisfaction. Lastly, the **Financial** perspective is the result of the other three perspectives and satisfaction of shareholders. It is possible to notice that there is a clear rationale between these perspectives, which is given by a strategic map as proposed by Kaplan and Norton (1996).

According to Niven (2002), the Balanced Scorecard is a model that considers three main functions: System of Measures, System of Strategic Management and Tool of Communication. Kaplan and Norton (2001) establish that organizations use the following five principles in order to get the alignment of its strategy throughout the organization: 1) translate the strategy into operational terms, 2) align the organization to the strategy, 3) make the strategy everyone's job, 4) make the strategy a continual process, and 5) mobilize change through executive leadership. The Balanced Scorecard is more than just a system to measure performance. It is also used as an instrument of strategic management, supporting the clarification and transmission of strategies. It allows companies to measure effective performance aligned to strategic objectives in a comprehensive set of perspectives, much more than only operational performance.

Taking into consideration that Industry 4.0 programs in supply chains will involve strategic orientation as well as broader perspectives, Balanced Scorecard, as a modern approach, is an option to be followed in order to structure a PMS to effectively measure Industry 4.0's initiatives in supply chains. Nonetheless, it is important to emphasize that other PMS frameworks may be considered in order to measure supply chain performance in the Industry 4.0's context, which would need further studies. This article is limited in presenting a PMS framework having the BSC as the foundation.

2.3 Dimensions of Supply Chain within the Industry 4.0's Context

Due to the emerging topic of Industry 4.0 since 2012, various authors have proposed different approaches on the literature relating to the so-called supply chains 4.0. These approaches bring different views about how supply chains may be understood and/or structured in the Industry 4.0 era.

The dimensions presented in Table 1 were extracted from the literature review process, as proposed by Tranfield, Denyer and Smart (2003), considering three phases: Planning, Conducting and Reporting. This paper was focused more on the planning and conducting phase in order to identify the dimensions of supply chain in the context of Industry 4.0 for a conceptual basis, since it is not entirely a systematic literature review paper itself.

In the planning process the keyword used to search was the combination of two words “Supply Chain” and “Industry 4.0”. The databases considered for the search were: Emerald, Elsevier, Taylor & Francis, Wiley, Inderscience, IEEE Xplore, Springer and, Google Scholar. The period considered was from 2011 to 2019, taking into consideration that 2011 was the moment when the Industry 4.0 concept was launched by Kagermann et al. (2013). In the conducting phase, 140 papers were identified. The screening step consisted of the reading of the title and abstract of each paper. Where needed, the entire manuscript was read. The selection criteria used was the alignment with the research purpose. For instance, those papers which were more focused on managerial aspects of Supply Chain 4.0, were selected instead of those more focused on technical issues. In the end of screening step, 24 papers were considered, being the basis for the Table 1. Following concept matrix technique as suggested by Webster and Watson (2002), it was possible to group the elements by authors and then to the five dimensions as explained below.

According to Table 1, there are five main dimensions which shape a supply chain into the Industry 4.0 context: 1) **Capabilities**, 2) **Technologies**, 3) **Interoperability**, 4) **Supply Chain Processes**, and 5) **Financial and Strategic Results**. These dimensions were identified from the literature, which has approached the relation between Industry 4.0 and supply chains. Each author has considered one or more elements of the dimensions presented.

The **Capabilities** dimension is related to the competences that are needed in order to support the implementations of Industry 4.0's technologies throughout supply chains. They are linked to aspects such as human resources and organizational skills, information technology infrastructure, compliance and legal issues, leadership support and strategic orientation, and organizational coordination. On the other hand, the **Technologies** dimension refers to the transformational technologies of Industry 4.0 to be implemented on supply chains. These main technologies include: Internet of Things – IoT, Big Data Analytics, Cloud Computing, Artificial Intelligence, Robotics and Automation, 3D-printing, Augmented Reality, Sensors Technology, Self-Drive Vehicles, Cyber Security, Radio Frequency Identification - RFID, Omnichannel, Mobile Technology and Nanotechnology. Furthermore, the **Interoperability** dimension is related to the level of integration (horizontal and vertical) of information and technologies across the supply chain. The integration in both horizontal and vertical forms will ensure that technologies and information will work in an integrated way, allowing the planned level of automation and digitalization of processes at supply chains. Interoperability is a key factor for the success of Industry 4.0 technologies implementation, considering that even if the best technologies are implemented, the lack of their integration will not generate the improvement planned to the processes of supply chain. The **Supply Chain Processes**

dimension refers to the benefits that may be gained from the transformational technologies' implementation into the supply chains. These benefits may be related to efficiency, responsiveness, flexibility, collaboration, visibility and transparency, integration and leaner processes. These improvements can occur in the classic processes of supply chain such as Supply Chain Operations Reference Model – SCOR approach (plan, source, make, delivery and return). Finally, the **Financial and Strategic Results** dimension describes the profitability and cost reduction achieved by the improvement of supply chain processes due to the transformational technologies' implementation. Profitability can be achieved also by the increase of sales due to the value added provided to customers by the new level of supply chain processes performance. As the supply chain processes may be improved by Industry 4.0's technologies responsiveness, flexibility, transparency and visibility, they will have better performance, directly impacting on customer value.

3. Performance Measurement for Supply Chains 4.0

In order to propose a theoretical framework to measure the performance of supply chains in the Industry 4.0 era, this section makes an alignment between the perspectives of Balanced Scorecard and the dimensions of supply chains within the Industry 4.0's context extracted from the literature as discussed in Section 2.3.

Surely, the Balanced Scorecard is not the only way to measure performance in Organisations. However, it has been largely used on business environment since the 1990s. Nonetheless, there are some points to be considered regarding the BSC adoption for the purpose of this study. One is related the justification to adopt a PMS, based on the clear cause-and-effect relationship which the BSC is structured. Malina, Nørreklit and Selto (2007) claims this argument as totally valid one that sometimes the organizational validity in terms of its perception of legitimacy and effectiveness control may be more important than just only the cause-and-effect relationship. Another relevant issue that was pointed out by Nørreklit et al. (2012) regarding BSC is that it cannot only be adopted by its genre itself. These authors emphasize the need for a constructivist approach on the implementation of BSC. This is needed because the cause-and-effect relations involved in business practices and processes may be different for each kind of business considered. This is very much aligned in a supply chain scheme, considering that supply chains are specific for each kind of business and it is hardly possible to adopt a stand-alone solution to measure performance. There are different ways of processes to be integrated and coordinated between supply chain's members with different schemes. Not different, Industry 4.0 programs on supply chains will need PMSs with causalities relations built for each specific situation, making the constructivist approach very suitable for the proposal herein considered.

Also, some authors have proposed BSC as the method to be used in order to measure performance in supply chains e.g. Brewer and Speh (2000), Park, Lee and Yoo (2005), Bhagwat and Sharma (2007), Reefke and Trocchi (2013) and Nouri, Nikabadi and Olfat (2019). BSCs can be used through the supply chain using its fundamentally structured four perspectives. Brewer and Speh (200) have proposed a comprehensive BSC framework which relates each one of the four perspectives of BSC to the specific perspectives of supply chain. For instance, according to these authors, the **Learning and Growth** perspective of BSC is related to the Supply Chain Improvement aspects (e.g. measurement of responsivity in product development involving suppliers, focus company and customers). **Business Processes** perspective is linked to the Supply Chain Goals such as measurement of waste reduction, responsivity, efficiency and flexibility. **Customers** perspective of BSC relates to benefits generated to the Supply Chain's Customers (e.g. measurement of delivery level of service to

final clients). Finally, **Financial** perspective of BSC means the financial benefits obtained by the supply chain's members (e.g. measurement of revenue growth and profit margin of supply chain partners and return on assets).

With regards to its alignment with the Industry 4.0, BSC has important characteristics which make it suitable with the phenomenon of Industry 4.0. Certainly, future empirical studies are needed to validate the proposal herein discussed. However, considering the limited evidence where PM for supply chains into the Industry 4.0 context has been approached, this theoretical framework is a starting point for researchers and practitioners for deploying new studies related to this subject area.

As the basis for this alignment, the strategic map proposed by Kaplan and Norton (1996) was used. The strategic map provides a clear rationale in terms of cause-and-effect relationship between the BSC perspectives. Figure 2 shows how the five dimensions of supply chain in the Industry 4.0 context can be aligned with the four perspectives of the Balanced Scorecard.

The dimensions of **Capabilities**, **Technologies** and **Interoperability** are related to the perspective of **Learning and Growth**. This is because the capabilities elements, as presented in Table 1, are those that will support the supply chains' business processes by following the same rationale of the learning and growth perspective. Additionally, in the context of the Industry 4.0, transformational technologies will ensure a better performance of the elements of supply chain processes. Moreover, this will only be feasible if these technologies are effectively integrated to each other in both horizontal and vertical forms. According to Frederico et al. (2019), the disruptive technologies are actually technology levers to the Supply Chain Processes of the SCOR model and then generating Strategic Impacts. These authors point out that these technology levers must have as scaffold the Managerial and Capabilities Supporters and that the Interoperability is the key for the maximum technologies integration and the implementation success of Supply Chain 4.0 programs.

The **Supply Chain Processes** dimension can be directly linked to the **Business Processes** perspective of the Balanced Scorecard. As is same for the BSC structure, supply chain processes aim to guarantee customer satisfaction according to its performance elements (Table 1). For example, responsiveness and flexibility will influence the response time expectation from the customers. In the same way, transparency can generate a better customer experience by providing visibility regarding the order flow. Efficiency and leaner processes can also play a role on cost reduction and consequently improving profitability (value added margin from supply chain).

According to the elements presented in Table 1, the dimension of **Financial and Strategic Results** is related to the **Customer** and **Financial** perspective of the Balanced Scorecard. The reason for this is that in this dimension of supply chain, other elements, e.g. customer value added, are considered besides only financial aspects. As previously discussed, customer value will benefit from the performance of supply chain processes. The same will occur with financial elements such as profitability, cost reduction and shareholders value.

Table 1. Supply Chain Dimensions in the Industry 4.0 Context Identified on the Literature

| <i>Supply Chain Dimensions in the Context of Industry 4.0</i> | <i>Elements</i> | <i>Authors</i> |
|---|---|---|
| <i>CAPABILITIES</i> | Information Technology Infrastructure, Human Resources and Organizational Capabilities, Organizational Coordination, Leadership Support, Compliance, Strategic Orientation and Awareness | Barreto, Amaral and Pereira (2017), Tjahjono et al. (2017), Pfohl, Burak and Kurnaz (2017), Hoffmann and Ruch (2017), Dallasega, Rauch and Linder (2018), Wang et al. (2016), Alicke, Rexhausen and Seyfert (2016), Bienhaus and Haddud (2018), Iddris (2018), Queiroz and Telles (2018), Tu (2018), Kache and Seuring (2017), Schrauf and Bertram (2016), Ghobakhloo (2018), Haddud et al.(2017), Büyükoçkan and Göçer (2018), Gotge and Mentzel (2017), Muthusami and Srinvisan (2017) and Bukova et al. (2018) |
| <i>TECHNOLOGIES</i> | Internet of Things IoT, Big Data Analytics, Cloud Computing, Artificial Intelligence, RFID, Cyber Security, Robotics and Automation, Augmented Reality, Nanotechnology, Sensors Technology, Self-Drive Vehicles, 3D-printing, Mobile Technology and Omnichannel | Ardito et al. (2016), Barreto, Amaral and Pereira (2017), Tjahjono et al. (2017), Pfohl, Burak and Kurnaz (2017), Hoffmann and Ruch (2017), Dallasega, Rauch and Linder (2018), Bienhaus and Haddud (2018), Iddris (2018), Wu et al. (2016), Tu (2018), Kache and Seuring (2017), Schrauf and Bertram (2016), Ghobakhloo (2018), Haddud et al.(2017), Büyükoçkan and Göçer (2018), Gotge and Mentzel (2017) and Muthusami and Srinvisan (2017). |
| <i>INTEROPERABILITY</i> | Vertical Integration of Technologies and Information, Horizontal Integration of Technologies and Information | Tjahjono et al. (2017), Hoffmann and Ruch (2017), Wu et al. (2016), Tu (2018), Ghobakhloo (2018), Büyükoçkan and Göçer (2018) and Bukova et al. (2018) |
| <i>SUPPLY CHAIN PROCESSES</i> | Collaboration, Integration, Flexibility, Responsiveness, Transparency & Visibility, Efficiency, Leaner Processes | Barreto, Amaral and Pereira (2017), Tjahjono et al. (2017), Pfohl, Burak and Kurnaz (2017), Swanson (2017), Hoffmann and Ruch (2017), Dallasega, Rauch and Linder (2018), Wang et al. (2016), Alicke, Rexhausen and Seyfert (2016), Iddris (2018), Wu et al. (2016), Tu (2018), Kache and Seuring (2017), Schrauf and Bertram (2016), Ghobakhloo (2018), Haddud et al.(2017), Büyükoçkan and Göçer (2018), Gotge and Mentzel (2017), Muthusami and Srinvisan (2017) and Bukova et al. (2018) |
| <i>FINANCIAL AND STRATEGIC RESULTS</i> | Cost Reduction, Profitability, Customer Value and Shareholders Value | Tjahjono et al. (2017), Swanson (2017), Dallasega, Rauch and Linder (2018), Ardito et al. (2018), Bienhaus and Haddud (2018), Wu et al. (2016), Tu (2018), Kache and Seuring (2017), Brinch (2018), Haddud et al.(2017), Büyükoçkan and Göçer (2018), Gotge and Mentzel (2017), Muthusami and Srinvisan (2017) and Bukova et al. (2018) |

Based on the aforementioned explanations, Figure 2 illustrates the alignment between dimensions of supply chains 4.0 and the perspectives of Balanced Scorecard.

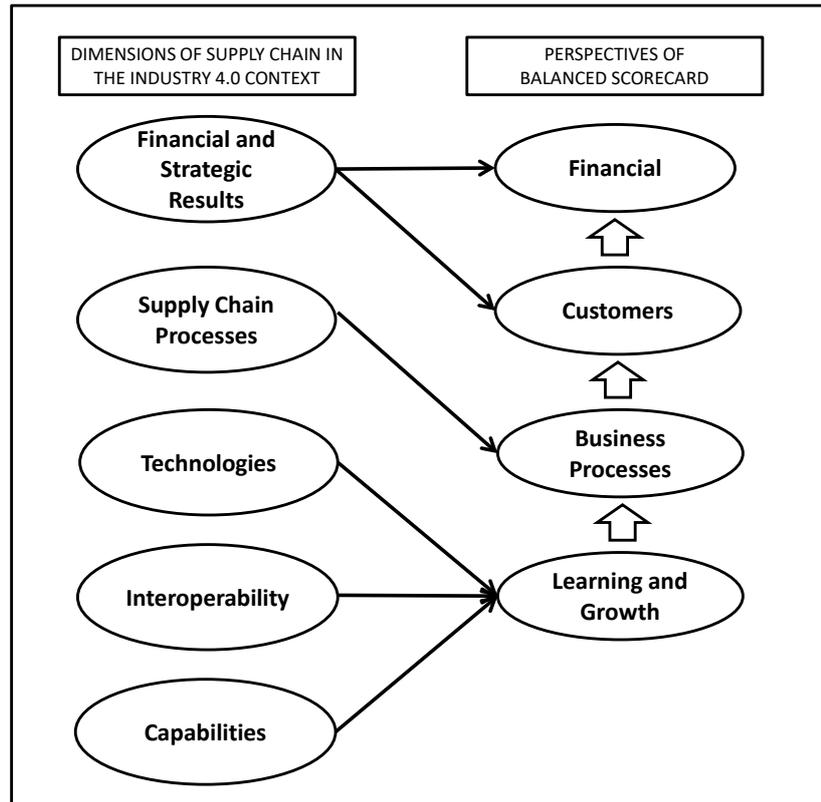


Figure 2. Alignment between dimensions of Supply Chain in the Industry 4.0 context and perspectives of Balanced Scorecard

In order to propose a PMS based on the Balanced Scorecard, from the alignment presented in Figure 2, it was possible to fit the elements of supply chain dimensions, which were presented in Table 1, in each perspective of the BSC. Following this process, Figure 3 was elaborated. This figure presents the measurement approaches for each perspective of BSC, according to the elements of supply chain dimensions. Considering the purpose of this paper, the theoretical framework demonstrated in Figure 3 will be referred as **Supply Chain 4.0 Scorecard**. It follows the same rationale of BSC, having a clear cause-and-effect relationship between perspectives. In Table 2, the deployment of measurement approaches is presented, according to each perspective of BSC, the supply chain dimensions and their respective elements.

It is important to emphasize that the Supply Chain 4.0 Scorecard is a generic framework which can be used as a guidance for each specific proposal. Furthermore, it presents the perspectives and measurement approaches, which means that specific performance indicators need to be developed based on that structure according to each specific context of supply chain in an initiative of Industry 4.0 implementation.

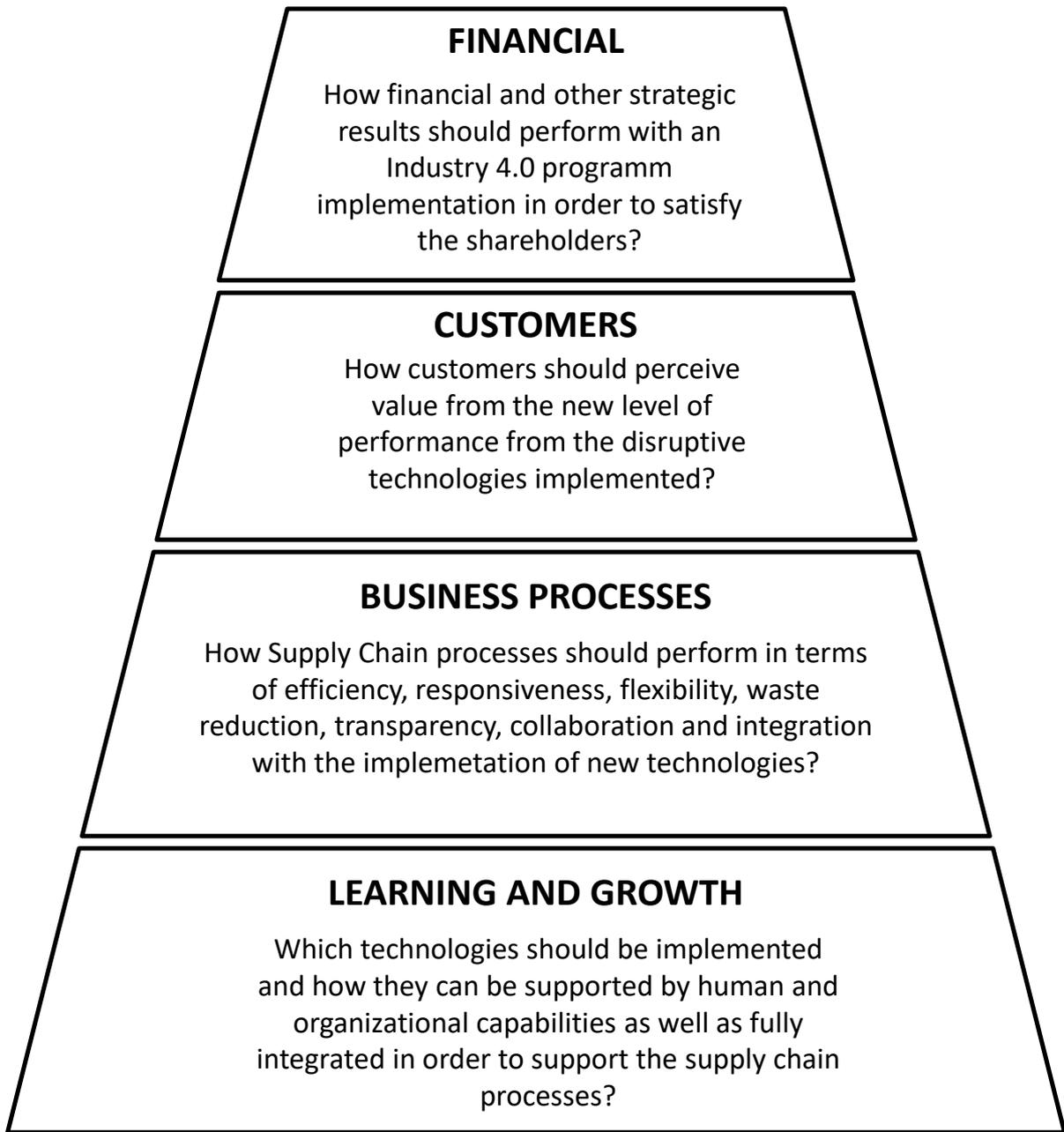


Figure 3. The Supply Chain 4.0 Scorecard

Table 2. Measurement Approaches Deployment of Supply Chain 4.0 Scorecard

| <i>BSC PERSPECTIVES</i> | <i>SUPPLY CHAIN DIMENSIONS IN THE INDUSTRY 4.0 CONTEXT</i> | <i>MEASUREMENT APPROACHES FOR THE SUPPLY CHAIN 4.0 SCORECARD</i> |
|----------------------------|---|--|
| FINANCIAL | FINANCIAL AND STRATEGIC RESULTS (result indicators) | Shareholder Value |
| | | Level of Cost Reduction |
| | | Profitability |
| | | EVA (Earned Value Added) |
| | | EBITDA (Earnings before Interests, taxes, depreciation and amortization) |
| CUSTOMERS | | Level of Market Share |
| | | Value Added Perception |
| | | Level of Customer Interaction on Processes |
| | | Level of Customer Satisfaction |
| BUSINESS PROCESSES | SUPPLY CHAIN PROCESSES (impact and result indicators) | Processes Efficiency |
| | | Response Time |
| | | Level of Flexibility |
| | | Level and Extension of Transparency |
| | | Level of Collaboration |
| | | Level of Waste Reduction |
| | | Level and Extension of Processes Integration |
| | | Adequacy and Extension of Technologies |
| LEARNING AND GROWTH | CAPABILITES, TECHNOLOGIES AND INTEROPERABILITY (impact indicators) | Adequacy of Infrastructure to the new Technologies |
| | | Level of Horizontal Integration (Information and Technologies) |
| | | Level of Vertical Integration (Information and Technologies) |
| | | Level of People Competences |
| | | Adequacy to the Compliance and Legal Requirements |
| | | Level of Leadership Engagement |
| Coordination Effectiveness | | |

From the Table 2 it is possible to notice that there are two kinds of indicators which are known as **impact indicators** and **result indicators**. In the case of Supply Chain 4.0 Scorecard, **impact indicators** are those whose actions related to them will directly impact on the performance effect of other related indicators (**result indicators**) of the Supply Chain 4.0 Scorecard. For instance, in the **Capabilities, Technologies and Interoperability** dimension, indicators such as **level of people competences (impact indicator)** are measured in order to understand how the skills of people involved in supply chains in the Industry 4.0's initiatives are capable to support the implementation and conduction of new disruptive technologies. This provides managers the visibility of how capable people are, in terms of abilities required to work in this new environment. Consequently, the level of these people skills will impact on the other indicators such as **processes efficiency (result indicator)** which belongs to the **Supply Chain Processes** dimension and then on the indicators of **Strategic and Financial** dimension of the Supply Chain 4.0 Scorecard framework. This rationale follows the logic of the Strategic Map, broadly considered in the BSC structure. In the same sense, another example is related to the **level of horizontal and vertical integration (impact indicators)**. They will cause a direct impact on the interoperability of systems and information in order to guarantee the effectiveness of new disruptive technologies (supporting the dimension of **Capabilities, Technologies and Interoperability**) and then improve the indicators of **Supply Chain Processes** dimension (**result indicators**) of the Supply Chain 4.0 Scorecard.

Important to note that the indicators of **Capabilities, Technologies and Interoperability** dimension are in essence **impact indicators** because they are not impacted by any other previous dimension. On the other hand, indicators of **Strategic and Financial** dimension of Supply Chain 4.0 Scorecard are typically **result indicators** considering that they will not impact any other subsequent dimension. Unlikely, indicators of **Supply Chain Processes** dimension are both classified **impact and result indicators**. They are considered as **impact indicators** because will cause an impact on the indicators of **Strategic and Financial**

dimension. At the same time, they are also **result indicators** due to be impacted by indicators from **Capabilities, Technologies and Interoperability** dimension of the Supply Chain 4.0 Scorecard.

4. Conclusions

Performance measurement in Supply Chains in the Industry 4.0 era is a relevant and under explored topic of discussion and research. In particular, the literature shows very limited research in terms of present PMSs and in regards to their modern characteristics (i.e. broad perspectives, cause-and-effect relationship and strategic link).

Taking into consideration the aforementioned gap, this paper proposed a novel framework to measure the performance of Supply Chains 4.0. With the purpose to answer the research question “*How can the performance of supply chains within the context of Industry 4.0 be measured?*”, a theoretical background was presented with regards to Performance Measurement, Balanced Scorecard and Supply Chain Dimensions linked to the Industry 4.0 phenomenon. It was possible to establish, from the literature review, five main dimensions linked to industry 4.0, namely: **Capabilities, Technologies, Interoperability, Supply Chain Processes** and **Financial and Strategic Results**. Moreover, elements of each dimension were identified and presented in Table 1.

Seeking to build a theoretical framework, an alignment between these five dimensions of Supply Chain and four dimensions of BSC (**Learning and Growth, Business Processes, Customers** and **Financial**) was carried out, as demonstrated in Figure 2. This allowed to elaborate and propose the Performance Measurement System framework herein called **Supply Chain 4.0 Scorecard**.

4.1 Practical and Theoretical Implications

Practical implications from this paper are significant as Industry 4.0 is a new phenomenon and supply chains will have to review the way they measure performance into this new context. Hence, the Supply Chain 4.0 Scorecard may be used as a guidance foundation to start a new PMS faced with the need from an Industry 4.0 initiative. It provides broader perspectives to be considered as well as the deployment of each perspective presenting the measurement approaches, which is a positive starting point for the process of constructing performance indicators.

Nonetheless, besides the limitations of the proposed approach, as explained in the following section, the theoretical implication is also relevant. This study highlights important constructs for the measurement of performance in supply chains in the current context. The study also shows what the measurement through the Supply Chain 4.0 Scorecard implies for the practitioner in terms of **impact indicators** and **results indicators** of supply chain performance in the context of Industry 4.0. Thus, addressing a relevant gap related to the theory and practice. Moreover, the proposed framework does not completely overcome the gap in the literature regarding this subject, but it encourages researches to conduct more studies to establish a robust theory of PM in the era of Industry 4.0.

This paper can also be useful for practitioners such as operations managers, supply chain specialists and general/senior managers involved in Industry 4.0 program implementation in

supply chains. The proposed scorecard can help both the supply chain practitioners as well as technology professionals involved in new industry 4.0 implementation projects in order to properly measure the impacts and results on supply chains.

4.2 Limitations and Research Directions

Although this paper brings up relevant contributions, further research is required in order to overcome the limitations related to the validation of the framework herein proposed. From theoretical perspective, the Supply Chain 4.0 Scorecard is still limited in terms of its effectiveness when applied in an Industry 4.0 supply chains context. In addition, its limitation can be also found in relation to the detailed indicators to be used, once it presents the measurement approaches, which were created in line with the Balanced Scorecard structure and Supply Chain dimensions in the Industry 4.0 context. Furthermore, the proposal herein discussed is not the only one to be considered. Other PMSs frameworks must be investigated with regards its suitability for supply chains in this fourth revolution context.

It is important to emphasize that, according to Soderberg et al. (2011), the implementation of BSC on organizations and between organizations must respect levels and provide the common understanding between the managers involved. This means that the BSC structure itself is not enough to guarantee the successful performance measurement.

Despite some limitations, the framework provides important contribution as it can be used as guidance for future research related to Performance Measurement. Some studies that may be deployed are:

- 1) Longitudinal studies like action research, seeking to identify the barriers and success factors to implement the Supply Chain 4.0 Scorecard and deploy the specific key performance indicators for each perspective of the framework.
- 2) Surveys with hypothesis built from the framework herein presented, seeking views of academics and practitioners around the adequacy and applicability of the dimensions and elements considered in the framework.
- 3) Case studies, with the purpose to explore the phenomenon of PMS implementation in supply chains involved in an Industry 4.0 program and to make comparisons with the perspectives and elements of Supply Chain 4.0 Scorecard.

In addition, further theoretical insights are encouraged in order to consider other PMSs frameworks such as SCOR model and Performance Prism, bringing new advancements in terms of PM for supply chains in this challenged and promised fourth industrial revolution era.

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