UNIVERSITY OF SÃO PAULO
SÃO CARLOS SCHOOL OF ENGINEERING
PRODUCTION ENGINEERING DEPARTMENT

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Leadership 4.0: prioritization of competences based on the challenges towards Industry 4.0

São Carlos
2021

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Corrected Version

Dissertation presented at the São Carlos School of Engineering, at the University of São Paulo, as a requisite to obtain the degree of Master of Science in Production Engineering.

Concentration area: Processes and Operations Management

Supervisor: Prof. Dr. Mateus Cecílio Gerolamo

São Carlos

2021

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Callejas Guzmán, Valeria Emma
C157l Leadership 4.0: prioritization of competences based on the challenges towards industry 4.0 / Valeria Emma Callejas Guzmán; supervisor Mateus Cecílio Gerolamo. -- São Carlos, 2021.

Master Dissertation - Graduate Program in Production Engineering and Research area: Processes and Operations Management -- São Carlos School of Engineering of the University of São Paulo, 20 21.

1. Leadership 4.0. 2. Leadership competences. 3. Industry 4.0. 4. Challenges. 5. Fuzzy delphi. 6. Experts' perspective. I. Título.

Prepared by Eduardo Graziosi Silva - CRB-8/8907

FOLHA DE JULGAMENTO

Candidata: Engenheira **VALERIA EMMA CALLEJAS GUZMAN**.

Título da dissertação: "Liderança 4.0: priorização de competências com base nos desafios da Indústria 4.0".

Data da defesa: 24/06/2021

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ACKNOWLEDGMENTS

First of all, I thank God for life, and for the support to keep my persistence during this significant trajectory.

To my family, especially to my parents Rosario and Miguel, who have always encouraged me to go beyond my dreams, both are my inspiration. To my aunt Ive, to my uncles, Gustavo, Coco, Juan, Marcelo and Luis, and all my cousins. Thank you all for always being present in my life, even so kilometers away.

To my supervisor Prof. Mateus Gerolamo for all the opportunities and learning contributed during this valuable trajectory. Thank you for preparing me for the battlefields (even when I was not totally ready), each one allowed me to grow both personally and professionally. This achievement also resulted from your advices given.

To Professors Henrique Rozenfeld, Daniel Braatz, Holger Kohl, Kleber Esposto and Edson Cazarini for allowing me to be part of the Bragecrim project. To Bernd, and Wolf who supported me during my awesome experience at Technische Universität Berlin (TU Berlin), I thank you both for all, and for the time spent to teach me something new, contributing to my personal and professional experience. I also thank all of the Bragecrim team, for the support and collaboration.

To all experts, who accepted and dedicated their time to participate in this research, your contribution was essential to this work, thank you for the exchange of knowledge. To Professors Joseane Pontes and Daniel Braatz for their valuable suggestions to improve this study.

To all my friends around the world for the bonds of friendship created along this life. To my friends *Raparig@s*, who have made my days happier and lighter during this journey. To my colleagues of the research laboratory. To every person who contributed to this research with new insights and suggestions.

To the São Carlos School of Engineering for this incredible opportunity, and for all collaborators of the Department of Production Engineering, thank you all for the support. Finally, I thank CAPES. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001

"If your dreams do not scare you, they are not big enough"
(Ellen Johnson Sirleaf)

ABSTRACT

GUZMÁN, V.E. **Leadership 4.0: prioritization of competences based on the challenges towards Industry 4.0.** 2021. Dissertation (Master) - São Carlos School of Engineering, University of São Paulo, São Carlos, 2021.

The benefits offered by the Industry 4.0 (I4.0) technologies (which are in the context of the 4th Industrial Revolution) to companies include a smarter and more connected manufacturing process, thus ensuring customized products and services. However, some challenges from the transition process towards I4.0, such as acceptance of organizational transformation, adaptation or development of business model, qualification of workers, connection and security issues, among others are posed. The role of leaders and managers in guiding organizations as a whole to the current revolution, as well as preparing and qualifying them with the respective leadership competences required in I4.0 context (I4.0 LC) for their dealing with those challenges is fundamental. However, this latter topic is still little explored in the literature. Therefore, this study aims to identify and prioritize I4.0 LC that supports leaders and managers to deal with challenges towards I4.0. To achieve this goal, the FDM (Fuzzy Delphi Method) was carried out in two phases according to a Brazilian and international experts' perspective. The First was devoted to analyzing and prioritizing I4.0 LC and challenges towards I4.0 separately. The Second was dedicated to analyzing and prioritizing the I4.0 LC that support the challenges, resulting from the first phase. The outcomes show that: 11 out of the 15 I4.0 LC were prioritized contributing with the challenges, and 7 out of the 11 I4.0 LC were highlighted due to their higher degree of evaluation showed when those I4.0 LC were related to challenges, and 3 out of the 7 I4.0 LC (digital perspective, connector and asking big questions) were identified as the I4.0 LC that contribute to deal with more than one challenge. A synthesis is proposed to encompass both phases during I4.0 LC prioritization until the identification of those I4.0 LC that contribute with challenges, the I4.0 LC are categorized into four groups (methodological, social, personal and technological). From an academic perspective, these results support the understanding of the role of prioritized I4.0 LC and its proposal descriptions, thus contributing to the literature on managerial approaches. From an industrial perspective, these results support the preparation of leaders and managers with the I4.0 LC required for dealing with the challenges towards I4.0, considering the higher degree of evaluation when both variables are related.

Keywords: Leadership 4.0. Leadership competences. Industry 4.0. Challenges. Fuzzy Delphi. Experts' perspective.

RESUMO

GUZMÁN, V.E. **Liderança 4.0: priorização de competências com base nos desafios da Indústria 4.0.** 2021. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, São Carlos, 2021.

Os benefícios oferecidos pelas tecnologias da Indústria 4.0 (I4.0) (que estão no contexto da 4ª Revolução Industrial) às empresas incluem um processo de manufatura mais inteligente e conectado, assegurando assim produtos e serviços personalizados. Contudo, alguns desafios do processo de transição para I4.0, tais como a aceitação da transformação organizacional, adaptação ou desenvolvimento do modelo de negócio, qualificação dos trabalhadores, questões de conexão e segurança, entre outros, são colocados. O papel dos líderes e gestores na orientação das organizações como um todo para a atual revolução, bem como na sua preparação e qualificação com as respectivas competências de liderança exigidas na I4.0 (I4.0 LC) para lidar com esses desafios, é fundamental. Contudo, este último tópico é ainda pouco explorado na literatura. Dessa forma, esta pesquisa visa identificar e dar prioridade às I4.0 LC que apoia líderes e gestores a lidar com os desafios na I4.0. Para atingir este objetivo, o FDM (Método *Fuzzy Delphi*) foi executado em duas fases, de acordo com a perspectiva de especialistas brasileiros e internacionais. A primeira foi dedicada à análise e priorização das I4.0 LC e dos desafios para a I4.0 separadamente. A segunda foi dedicada à análise e priorização das I4.0 LC que contribuem para lidar com os desafios, resultantes da primeira fase. Como resultados obtidos: 11 das 15 I4.0 LC foram priorizados para contribuir para lidar com os desafios, e 7 das 11 I4.0 LC foram destacadas devido ao seu maior grau de avaliação demonstrado quando essas I4.0 LC estavam relacionados com desafios, e 3 das 7 I4.0 LC (perspectiva digital, conector e fazer grandes perguntas) foram identificados como as I4.0 LC que contribuem para lidar com mais do que um desafio. É proposta uma síntese para abranger ambas as fases durante a priorização das I4.0 LC até à identificação das I4.0 LC que contribuem com os desafios, as I4.0 LC são categorizados em quatro grupos (metodológicas, sociais, pessoais e técnicas). De uma perspectiva académica, estes resultados apoiam a compreensão do papel das I4.0 LC priorizadas e das suas descrições propostas, contribuindo assim para a literatura sobre abordagens de gestão. De uma perspectiva industrial, estes resultados apoiam a preparação de líderes e gestores com as I4.0 LC necessárias para lidar com os desafios para I4.0, considerando o maior grau de avaliação quando ambas as variáveis estão relacionadas.

Palavra-chave: Liderança 4.0. Competências de liderança. Indústria 4.0. Desafios. *Fuzzy Delphy*. Perspectiva de especialistas.

LIST OF FIGURES

FIGURE 1 -RESEARCH OVERVIEW 28
FIGURE 2 -MENTAL MAP: AN OVERVIEW OF THE LITERATURE REVIEW 29
FIGURE 3 – THE INDUSTRY 4.0 TECHNOLOGIES EXPECTED TO HAVE IN ORGANIZATIONS 32
FIGURE 4 - PERSPECTIVE OF INDUSTRY 4.0 WITH ITS TECHNOLOGIES IN A COMPANY 33
FIGURE 5 -OVERVIEW OF THE RESEARCH METHODOLOGY 49
FIGURE 6 - I4.0 LC ORGANIZED FROM PRIORITIZED TO NOT PRIORITIZED IN RELATION TO THE THRESHOLD VALUE 62
FIGURE 7 - CHALLENGES TOWARDS I4.0 ORGANIZED FROM PRIORITIZED TO NOT PRIORITIZED IN RELATION TO THE THRESHOLD VALUE 64
FIGURE 8 - EVALUATION OF DIMENSIONS CONSIDERED RELEVANT TOWARDS I4.0 TRANSITION BASED ON EXPERTS 67
FIGURE 9 - THE I4.0 LC THAT CONTRIBUTE TO SUPPORT EACH CHALLENGE TOWARDS I4.0: BASED ON ALL EXPERTS 75
FIGURE 10 - OVERVIEW OF THE PRIORITIZATION OF I4.0 LC: AN INFORMATION TREE 79
FIGURE 11 - DENSITY VISUALIZATION OF WOS, FIRST ROUND 91
FIGURE 12 - DENSITY VISUALIZATION OF SCOPUS, FIRST ROUND 93
FIGURE 13 - DENSITY VISUALIZATION OF WOS, SECOND ROUND 94
FIGURE 14 - DENSITY VISUALIZATION OF SCOPUS, SECOND ROUND 94
FIGURE 15 - THE I4.0 LC THAT CONTRIBUTE TO EACH CHALLENGE TOWARDS I4.0: BASED ON BRAZILIAN EXPERTS 123
FIGURE 16 - THE I4.0 LC THAT CONTRIBUTE TO EACH CHALLENGE TOWARDS I4.0: BASED ON INTERNATIONAL EXPERTS 128

LIST OF TABLES

TABLE 1 - DESCRIPTION OF CHALLENGES TOWARDS INDUSTRY 4.0 (CONTINUES) 36
TABLE 2 - LEADERSHIP COMPETENCES REQUIRED IN INDUSTRY 4.0 ENVIRONMENT BASED ON THE LITERATURE (CONTINUES) 44
TABLE 3 - SYNTHESIS OF THE MAINS FINDINGS IN LITERATURE REVIEW 48
TABLE 4 - RELATIONSHIP OF RESPONSES: FIRST PHASE 52
TABLE 5 - RELATIONSHIP OF RESPONSES: SECOND PHASE 54
TABLE 6 - OVERVIEW OF EXPERTS´ PROFILES FOR BOTH QUESTIONNAIRES: FIRST PHASE 57
TABLE 7 - RESULTS FROM THE TRIANGULAR FUZZY NUMBER-I4.0 LC QUESTIONNAIRE 58
TABLE 8 - RESULTS FROM THE TRIANGULAR FUZZY NUMBER-CHALLENGES TOWARDS I4.0 QUESTIONNAIRE 59
TABLE 9 - DEFUZZIFICATION OF TRIANGULAR FUZZY NUMBERS FROM I4.0 LC AND CHALLENGES TOWARDS I4.0 . 60
TABLE 10 - FILTERING OF VARIABLES: I4.0 LC PRIORITIZED BY EXPERTS 61
TABLE 11 - COMMENTS FROM THE EVALUATION OF THE I4.0 LC PRIORITIZED AND UNPRIORITIZED BY EXPERTS ... 63
TABLE 12 - FILTERING OF VARIABLES: CHALLENGES TOWARDS I4.0 PRIORITIZED BY EXPERTS 63
TABLE 13 - COMMENTS FROM THE EVALUATION OF CHALLENGES TOWARDS INDUSTRY 4.0 PRIORITIZED AND UNPRIORITIZED BY EXPERTS 64
TABLE 14 - DEMOGRAPHIC INFORMATION AND PROFESSIONAL PROFILE OF 40 EXPERTS 66
TABLE 15 - TRIANGULAR FUZZY NUMBER RESULTED FROM EXPERTS' PERSPECTIVE (CONTINUES) 67
TABLE 16 - DEFUZZIFICATION AND FILTERING OF THE I4.0 LC (15) REGARDING CHALLENGES TOWARDS I4.0 (6): BASED ON ALL EXPERTS' PERSPECTIVE (CONTINUES) 70
TABLE 17 - DEFUZZIFICATION: OVERVIEW OF THE I4.0 LC RELATED WITH THE CHALLENGES TOWARDS INDUSTRY 4.0 FROM PRIORITIZED TO UNPRIORITIZED BASED ON ALL EXPERTS 74
TABLE 18 - THE I4.0 LC WITH HIGHER DEFUZZIFICATION VALUE RELATED WITH CHALLENGES TOWARDS INDUSTRY 4.0 76
TABLE 19 - APPROACHES FROM THE LITERATURE REGARDING THE 34 LEADERSHIP COMPETENCES (I4.0 LC) (CONTINUES) 95
TABLE 20 - DEFUZZIFICATION AND FILTERING OF THE I4.0 LC (15) REGARDING CHALLENGES TOWARDS I4.0 (6): BASED ON THE PERSPECTIVE OF BRAZILIAN EXPERTS (CONTINUES) 117
TABLE 21 - DEFUZZIFICATION: OVERVIEW OF THE I4.0 LC RELATED WITH THE CHALLENGES TOWARDS INDUSTRY 4.0 TO ILLUSTRATE FROM PRIORITIZED TO NOT PRIORITIZED BASED ON BRAZILIAN EXPERTS' 122
TABLE 22 - DEFUZZIFICATION AND FILTERING OF THE I4.0 LC (15) REGARDING CHALLENGES TOWARDS I4.0 (6): BASED ON THE PERSPECTIVE OF INTERNATIONAL EXPERTS (CONTINUES) 124
TABLE 23 - DEFUZZIFICATION: OVERVIEW OF THE I4.0 LC RELATED WITH THE CHALLENGES TOWARDS INDUSTRY 4.0 TO ILLUSTRATE FROM PRIORITIZED TO NOT PRIORITIZED BASED ON INTERNATIONAL EXPERTS' 127

LIST OF ABREBRIATIONS

AI	Artificial intelligence
VR/AR	Augmented and Virtual reality
CPS	Cyber-physical systems
I4.0	Industry 4.0
ICT	Information and Communication Technology
IoT	Industrial Internet of Things
IT	Information Technology
FIR	Fourth Industrial Revolution
FDM	Fuzzy Delphi Method
I4.0 LC	Leadership Competences 4.0
USP	University of São Paulo
MIT	Massachusetts Institute of Technology
MTP	Massive Transformative Purpose
PESTEL	Political, Economic, Social, Technical, Environmental, and Legal factors
RQ	Research question
HR	Human Resource
SC	Social competences
PC	Personal competences
MC	Methodological competences
TC	Technical competences

Table of contents

1 INTRODUCTION 23
1.1 JUSTIFICATION AND RESEARCH GOAL 25
1.2 OVERVIEW OF THE RESEARCH DESIGN 27
2 LITERATURE REVIEW 29
2.1 INDUSTRY 4.0 CONTEXT 29
2.2 CHALLENGES TOWARDS INDUSTRY 4.0 CONTEXT 34
2.3 LEADERSHIP IN INDUSTRY 4.0 CONTEXT 38
2.4 LEADERSHIP COMPETENCES IN INDUSTRY 4.0 CONTEXT 40
2.5 SYNTHESIS OF LITERATURE REVIEW 48
3 RESEARCH METHOD 49
3.1 EMPIRICAL APPROACHES: FIRST PHASE 51
3.2 EMPIRICAL APPROACHES: SECOND PHASE 53
4 RESULTS 57
4.1 RESULTS AND ANALYSIS: FIRST PHASE 57
4.2 RESULTS AND ANALYSIS: SECOND PHASE 65
5 I4.0 LC REGARDING CHALLENGES TOWARDS I4.0 CONTEXT BASED ON EXPERTS PERSPECTIVE 79
6 CONCLUSION AND FINAL CONSIDERATIONS 81
REFERENCES 83
Appendix A - An analysis of databases results (abstracts and key words) in VOSviewer 91
Appendix B - Approaches from the literature regarding the 34 Leadership Compentences (I4.0 LC) analyzed with the support of NVivo 95
Appendix C - Questionnaires of the first and second phase (empirical approaches) 102
Appendix D – Questionnaire for the second phase to analyze and identify the leadership competences that supports to the challenges towards Industry 4.0 108
Appendix E – Analysis of data resulted from Brazilian and international experts' perspective based on FDM 117

1. INTRODUCTION

Industry 4.0 (I4.0), also known as the Fourth Industrial Revolution (FIR) (VAIDYA, AMBAD, BHOSLE, 2018; EROL et al., 2016), was introduced in the 2011 during the Hannover Fair, as part of the German governmental strategy for high-tech development in manufacture (SMIT et al., 2016). The Industry 4.0 term has become popular in other countries as a global technology trend from government's initiative (FIRJAN, 2016). In Germany the term adopted is *Industrie* 4.0 (HERMANN; PENTEK; OTTO, 2015).

According to Schwab (2016), three reasons distinguish the 4th Industrial Revolution from the other ones firstly, the exponential velocity of the world's interconnection and emergence of new technologies that lead to innovation; secondly, the breadth and depth, since the digital revolution is the basis of FIR combined with many technologies, thus enabling paradigms shifts; lastly, the systemic impact of the transformation of the entire systems on companies, value creation networks, countries, and the society.

Industry 4.0 is related to technological trends, according to which the internet and supporting technologies (e.g. embedded systems) can be a backbone for the integration of physical objects, human actors, intelligent machines, production lines, and processes, as well as boundaries of the organization for the creation of a new intelligent network and agile value chain (SCHUMACHER; EROL; SIHN, 2016).

Companies that are moving towards Industry 4.0 must be aware of the aspects that can be influenced, understanding the impacts such as challenges and opportunities (PEREIRA; ROMERO, 2017). According to Rüßmann et al. (2015), Industry 4.0 enables a quick response to customers' needs, and improves the flexibility, speed, productivity, and quality of the production process. Consequently, new business models, production processes and other innovations can be adopted (RÜßMANN et al., 2015) (e.g., new products and services (PEREIRA; ROMERO, 2017)).

Industry 4.0 and its technologies offer new opportunities for the optimization of manufacture in real time when intelligent sensors, artificial intelligence and data analytics are combined (XU; XU; LI, 2018). It also promotes the development of manufacturing systems integrating and synchronizing real-time data between physical objects and cyber computational space (XU; XU; LI, 2018).

Müller; Kiel; Voigt (2018) highlighted the opportunities from strategic, operational, environmental and social perspectives that drive the Industry 4.0 implementation. Strategic opportunities can offer competitive advantages and long-term success, whereas operational ones improve efficiency, timing, flexibility and quality. Environmental and social opportunities

reduce waste and resource and energy consumption. From a social perspective, opportunities result from the adoption of smart and autonomous production systems that support employees in repetitive and monotonous activities (MÜLLER; KIEL; VOIGT, 2018).

Alternatively, some challenges and issues must be considered for a more comprehensive application of Industry 4.0 (XU; XU; LI, 2018). Pereira; Romero (2017) argue that its introduction will also pose challenges to companies with changes in products and manufacturing systems regarding design, processes, operation, and systems, related to the adaptation of the production processes and operations due to the technological developments (PEREIRA; ROMERO, 2017). Consequently, such new customized products and services will affect traditional business models and demand for new ones, and the workforce environment will be impacted with new job profiles in an Industry 4.0 context. All such impacts will require the preparation and qualification of workers in all organizational levels and development of competences and skills (PEREIRA; ROMERO, 2017) such as capacity for teamwork, communication, motivation, affinity for technology, personal responsibility, openness, knowledge of sciences & mechanics, among others (MÜLLER-FROMMEYER et al., 2017).

The emerging technologies of Industry 4.0 and organizational changes in the workplace will impact (as already occurring) the future of jobs (WORLD ECONOMIC FORUM, 2018) and the environment of millions of workers (EROL et al., 2016). In this context, the authors argue that individuals involved in engineering and management practices must handle uncertainties and incomplete and contradicting information from an organization's environment (EROL et al., 2016). Therefore, the Industry 4.0 paradigm stimulates changes in both competences and skills of employees and managers (ASSANTE et al., 2019).

According to Erol et al. (2016), the Industry 4.0 challenges are not limited to financial aspects of the acquisition of new technologies, but also related to the evaluation of qualified staff in all organization levels for the future production system of Industry 4.0 (EROL et al., 2016), whose digital systems are based on CPS (Cyber-physical Systems) (ZHOU; LIU; ZHOU, 2015). The FIR requires management skills and qualification strategies of industrial work with the introduction of new technologies - executives must be qualified to manage with digital technologies (KOMAROVA, ZAMKOVOI, NOVIKOV, 2018). Therefore, such challenges must be faced for guaranteeing the full potential of the Industry 4.0 adoption (XU; XU; LI, 2018).

In this regard, top management plays a fundamental role in the FIR, since it perceives organizational opportunities for integrating Industry 4.0 technologies and environmentally-sustainable manufacturing into the existing production systems (DE SOUSA JABBOUR et al.,

2018). According to Sony; Naik (2019), the involvement and commitment (engagement) of top management will be essential for a successful Industry 4.0 implementation.

Schneider (2018) emphasizes the essential role of leadership in guiding the transition process, changes, and challenges towards Industry 4.0, and Kohl; Swartz (2019) claim Industry 4.0 will require leaders who will become mentors and coaches that provide feedback on its good performance and encouraging improvement. Moreover, they will drive people by incentivizing opinions, developing ideas, and designing solutions to problems and challenges.

A survey developed by Deloitte to examine the leaders' readiness towards Industry 4.0 transition was applied to more than 2000 C-suite executives across 19 countries. One of the results showed that only 10% of leaders have longer-range strategies to leverage new technologies within their organizations. These executives are innovating and growing successfully integrating I4.0 technologies. Consequently, this low percent of leaders is more confident (than the others) leading in Industry 4.0 context, attracting, preparing and training the talent to be ready in the current context (DELOITTE INSIGHTS, 2020).

Schneider (2018); Sony, Naik (2019) and Helming et al. (2019) highlighted the relevant role of leaders and managers in Industry 4.0, who adopt technological trends and management strategies towards meeting market requirements (PEREIRA; ROMERO, 2017) and dealing with challenges from the current revolution. Since leaders, managers and workers must be qualified for successfully acting in such a context (RICHERT et al., 2016), the development of competences becomes essential. Therefore, this study focuses on the leadership competences required in the Industry 4.0 context and its challenges. In this study, the leadership approach is explored in the literature in a general view, since leadership in I4.0 context is still being defined in the literature.

1.1 JUSTIFICATION AND RESEARCH GOAL

Leaders in the FIR should be prepared to understand all dimensions and possibilities of technologies and their derivations (MAGALDI; SALIBI NETO, 2018); therefore, new models, theories and concepts related to this new revolution (MAGALDI; SALIBI NETO, 2018) must be known. According to Allen (2020) leaders in the different industries (including higher education) will require to understand the distinct disruptive technologies that are part of the I4.0 context and how they transform business.

A global research study developed by MIT Sloan (Massachusetts Institute of Technology) (surveyed 4296 global leaders and 17 executives' interviews) to explore shifting attitudes about the future of leadership in an agile and digital environment revealed that a

successful leadership is conditioned by digital competences (SCHRAGE et al., 2021). Moreover, such competences will become relevant to the positive progress of the organization (SCHRAGE et al., 2021). However, less than half of the survey respondents (48%) affirm that their companies create a diverse project teams in terms of digital savviness. In addition, 31 % of respondents believe that their organizations assess whether managers are improving their digital skills. Also, 93% of respondents affirm that being digitally savvy is essential to performing well in their role, although few recognize that leaders are committed to their digital talent development (SCHRAGE et al., 2021).

According to Bianco et al (2021), Shamim et al. (2016) and Oberer, Erkollar (2018) most the studies on Industry 4.0 have focused on the technological aspects of companies, disregarding management approaches in the current revolution that must be explored (e.g., leadership). The introduction of new technologies as part of Industry 4.0 exerts new impacts on management-oriented subjects, such as teams, organizational culture, motivation, project management, and leadership (ALLEN, 2020).

Borges et al. (2019) described opportunities for the exploration of other aspects related to leadership and Industry 4.0, since it is a new subject to be developed and discussed and the literature on competences for leaders and managers in Industry 4.0 context is scarce (SCHNEIDER, 2018; HELMING et al., 2019). “High-performance organizations must cultivate leaders capable of effectively leading a digitally savvy workforce” (SCHRAGE et al., 2021, p.3). However, in the MIT Sloan global study, few respondents recognized thet organization was fostering digital talent development, particularly among managers (SCHRAGE et al., 2021).

Hecklau et al. (2016) proposed a competence model for workforce in Industry 4.0 from the emerging challenges (macro-environmental challenges) based on PESTEL-framework[1] that considers political, economic, social, technical, environmental, and legal factors. Erol et al. (2016) developed a competence model according to competences in production (e.g., workers, engineers and managers) required by Industry 4.0. The FIR results in disruptive challenges on different scales (i.e. business models, manufacturing processes, economy), which demand the upgrade of human force at all levels towards facing those challenges (FLORES; XU; LU, 2020). Magali; Salibi Neto (2018) emphasize the importance of leadership roles and their respective competences in the environment of the FIR. However, the literature reports no proposal of

[1] PESTEL-framework “is used to analyze and map how the external environment influences an industry” (SONG; SUN; JIN, 2017, p.277) considering Political, Economic, Social, Technical, Environmental, and Legal factors.

leadership competences in Industry 4.0 that considers challenges in theoretical and empirical perspectives.

According to Leskiw; Singh (2007, p.460), “Leadership development will continue to be a key organizational issue in the future”. Therefore, the development of leaders and managers is a key organizational issue in Industry 4.0 context. Consequently, **the main goal of this research is to prioritize the leadership competences towards the development of leaders and managers who act and deal with the requirements of Industry 4.0 and FIR as a whole**. The Research Question (RQ) that guides it is: *what are the main leadership competences that better fit with the challenges towards Industry 4.0 context?*

The following three specific goals were considered:

(I) Identification of challenges towards Industry 4.0.

(II) Identification of leadership competences and their descriptions in Industry 4.0.

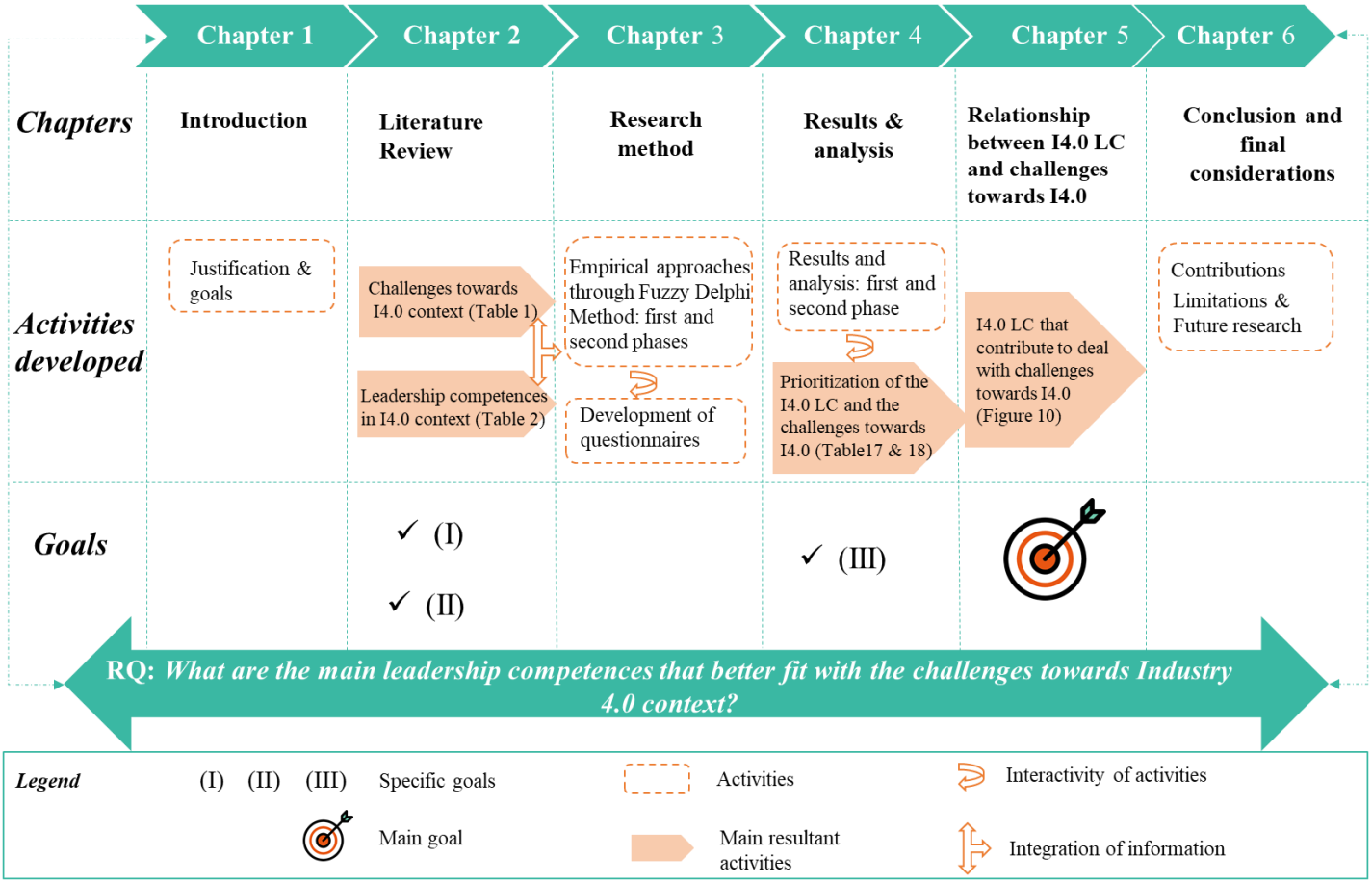
(III) Analysis of leadership competences and challenges towards Industry 4.0.

The research will contribute to managerial and organizational approaches in the Industry 4.0 environment due to the scarcity of current literature (SHAMIM et al., 2016; AGOSTINI, FILIPPINI, 2018; BIANCO et al., 2021).

1.2 OVERVIEW OF THE RESEARCH DESIGN

This study is organized into six chapters. Chapter 1 addresses the introduction, justification, main goal, and specific goals; Chapter 2 describes a literature review on Industry 4.0 and its challenges, and leadership and its competences; Chapter 3 presents the methodology applied, which is comprised of empirical approaches; Chapter 4 reports the results and analysis; Chapter 5 proposes a relationship of leadership competences that support challenges towards Industry 4.0; finally, Chapter 6 is devoted to the conclusions, limitations, and suggestions for future research. Figure 1 shows an overview of the research.

Figure 1 -Research overview



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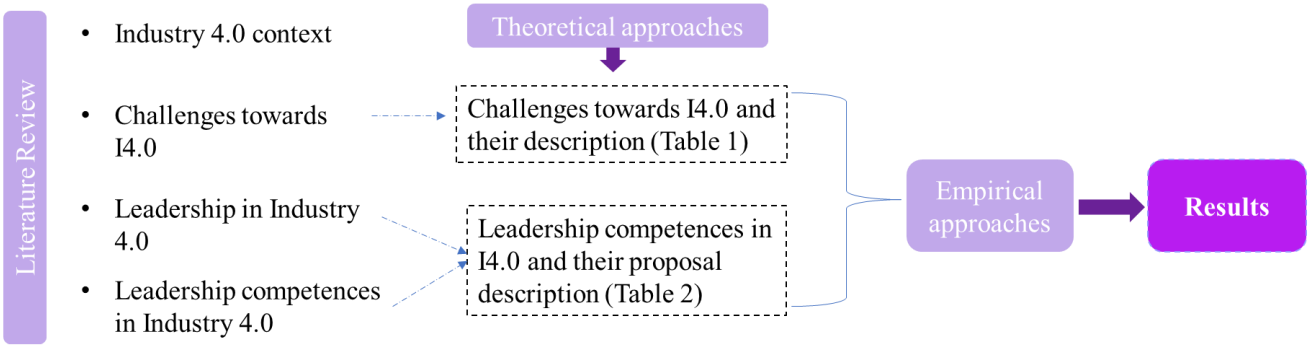
2. LITERATURE REVIEW

This chapter addresses the following subjects: Industry 4.0, its challenges, the approach of leadership and its competences in Industry 4.0. All subjects are aimed at elucidating the main objective of the research, i.e., a deeper understand of the relevance of leadership and its respective competences in Industry 4.0 and exploration of challenges related to Industry 4.0. A theoretical relationship that supports the proposal of leadership competences regarding the challenges towards Industry 4.0 was developed. Figure 2 displays a mental map of the relations of the literature review topics as theoretical approaches for supporting the empirical process that contributes to the achievement of the main goal.

Figure 2 -Mental map: an overview of the literature review



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2.1 INDUSTRY 4.0 CONTEXT

Industry 4.0 concept embraces the integration of information and communication technologies and industrial technology that focuses primarily on the construction of a Cyber-physical System (CPS) towards a digital and intelligent factory (ZHOU, LIU, ZHOU, 2015). Industry 4.0 enables manufacturing to become more digital, customized, green and guided by information (ZHOU, LIU, ZHOU, 2015). According to Rüßmann et al. (2015), in the Industry 4.0 transformation process, sensors, machines, workpieces, and IT (Information Technology) systems will be connected along the value chain cross limits beyond a single company.

Industry 4.0 is triggered by new digital technologies, such as cloud computing and the Internet of Things (COLLI et al., 2019), which have been transforming the operations, services, and products in large and small organizations (HEAVIN; POWER, 2018). “A core element of

Industry 4.0 is the full digitalization of production and the exploitation of data[2] to enable intelligent planning and control of production processes and networks" (EROL et al., 2016, p.15), i.e., digitalized and decentralized production networks act autonomously and efficiently to control their operations in response to changes (EROL et al., 2016). "The level of digitization is the percentage of organizational assets which can communicate, control and supervise itself digitally, e.g., using sensors" (SONY, NAIK, 2019, p.47).

According to Kagermann et al. (2013), Industry 4.0 can support the development of horizontal value networks at a strategic level, prepare end-to-end integration across the entire value chain of the business process level, considering engineering, and facilitate a vertical integrated and networked design of manufacturing systems. Based on Wang et al. (2016), Kagermann et al. (2013) proposed three characteristics of Industry 4.0 to be considered, namely horizontal integration through value networks, vertical integration of hierarchical subsystems, and end-to-end engineering integration across the entire value chain.

Horizontal integration refers to the different IT systems used in stages of manufacturing and business planning processes related to collaborative exchange (e.g., materials, energy and information) both within a company and among several different companies (KAGERMANN et al., 2013). Vertical integration refers to the different physical and informational subsystems of a company, such as actuator and sensor, control, production management, manufacturing, and corporate planning (WANG et al., 2016). Finally, end-to-end engineering integrations are related to the activities supported across the entire value chain (customer requirement expression, product design and development, production planning, production engineering, production services, maintenance, and recycling), ensuring product customization (WANG et al., 2016).

"*Industrie* 4.0 is a collective term for technologies and concepts of value chain organization" (HERMANN; PENTEK; OTTO, 2015, p.11). As part of the smart companies, Cyber-Physical Systems (CPS) monitor the physical process to create a virtual copy of the physical world and make decentralized decisions (HERMANN; PENTEK; OTTO, 2015). According to Schwab (2016), the Internet of Things (IoT) is consider the bridge between physical and digital applications, connecting uniquely identifiable physical objects (things) with a virtual representation in an Internet-like structure. It is no longer comprised of only human participants, but things (SCHWAB, 2016), and enables the CPS to communicate and cooperate

[2] Exploitation of data-The company's IT infrastructure is a key element for data exploitation (MOEUF et al., 2019, p.1394), which is supported by technologies such as big data and simulations (MOEUF et al., 2020).

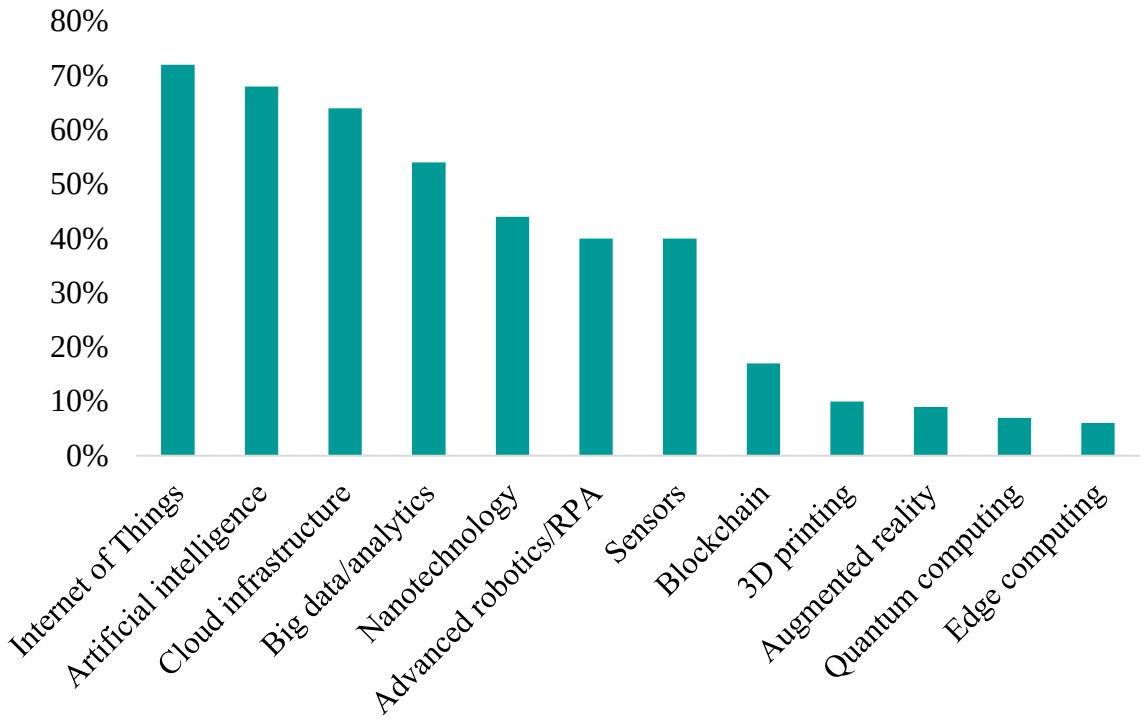
with people in real-time. In addition, the Internet of Services (IoS) contributes to the internal and cross-organizational services offered to value chain participants (HERMANN; PENTEK; OTTO, 2015).

According to Rüßmann et al. (2015), Industry 4.0 encompasses nine advances in technology, namely:

- autonomous robots, which interact and work safely with humans;
- simulation, which mirrors the physical world in a virtual model that includes machines, products, humans, etc.;
- horizontal and vertical system integration, which supports the integration of departments, suppliers, customers, functions, companies, capabilities, among other;
- Industrial Internet of Things (IIoT), which enriches devices with embedded computing through standard technologies;
- cybersecurity, which protects the connectivity of industrial systems and manufacturing lines;
- the cloud, which increases data sharing across sites and company boundaries, such as production systems;
- additive manufacturing, which is primarily used for the prototyping and production of individual components by 3-D printing, for example;
- augmented reality, which provides workers with real-time information for improving decision-making and work procedures,
- big data and analytics, which support real-time decision-making.

Based on a survey developed by Deloitte Global more than 2000 C-suite executives across 19 countries examined the readiness towards Industry 4.0 and its technologies. The leaders defined the I4.0 technologies expected to have the most profound impact on their organizations. The big four technologies that present a high ranking are: IoT, Artificial intelligence (AI), Cloud infrastructure, and Big data/analytics. Such technologies work together to connect organizations and systems, generate data, and drive more intelligent operations (DELOITTE INSIGHTS, 2020). Figure 3 shows all I4.0 technologies ranked by leaders.

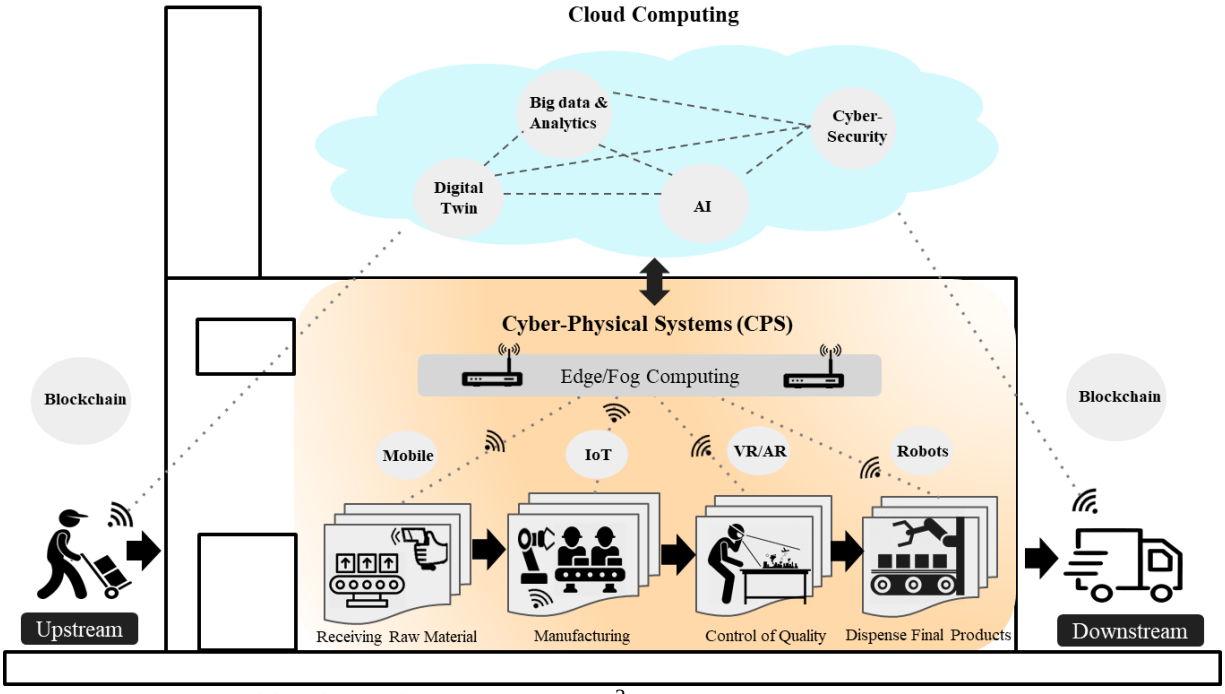
Figure 3 – The Industry 4.0 technologies expected to have in organizations



Source: Deloitte Global analysis, 2020

According to Figure 3, Internet of Things (IoT), Artificial intelligence (AI), Cloud infrastructure, and Big data/analytics are the main technologies to be adopted in the organization, based on the leaders' opinion. In that perspective, Frank et al. (2019) proposed four base technologies in their theoretical framework of Industry 4.0, namely IoT, cloud, big data, and analytics towards supporting the Industry 4.0 dimensions (i.e., smart manufacturing, smart products, smart supply chain, and smart working), and which refer to technologies that enable both interconnectivity and intelligence. IoT aims to solve communication issues of all objects and systems in a factory, and cloud services provide access to information and services. "Lastly, big data and analytics are considered enablers to advanced applications of Industry 4.0" (FRANK et al., 2019, p.19). Figure 4 illustrates an Industry 4.0 perspective in companies with the connection of its technologies in real-time.

Figure 4 - Perspective of Industry 4.0 with its technologies in a company



Source: created by the author & Mourarias[3] (2021)

Legend: The image illustrates a company interconnected with different technologies into Industry 4.0 context. The Upstream represents the arrival of material inputs for the production. Figure 4 shows an example of production line from the Receiving raw material (first stage) to the Dispense final products (last stage) in order to start the distribution of end products (Downstream). All the stages presented in Figure 4 are interconnected in real time by the cloud computing that integrates technologies into Industry 4.0 context. such as AI, *Digital twin, Biga data &Analytics, Cyber-security, **Blockchain, IoT, Robots, VR/AR and Mobile. *Digital twin supports to break the barriers between the physical and the cyber world of manufacturing (QI; TAO, 2018).**Blockchain can be considered a database organized in as a list of ordered blocks. “Blockchain facilitates transactions’ auditing” (CASINO; DASAKLIS; PATSAKIS, 2019 p.56).

The advanced technologies resulting from FIR can potentially improve different aspects of life (XU; DAVID; KIM, 2018). FIR creates an environment where virtual and physical manufacturing systems cooperate in a global and flexible way, and supports an exclusive customization of products and creation of new operational models (SCHWAB, 2016), thus opening up opportunities.

Among such opportunities, Xu; David; Kim (2018) highlighted: 1) lower barriers between inventors and markets with the introduction of new technologies such as 3D printing; 2) new opportunities for economic growth offered by AI (despite its being considered a threat to several employees); 3) integration of emerging technologies and domains (fusion) for the

[3] Mourarias (2021) is a researcher in the area of Industry 4.0 and Agriculture 4.0 forming part of the Change and innovation management research group in the Department of Production Engineering at the São Carlos School of Engineering, at the University of São Paulo (EESC-USP). He is in the process of finishing his master’s thesis.

creation of new markets and growth opportunities; 4) improvements in life quality at home, work, and other places promoted by robots; and 5) spread of interconnected devices in different areas.

Industry 4.0 and its technologies will enable data gathering and analyses across machines, hence, faster, flexible and efficient processes for the production of higher-quality goods at lower costs (RÜßMANN et al., 2015; OLSEN; TOMLIN, 2020). As a result, the manufacturing productivity will foster industrial growth and modify the workforce profile (RÜßMANN et al., 2015).

Industry 4.0 will also transform manufacturing processes integrating production and logistics through the exchange of products and production data among companies and between customers and suppliers, enhancing cooperation among machines and humans. Consequently, manual labor will be reduced with the use of real-time data, improving product quality, and increasing factory floor efficiency through automation (RÜßMANN et al., 2015).

Herceg et al. (2020) and Müller; Kiel; Voigt (2018) claim studies on opportunities and challenges considered important for the implementation of Industry 4.0 in companies, since these studies are still scarce. Such an implementation in companies can offer long-term benefits and opportunities if challenges are accepted and handled consciously (MÜLLER; KIEL; VOIGT, 2018). The following section addresses the challenges identified in the literature towards Industry 4.0.

2.2 CHALLENGES TOWARDS INDUSTRY 4.0 CONTEXT

According to Mohamed (2018), some companies and factories do not consider possible challenges for the Industry 4.0 implementation, which are highlighted by Xu; Xu; Li (2018) (e.g., need for the development of ICT (Information and Communication Technology) infrastructure at both intra-organizational and inter-organizational levels, scalability, since more physical objects are connected to the manufacturing network, data science/data analytics, and integration of IoT with existing ICT systems or legacy systems[4]).

Culot et al. (2019) pointed Cybersecurity as another challenge of Industry 4.0, since business operations are associated with data, and, in the current scenario, organizational and supply chain information systems are still vulnerable to cyber-attacks (CULOT et al., 2019). Kiel et al. (2017) also presented challenges of Industry 4.0 from the perspective of industrial

[4] Legacy systems also known as ICT systems (XU; XU; LI, 2018) or new systems are developed by modern techniques and technologies (GRANGEL-GONZÁLEZ et al., 2016).

experts, which are based on the Triple Bottom Line (TBL) of sustainable value creation in social, economic, and environmental aspects. In an approach of organizational and managerial practices for Industry 4.0, Agostini; Filippini (2018) concluded that managers must be prepared at organizational and managerial levels for the Industry 4.0 transformation, before managing and acting with the technology.

Schneider (2018) reported that research on I4.0 is less deep regarding managerial challenges than that on technologies in a specific application domain. Managerial challenges approach the importance of the development of organizational and managerial practices, which are key points to be faced in the FIR (AGOSTINI; FILIPPINI, 2018). After conducting a systematic literature review and validating the findings with academic and industrial experts of Industry 4.0, the author suggested the following managerial challenges as future research: 1) acceptance of change and counteraction to organizational inertia, 2) construction of digital capabilities, 3) design of a workplace of future and qualified employees, and 4) development of new business models.

Piccarozzi; Aquilani; Gatti (2018) reported that there is still a scarce literature review on themes that integrate Industry 4.0 with managerial aspects, related, for example, to strategy, business model, sustainability, human resources, social innovation, etc. The authors highlighted the adoption of Industry 4.0 is not only about the use of new technologies, or tools, or production methods, but also on changes in all management aspects at an intra-firm level, as well as in the relationships with all partners and actors of the ecosystem in which companies operate (PICCAROZZI; AQUILANI; GATTI, 2018). Table 1 shows an analysis of nine Industry 4.0 challenges (in alphabetical order) identified in the literature review. It is based on papers that cover challenges towards the transition process or implementation of Industry 4.0 and that have been cited at least twice.

Table 1 - Description of challenges towards Industry 4.0 (continues)

Challenges towards Industry 4.0	*Description*
Acceptance of organizational transformation for Industry 4.0	The acceptance of transformation processes with I4.0 solutions and their technologies must be stimulated in the company as a whole (SCHNEIDER, 2018), counteracting organizational inertia (SCHNEIDER, 2018; HIRSCH-KREINSEN, 2014). Workers of different hierarchical levels must be involved towards a common understanding of Industry 4.0, avoiding their resistance (KIEL et al. 2017) and creating an adaptable corporate culture convinced of I4.0 technologies applications in favor of the company (KIEL et al. 2017).
Adapt/complement or develop a new business model	Companies should reflect on the implications for the business model considering the I4.0 introduction (SCHNEIDER, 2018). Such implications refer to possible adaptations, complementation, or replacement of the business model with a new one (SCHNEIDER, 2018). Changes must also be considered so that the current business models become more innovative, service-oriented, and integrated with customer demands (KIEL er al., 2017). The rethinking of business models must involve multiple stakeholders for a beneficial mutual understanding of different developments within and beyond a company's boundaries and an Industry 4.0 strategic relevance for the whole company (EROL, SCHUMACHER, SIHN, 2016).
Analyzing companies' scenarios and particularities to implement Industry 4.0	The I4.0 implementation must be designed specifically for different organizational production scenarios (MÜLLER, KIEL, VOIGT, 2018). "Firms need to be shaped at all levels to reach high levels of implementation of I4.0 technologies" (AGOSTINI, FILIPPINI, 2018, p. 417). Therefore, the complexity for retrofitting companies should be considered towards the adoption of the new I4.0 paradigm, integrating their technologies into different organizational hierarchies, structures, production, and logistic systems (MÜLLER, KIEL, VOIGT, 2018). The company's scenarios must be defined for the I4.0 implementation, considering, for example, their current situation, goals, interfaces with other systems, technical requirements, projects´ schedules, and estimations of costs and benefits (HERMAN, PENTEK, OTTO, 2016). Characteristics and requirements from different companies regarding I4.0 are not similar, since each company's scenario is distinct (HERMAN, PENTEK, OTTO, 2016); the idea is to match the company's I4.0 strategy with its particularities (KIEL, 2017). The I4.0 implementation requires a long coordination process between the new system to be implemented and the company's conditions (HIRSCH-KREINSEN, 2014).
Dealing with competitiveness and analyzing the future viability of Industry 4.0	The Industry 4.0 implementation reshapes companies' boundaries, creates new industries, and carries established manufacturing to manage with new competitive challenges (MÜLLER, KIEL, VOIGT, 2018). Therefore, an increase in competitive dynamics leads to changes in companies and adaptations of their environments to a competitive context (KIEL et al., 2017). Several companies have been adjusted to the dynamic market towards meeting customers' demands due to competitions of product quality and production costs (BRETTEL et al. 2017). However, they should also analyze the viability of I4.0 technologies for their competition in the market, considering positive and negative effects (MÜLLER, KIEL, VOIGT, 2018; KIEL et al., 2017).

Table 1 - Description of challenges towards Industry 4.0 (conclusion)

Challenges towards Industry 4.0	*Description*
Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	Industry 4.0 demands privacy protection and information security (XU; XU; LI, 2018). The connection of different devices and networks increases the risk of data and the vulnerability of networks connected, which can be accessed by hackers and cyber-terrorists (XU; DAVID; KIM, 2018). Moreover, cyber-attacks and viruses can interfere in the shutdown of networks and smart production systems (DELOITTE, 2015). "Industry 4.0 can only be successfully introduced if operational security, data protection and IT security are guaranteed" (MÜLLER, 2019, p.2193). Data risk also occurs across the entire value chain with the connection/exchange open of data (KIEL et al. 2017); therefore, companies must consider requirements in terms of data protection (KIEL, 2017).
Having a modern IT/ICT infrastructure to meet Industry 4.0 demands	Companies should incorporate and develop a modern IT/ICT infrastructure (KIEL et al. 2017; XU, XU, LI, 2018; AGOSTINI, FILIPPINI, 2018), or consider its adaptation (DELOITTE, 2015) to meet Industry 4.0 demands (XU, XU, LI,2018; AGOSTINI, FILIPPINI, 2018; DELOITTE, 2015). A modern IT infrastructure supports intra-firm (connection between different components that facilitates production) and inter-firm (connection throughout the entire supply and value chain that ensures cross-company interactions) connections (KIEL et al. 2017). Cost implications should also be considered by companies with the IT infrastructure (DELOITTE, 2015).
Managing and analyzing a large quantity of data	Large quantities and complex data connected in real-time and generated by networks, machines, productions, equipment, products, applications and services must be analyzed and managed (ZHOU, LIU, ZHOU, 2015; XU, XU, LI, 2018; DELOITTE,2015). Efficient real-time integration and analysis in the industrial production process should be guaranteed for optimizing the production chain resources (ZHOU, LIU, ZHOU, 2015). Big data can offer enterprises information protection and privacy issues, such as information security (ZHOU, LIU, ZHOU, 2015), and data science and data analytics techniques will play relevant roles in managing with large quantities of real data (XU, XU, LI, 2018).
Qualifying and preparing employees to deal with Industry 4.0	"The existing tasks such as simpler machine operation, handling materials and materials-linked machine settings, as well as various monitoring and regulating functions, will be automated in the future" (HIRSCH-KREINSEN, 2014, p.9). Therefore, the qualification and preparation of employees for the development of their competences and skills to handle with I4.0 technologies are fundamental (XU, DAVID, KIM, 2018; MÜLLER, KIEL, VOIGT, 2018; KIEL, 2017; AGOSTINI, FILIPPINI, 2018; SCHNEIDER, 2018), since digitalization has increased in companies (DELOITTE, 2015).
Stimulating collaboration and trust with key partners	The guarantee of collaboration and cooperation requires openness, cross-company cooperativeness, a high degree of trust, and compatibility of technologies (KIEL et al. 2017). Such collaboration should consider different partners to be more closely integrated into value creation (e.g., customers, suppliers) (KIEL et al. 2017). One of the obstacles for a close collaboration among companies is the lack of trust, since some managers are uncomfortable sharing critical information with other companies (BRETTEL et al. 2017). Therefore, collaboration should ensure vertical and horizontal integration through the value chain towards improving and increasing connectivity and exchange of knowledge and information flow (AGOSTINI, FILIPPINI, 2018).

Source: author

The implementation of I4.0 requires the involvement of top management for supporting the change management process of preparation and arrangement of organizational and production structures according to the demands of a more connected value creation (MÜLLER; KIEL; VOIGT, 2018), i.e., leaders and managers are essential for the guidance of Industry 4.0 and for managing with their challenges (SCHNEIDER, 2018; HELMING et al., 2019; MDLULI; MAKHUPE, 2017). Managers should convince employees of the benefits of Industry 4.0 and drive their concerns about its changes and challenges (MÜLLER; KIEL; VOIGT, 2018).

Therefore, the development of leaders and managers in the Industry 4.0 context becomes relevant for companies. Leadership and its respective competences should be better understood and explored towards guiding executives in successfully dealing with challenges towards Industry 4.0.

2.3 LEADERSHIP IN INDUSTRY 4.0 CONTEXT

Leadership integrates a set of traits, qualities and behaviors possessed by leaders (BOLDEN; GOSLING, 2006) that encourage people's participation, development, and commitment to guide them in the execution of goals within the organization (BOLDEN; GOSLING, 2006; ROBBINS, 2005). In addition, however, companies should consider leadership and management to achieve successful effectiveness (ROBBINS, 2005; KOTTER, 2001).

Leaders and managers have differences, on the one hand, managers seek stability and control (KOTTER, 2001), trying to resolve problems quickly, sometimes without a complete understanding of what it means (ZALEZNIK, 2004). On the other hand, leaders push for change (KOTTER, 2001), handle chaos, risks and unstructured situations, seek opportunities and understand a problem more fully and deeply (BOLDEN; GOSLING, 2006; ZALEZNIK, 2004).

Leadership and management are fundamental for success in a constantly volatile and complex business environment (KOTTER, 2001; ZALEZNIK, 2004). In this regard, the introduction and adoption of I4.0 technologies is an example of change in the business environment, demanding the role of leadership (SCHNEIDER, 2018). In this section, the leadership approach was analyzed and explored in a general perspective, since leadership in Industry 4.0 context is still being defined in the literature.

Leadership plays an important role in Industry 4.0, since leaders make strategic decisions at all levels of the organizations (KASAPOĞLU, 2018). Future leaders must be more responsive towards perceiving the patterns and signals shown by network data (KELLY, 2018),

and should incentivize connectivity and networks towards valuing organizational network learning (KELLY, 2018).

Leadership 4.0 refers to leadership in the age of Industry 4.0 (BIANCO et al., 2021; BOLTE; DEHMER; NIEMANN, 2018; OBERER; ERKOLLAR, 2018; MDLULI, MAKHUPE 2017). Although the term is still undefined in the literature, some authors' approaches explored the leadership 4.0, referencing it as: to be agile and adaptive, to respond quickly and flexibly to required changes. Leaders must promote innovation, experimenting and testing new technologies without being afraid to fail, ensuring high customer satisfaction. They should be open to learn, unlearn and relearn. Leaders should be oriented towards cultural changes, teamwork and cooperation.

Leaders in the FIR must also be prepared to adapt, learn, and challenge their own conceptual (avoiding silo mentality) and operational models, considering the wide availability of information and constant innovations (SCHWAB, 2016). They should manage challenges and problems in a holistic, flexible and adaptable way, integrating different interests and opinions (SCHWAB, 2016). Institutions are more creative, and will be more agile and resilient when leaders of high emotional intelligence are part of them (SCHWAB, 2016).

The leadership style adopted is one of the managerial approaches suggested by Shamim et al. (2016) to enhance the compatibility of companies with Industry 4.0 and facilitate learning and innovation, according to the respective situation (SHAMIM et al., 2016). A leadership that supports agile environment is essential as a basis to drive quick innovations and create high customers' satisfaction (BOLTE; DEHMER; NIEMANN, et al., 2018).

Leaders play an important role in guiding a successful change process to Industry 4.0 (HELMING et al., 2019), supporting the impact of its new technologies (HELMING et al., 2019), and dealing with management challenges (SCHNEIDER, 2018). The transformation in the business environment in the FIR scenario will require new management models, learning processes, and leadership characteristics (MAGALDI; SALIBI NETO, 2018), hence, new competences for managers and leaders.

According to Prodromos et al. (2017), an effective leadership role can influence the process of organizational change positively. However, leaders should be effectively prepared to manage and lead the process, with the respective required competences, and develop others investing in education and training (PRODROMOS et al., 2017).

2.4 LEADERSHIP COMPETENCES IN INDUSTRY 4.0 CONTEXT

Jerman, Bach, Aleksi (2019) highlighted the importance of the development of competences for many organizations in the Industry 4.0 context as the key aspect for the promotion of a competitive advantages and strategies that improve individual and organizational performance and for the creation of knowledge at all levels of the organizations (JERMAN; BACH; ALEKSI, 2019). Competence is the combination of knowledge, skills, attitudes (BAARTMAN; BRUIJN, 2011; SHET; PATIL; CHANDAWARKAR, 2017) and behaviors (WOODRUFFE, 1993; BOYATZIS, 2008; BOYATZIS, 2011) for an individual to successfully perform a task or activity (SHET; PATIL; CHANDAWARKAR, 2017; BAARTMAN; BRUIJN, 2011).

Competences in Industry 4.0 play a relevant role for workers to meet industrial needs (SIDDOO et al., 2019), who should have a set of competences that go beyond technical know-how (WHYSALL; OWTRAM; BRITTAIN, 2019) (e.g., soft workforce for interconnectivity, self-adaptability and decentralization (FLORES; XU; LU, 2020)). According to Erol et al. (2016), competences should be rethought in view of the new technological developments that characterize Industry 4.0, which significantly impact on the future design of production systems.

Hecklau et al. (2016), Hecklau et al. (2017) and Erol et al. (2016) classified the competences required by workers in Industry 4.0 into four categories: **social competences**, which refer to the abilities, attitudes and skills for the development of relationships, cooperation and communication with others (HECKLAU et al., 2017) (e.g., intercultural skills, communication skills, ability to work in team, ability to transfer knowledge, etc.); **methodological competences**, related to the availability of means and resources, and their use for the development and structuring of a task (KAUFFELD, 2006) (e.g., creativity, entrepreneurial thinking, problem-solving, decision-making, etc.); **personal competences**, which refer to motivations, social values and attitudes of individuals (HECKLAU et al., 2017) (e.g., flexibility, motivation to constantly learn, ambiguity tolerance, etc.); and **technical competences**, related to the access and use of knowledge for a job or a specific task (EROL et al., 2016) (e.g., technical skills, coding skills, understanding IT security, etc.).

Competences in different levels of a company are fundamental in Industry 4.0 (SCHNEIDER, 2018; HELMING et al., 2019) (e.g., competences for leaders and managers to meet market demands). Organizations that survive and compete in a constantly changing marketplace will be those that have actively and strategically equipped themselves to handle with the future challenges through effective leadership development programs, practices and

systems (LESKIW; SINGH, 2007). As part of such activities, leadership competences remain a core dimension in most organizations (HERNEZ-BROOME; HUGHES, 2004).

Leadership competences refer to technical requirements of specific job roles, including softer interpersonal qualities from people at different levels across the company (BOLDEN; GOSLING, 2006). Such competences should be oriented to the organization's future vision and strategic requirements (CONGER; READY, 2004). Leadership competences can be identified both in the corporate context and in professional associations in different fields (CROFT; SEEMILLER, 2017).

Battilana et al. (2010) evidenced the role of leadership competences in contributing to leaders and managers in different activities regarding organizational change implementation (e.g., communication the need for change, mobilizing others to support change and evaluating change implementation). Microsoft is an example of a company that has built leadership competences, based on internal research, its future business strategy, and the analysis of organizational attributes required for successfully handling future challenges (CAMPION et al., 2011).

Although leadership competences (such as emotional intelligence, leading and working in teams) will be still relevant, they will change as the competitive environment changes, and must be aligned specifically with the distinct business challenges and goals (HERNEZ-BROOME; HUGHES, 2004). In an Industry 4.0 context triggered by digital and trend technologies, different leadership competences will be adopted and changed in a competitive environment. Digital technologies make leaders more transparent, agile, and vulnerable (SCHRAGE et al., 2021). "Leaders will clearly have to be much more savvy with regard to technology in general" (HERNEZ-BROOME; HUGHES, 2004, p.30).

According to Nel et al. (2020), the following four trends reshape the leadership landscape in Industry 4.0: I) emergence of nontraditional teams, which refers to the different dimensions of team members´ diversity, i.e., leaders should manage individuals from different geographic locations and robotic workers (e.g., AI assistants); II) creation of exponential roles, related to the leader' perspective for the creation of a team with required skills for acting with new tasks demanded in I4.0 environment; III) data proliferation, which refers to the use and understanding of large datasets for supporting leaders' decision making; and IV) diversity, inclusion, and collaboration, which should be considered by leaders, since they increase innovation, agility, and performance and achieve financial targets. Such trends will demand a new set of leadership competences (NEL et al., 2020).

According to Grzybowska; Łupicka (2017), Industry 4.0 and its respective technologies will demand key competences for the qualification and preparation of managers to manage with the new challenges of I4.0. Erol et al. (2016) claimed the preparation of workers at different organizational levels with their required competences is relevant, and Cimini et al. (2019) highlighted the importance of workers at different organizational levels being ready to develop and execute the new jobs' profile in the Industry 4.0 context.

Although leadership competences in Industry 4.0 are referenced in literature for their important role in preparing leaders and managers, there are still few articles exploring this subject (BIANCO et al., 2021; HELMING et al., 2019; SCHNEIDER, 2018). Some authors mention the relevance to prepare leaders with respective competences and skills, such as Schneider (2018), Helming et al. (2019), and Shamim et al. (2016). In this regard, Helming et al. (2019) present dimensions of competences for leaders and managers in Industry 4.0, among them communication, structure and transparency. Shamim et al. (2016) show a perspective of managerial practices, such as, reflection about the role of leadership to incentive innovation, and the flexible structure of companies in Industry 4.0 environment.

Zangiacomi et al. (2019) proposed managerial practices to support transformation towards Industry 4.0, exploring three dimensions, namely investments in I4.0 technologies, ability in perceiving the path towards digital transformation, and knowledge sharing. Jerman; Bach; Aleksic (2019) discussed the demands of technical competences and knowledge of new technologies of I4.0 for new job profiles.

Siddo et al. (2019) presented digital competences (e.g., basic IT for works, English for IT, IT support, mobile tech, etc.) for new graduates or future workers, and Martinez-Gonzales, Olid, Crespo (2019) described the competences required by human resources in FIR (e.g., flexibility and adaptation, strategic vision, desire to learn, value knowledge, etc.). Choi, Han, Lee, (2018) proposed competences for the preparation of engineering students in FIR (e.g., creative attitude, problem-solving, analytical thinking, etc.). Hecklau et al. (2016) designed a competency model based on four groups, namely social, methodological, technical, and personal for workers, considering some challenges in I4.0 context. In addition, Whysall, Owtram, Brittain (2019) highlighted the importance of engineers having a new mindset and a set of competences (e.g., client management skills, relationship and communication skills, systems thinking, etc.) that go beyond technical know-how. However, all of these authors have explored competences required in Industry 4.0 without considering a perspective on leadership or leadership competences.

Due to the few results provided in the databases[5] on the main topic of this study, we considered other sources, such as papers in Google Scholar, technical reports, and books that connect leadership or leadership competences with I4.0 or FIR. In this regard, Borges et al. (2020) proposed a leadership model in the FIR context, based on consolidated management tools and the inputs of Brazilian professionals' perspectives. Akdere; Hickman; Kirchner (2019) explored leadership competences to prepare collaborators and students in the perspective of STEAM (Science, technologies, engineering and math). Although the paper does not address I4.0 directly, it refers to leadership competences in the area of science, technology, engineering, and math towards acting in a global environment that might be related to I4.0. Mdluli; Makhupe (2017) presented a molecular[6] leadership competency model composed of leadership competences 4.0, each of which as a quotient[7] that supports leadership in I4.0 environment.

Nel et al. (2020), Price Water House Coopers PWC (2016), and Staffen; Schoenwald (2016) are publications that present technical reports exploring the importance of leadership in FIR, and the books of Magaldi; Salibi Neto (2018) and Schwab (2016) cover leadership and management issues for leaders and managers to be ready for the Industry 4.0 context. Appendix A provides an analysis of VOSviewer tool on the results found in databases (WoS and Scopus).

Thus, thirty-four (34) leadership competences in Industry 4.0, coined here I4.0 LC (Leadership Competences in Industry 4.0 context), were identified through analyses of academic articles from the databases, followed by a snowballing process[8] and complemented with other sources (e.g., technical reports and books (see Appendix B for the 34 I4.0 LC with the respective approaches identified). The 34 I4.0 LC were analyzed by NVivo tool, such tool supported the categorization of these I4.0 LC into four competences groups, namely social, personal, methodological and technical, and also identified their similarities and complementation of the 34 I4.0 LC. Thus, twenty-two (22) I4.0 LC with their proposal descriptions (see Table 2) resulted from the qualitative and theoretical analyses. The process from 34 to 22 I4.0 LC is explained and proposed based on Guzmán et al. (2021).

[5] Databases: Web of Science (WoS) and Scopus were our main databases used in the literature review (GUZMÁN et al.,2021).
[6] Molecular, as part of the "molecular leadership competency model", means leadership competences are linked towards forming a molecule of different atoms that make a "living leadership molecule" (MDLULI; MAKHUPE, 2017).
[7] Term quotient means "a particular degree or amount of something" (CAMBRIDGE DICTIONARY, 2021). Available at < https://dictionary.cambridge.org/pt/dicionario/ingles/quotient >. Accessed March 20, 2021
[8] Snowballing refers to the iteration of a paper, when new papers (resulting from an initial paper) are included in a study due to their significance (DANGLOT et al., 2019).

Table 2 - Leadership competences required in Industry 4.0 environment based on the literature (continues)

Category	Leadership competences	Proposed description	Author references
Personal competences	Agility and adaptability perspective	This competence comprehends: having intellectual agility, responding quickly to the changing requirements, and being adaptive and resilient to unpredictable technological disruption of the future. Leaders should keep an open mind, stimulate and integrate different ideas, and opinions. For that, experimentation, failure and risking to explore new opportunities and innovations in the company must be practiced by leaders.	Mdluli, Makhupe (2017); Schwab (2016); Staffen; Schoenwald, (2016); Magaldi; Salibi Neto (2018)
	Asking big questions	This competence relates to ask instigation questions to stimulate curiosity and create a curious corporate culture. Leaders should give incentive to the practice of questions, understanding and constantly aligning the questions with the company's business considering market demands.	Magaldi; Salibi Neto (2018)
	Connector	This competence is the ability to connect points interpreting the environment and emerging trends. Integrating all company's efforts (e.g., areas, departments, experts) for the organization's central objective. Leaders should be prepared with different knowledge sources, value networking and connections with those who have a similar interest in understanding the trends.	Magaldi; Salibi Neto (2018); Schwab (2016)
	Conflict solving	This competence should be developed and practiced by managers, to manage and resolve conflicts. For conflict solving it is necessary to consider emotional maturity, self-control and empathy.	Grzybowska, Łupicka (2017)
	Deep, interdisciplinary and self-learnings	This competence is the ability to learn continuously in a deep and interdisciplinary way. Goals, resources, and new learning strategies need to be practiced and developed, contributing to leaders' continuous self-learning. A deep and interdisciplinary knowledge should also be considered to supports connecting ideas and applying the knowledge to different contexts to find solutions.	Akdere, Hickman, Kirchner (2019); Richert et al. (2016); Schwab (2016)
	Emotional intelligence	This competence is the ability to sense, understand, and effectively apply the power of emotions. People's capacity to recognize their feelings and those of others, managing their own emotions and those of others. Leaders need to consider self-awareness, self-regulation, motivation, empathy, and social skills. Emotional intelligence keeps the balance in unstable situations allowing leaders to reflect on alternatives in favor of business.	Mdluli, Makhupe (2017); Schwab (2016); Magaldi; Salibi Neto (2018); Hay Group (2011a)

Table 2 - Leadership competences required in Industry 4.0 environment based on the literature (continues)

Category	Leadership competences	Proposed description	Author references
Social competences	Collaborative-diverse team	This competence is the ability to practice intra-inter company collaboration, value diversity in physical and virtual environments. Team diversity should be valued in terms of culture, education and geographical location. Also, human-machine collaboration must be practiced by leaders, managing robotic workers, such as AI assistants.	Akdere, Hickman, Kirchner (2019); Bauer et al. (2015); Hay Group (2011b); Mdluli, Makhupe (2017); Nel et al.(2020); Richert et al. (2016); Schwab (2016)
	Communication	This competence is about listening and understanding others and knowing the science and art of delivering information. The media production, communication, and dissemination techniques and methods to inform and entertain via written, oral, and visual media are required. Leaders should consider the use of digital communication to facilitate information exchange, such as web-based messaging service, allowing communication flows.	Akdere; Hickman; Kirchner (2019); O*Net Content Model (2020); Erol et al.(2016)
	Encourage knowledge sharing	This competence refers to give incentive for collaborative knowledge sharing regarding I4.0 technologies, considering external sources (e.g., universities, research centers, service and technology providers). It is also important to create a partnership to stimulate knowledge sharing with the use of networks and communication channels.	Zangiacomi et al. (2019); Hay Group (2011b); Schwab (2016)
	Focus on customer	This competence is about keeping proximity to customers and understanding their expectations based on the consumer market's fast responses to companies. Leaders should increase the value connections with their customers to build major proximity, considering mobile apps that offer connection and comfort to customers.	Magaldi; Salibi Neto (2018)
	Massive transformative purpose (MTP)	This competence refers to adopt a purpose's perspective considering technologies to contribute to global problems that impact individuals. This purpose's perspective should be executed through strategic actions. Leaders must ensure to guide collaborators around this common purpose perspective.	Magaldi; Salibi Neto (2018)
	Transparency	This competence is about being clear and transparent. Leaders should ensure transparency to involve all workers with the overall production, across the entire value chain, and during the distribution of tasks.	Helming et al. (2019); Wordnet (2010a); Nel et al.(2020)

Table 2 - Leadership competences required in Industry 4.0 environment based on the literature (continues)

Category	Leadership competences	Proposed description	Author references
Methodological competences	Big-data decision making	This competence is the process of making decisions based on data. The decision-making should use the right and relevant information and interpretation of Big-data avoiding intuition or expertise. Leaders need to consider critical thinking (judging and reasoning information), analytical thinking (evaluating, visualizing, gathering information), research skills (providing in-depth information and advice on a topic), digital fluency, and data visualization skills. Tools such as software, platform and other technologies to support volume, velocity and variety of Big-data are essential.	McAfee; Brynjolfsson (2012); Elkington (2018); Akdere, Hickman, Kirchner (2019); O*Net Content Model (2020); Grzybowska ; Łupicka (2017)
	Efficiency orientation	This competence is the ability to assess input-output relationships to guarantee the efficient use of resources to support decisions and action.	Grzybowska, Łupicka (2017); Boyatzis [9]et al. 1995 apud Trentin et al. 2019
	Managing complexity	This competence is about understanding complex entities based on their constituent parts. Complexity management can include delayering, decentralizing (or centralizing), streamlining processes and creating processes to ensure alignment. To manage the complexity, it is important to analyze the problem, break down the complex problem into smaller parts, verify their interactions to develop solutions finally, and carry out plans to drive them.	Akdere, Hickman, Kirchner (2019)
	Promoting innovation	This competence is about creating a new device or process resulting from study and experimentation. Promote innovation is also the creation of something in mind for new uses. For this, leaders need to consider creativity (ability to create), research skills (to provide in-depth information on a given topic), entrepreneurial thinking (ability to identify marketplace opportunities) and stimulate the experimentation (tolerating failure) in corporate culture for the development of new business models that meet market demands.	Mdluli; Makhupe (2017); Canals; Heukamp (2020); Wordnet[10] (2020b); Grzybowska, Łupicka (2017); Akdere, Hickman, Kirchner (2019); Rasca (2018)

[9] BOYATZIS, Richard E.; KOLB, David A. From learning styles to learning skills: the executive skills profile. Journal of managerial psychology, 1995.
[10] WORDNET "is a large lexical database of English. Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept" Available at:< https://wordnet.princeton.edu/>. Accessed April 26, 2020.

	Problem solving	This competence refers to use analytical or logical thinking and creativity to identify, evaluate, compare and select respective solutions.	Grzybowska, Łupicka (2017); O*Net content model[11] (2020)
	Rethink organizational structure	This competence is about considering the design of the organizational structure in Industry 4.0 environment. Rethought the organizational structure to be a flexible structure, collaborative and networked structure, facilitating information and data exchange, rather than a hierarchical structure. The design of a flexible structure should follow the needs and situations of the respective company.	Helming et al. (2019), Shamim et al. (2016), Schwab (2016)
Technical competences	Digital perspective	This competence gives incentive to a digital perspective to be adopted. Managers must understand the level of digitalization in their organization. The digitalization strategy in business can add value, improve customer experience, save time, increase productivity and improve margins. To support digitalization is necessary to consider digital wisdom (practical guidance for the use of digital technologies), tech literacy (general understanding about tools that promote digitalization), and adopt a digital mindset to explore new technologies, business models, opportunities and strategic advantages to favor the company.	Mdluli; Makhupe (2017); Allen (2020); Hay Group (2011b); Sony, Naik (2019)
	Evaluation and understanding of I4.0 and Moore's law	This competence is about evaluating the use of I4.0 technologies. Leaders should experience and understand these technologies, their implications and potentials, and choose technologies aligned with specific business and company needs. The adoption of I4.0 technologies must consider the effects of Moore's Law (speed of technologies changes) regarding the market demand and future business model changes. The execution of small pilot projects can support the feasibility of the technologies adopted.	Magaldi; Salibi Neto (2018); Zangiacomi et al. (2019)
	Lean approaches	This competence is about introducing the lean approach in favor of I4.0. Managers should consider the use of Lean tools, practices and principles to contribute with I4.0 technologies adopted. The integration of I4.0 technologies and Lean production management practices could improve operational performance.	Zangiacomi et al. (2019); Enke et al. (2018)
	Technical approaches	This competence is about having technical knowledge to handle with I4.0 technologies. Having know-how of IT devices (e.g., computers, mobile devices, and automation devices), software such as ERPs, MESs, understanding of artificial intelligence (to support decision-making process), programming codes (as a basis for building apps and systems), IT and data security issues. These are some technical approaches to be considered by leaders.	Cimini et al. (2019); Magaldi; Salibi Neto (2018); Hecklau et al. (2016); Thun et al. (2019)

Source: author

[11] O*NET Content Model is the conceptual foundation of O*Net. The content model offers a framework that shows relevant information about work, such as work characteristics, work requirements, experience requirements, occupational requirements, among others. Available at: https://www.onetcenter.org/content.html#cm2. Accessed August 20, 2020.

2.5 SYNTHESIS OF LITERATURE REVIEW

According to Hernez-Broome; Hughes (2004), organizations should focus on the development of leadership programs and leadership competences that correspond to the business environment, and their respective challenges and goals. Industry 4.0 is characterized by the velocity of interconnections, emergence and combination of new technologies that lead to innovation and transform entire systems contributing to value creation networks (SCHWAB, 2016). However, it also poses some challenges, which result from its process transition. They should be addressed and managed with by leaders and managers and their respective leadership competences. Table 3 shows a theoretical synthesis of the main variables from the literature which involve nine challenges towards Industry 4.0 and twenty-two of its leadership competences.

Table 3 - Synthesis of the mains findings in literature review

9 Challenges	**22 Leadership Competences**
1. Acceptance of organizational transformation for Industry 4.0	1. Agility and adaptability perspective
2. Adapt/complement or develop a new business model	2. Asking big question
3. Analyzing companies' scenarios and particularities to implement Industry 4.0	3. Connector
4. Dealing with competitiveness and analyzing the future viability of Industry 4.0	4. Conflict solving
5. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	5. Deep, interdisciplinary and self-learnings
6. Having a modern IT/ICT infrastructure to meet Industry 4.0 demands	6. Emotional intelligence
7. Managing and analyzing a large quantity of data	7. Collaborative-diverse team
8. Qualifying and preparing employees to deal with Industry 4.0	8. Communication
9. Stimulating collaboration and trust with key partners	9. Encourage knowledge sharing
	10. Focus on customer
	11. Massive transformative purpose
	12. Transparency
	13. Big-data decision-making
	14. Efficiency orientation
	15. Managing complexity
	16. Promoting innovation
	17. Problem solving
	18. Rethink organizational structure
	19. Digital perspective
	20. Evaluation and understanding of I4.0 and Moore's law
	21. Lean approaches
	22. Technical approaches

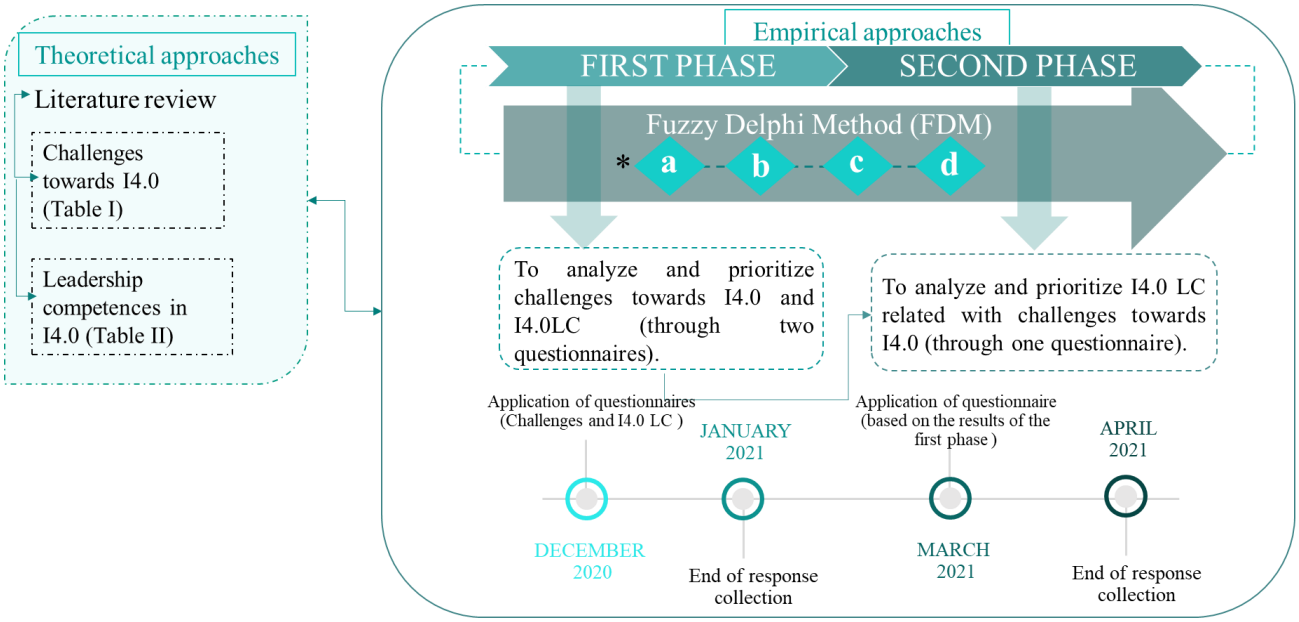
Source: author

Based on the leadership competences (22) and the challenges towards Industry 4.0 (9) identified in the literature, this study emphasizes the importance of the empirical assessment of both groups of variables for relating them and prioritizing the leadership competences to be developed by leaders and managers towards dealing with the challenges.

3. RESEARCH METHOD

The findings identified in the literature (challenges towards Industry 4.0 (Table 1) and I4.0 LC (Table 2)) support the empirical approaches of this study divided into two phases and conducted according to Fuzzy Delphi Method (FDM). The first refers to the analyses and the prioritization of the sets of challenges towards Industry 4.0 and the I4.0 LC, and the second considers the results from the first phase to analyze, identify and prioritize the leadership competences that mostly support the challenges. Figure 5 illustrates the process of the research methodology, and the following sections present the first and second phases.

Figure 5 -Overview of the research methodology



Source: author

According to Linstone, Turoff (2002, p. 3), “Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to manage with a complex problem”. Okoli, Pawlowski (2004) claim Delphi study is a group-decision mechanism composed of experts of deep understanding of a subject researched towards its consensus. “A Delphi study does not depend on a statistical sample that attempts to be representative of any population” (OKOLI; PAWLOWSKI, 2004, p.20). Therefore, the selection of qualified experts is one of the main points to be considered (OKOLI; PAWLOWSKI, 2004).

Delphi uses self-completed questionnaires (usually sent by e-mail to the participants) in different rounds for reaching a consensus (MCMILLAN; KING; TULLY, 2016). However, Ishikawa et al. (1993) emphasized the number of questionnaires (more than two) to be answered towards convergence as its weakness.

Schmidt (1997); Rowe, Wright (1999); Day, Bobeva (2005); Kuo, Chen (2008) discussed the disadvantages highlighting that several rounds can be exhausting for the participants, who may quit. Therefore, Saffie, Shukor, Rasmani (2016) proposed an adapted Delphi method, called Fuzzy Delphi Method (FDM). According to Padilla-Rivera et al. (2020), FDM is a hybrid methodology that combines qualitative methods (Delphi method) and mathematical tools (fuzzy analysis), reducing the ambiguity and uncertainty of experts' judgments (SHEN et al., 2010). Moreover, it requires a small number of samples to obtain objective and reasonable results (KUO; CHEN, 2008; TAHRIRI et al., 2014).

FDM was derived from the traditional Delphi technique and fuzzy set theory (SULTANA; AHMED; AZEEM, 2015) – the latter can simulate human reasoning using estimated information and uncertainty towards a decision (HSU; LEE; KRENG, 2010). In FDM, non-relevant criteria evaluated by experts can be eliminated (SULTANA; AHMED; AZEEM, 2015). The evaluations are performed through questionnaires that specify the relevance of each criterion. The experts assess the criteria using linguistic terms (e.g., from unimportant to very important) since human judgments have difficulty assessing their preferences by choosing an exact number (SULTANA; AHMED; AZEEM, 2015).

Tahriri et al. (2014) claim linguistic weighting variables and linguistic scale variables can be transformed into triangular fuzzy numbers (TFN). A TFN is composed of a triplet (l, m, r), where $l \leq m \leq r$. l, m and r represent, respectively, the lowest, medium and highest values that define a fuzzy occurrence (VAFADARNIKJOO et al., 2018). The max and min values of experts' opinions are the terminal points of a TFN, and the medium value is the geometric mean considered a membership degree of TFN for the obtaining of the statistically unbiased effect and avoidance of extreme values (KUO; CHEN, 2008).

After the contextualization of FDM approaches, four steps were considered in this study regarding FDM for the first and second phases of the empirical approaches of methodology. Such ***four steps***, described in what follows, were suggested by Kuo, Chen (2008); Wang, Durugbo (2013); Lin (2013); Stefano, Filho, Duarte (2014); Chen, Wang (2010), Tahriri et al. (2014):

a) identification of experts to participate in the evaluation criteria and development of questionnaire;

b) organization from collected data, definition of triangular fuzzy numbers;

c) defuzzification for TFN;

d) filtering and analyses of evaluation criteria by setting a threshold value (α).

The FDM guarantees the perspective of experts in a specific area (in this study experts with Industry 4.0 know-how) to assess the degree of importance that each I4.0 LC contributes to the challenges towards I4.0. As explained above, the traditional Delphi method presents some weakness, mainly due to the different questionnaires applied to the experts to achieve the convergence. In addition, a traditional survey was unadopted since the process method is different, focused on statistical analysis that must cover a large sample number. This study empirically analyzed two groups of variables by people with expertise in the approaches of Industry 4.0, for that reason, the FDM was chosen to conduct two phases that are part of the empirical process.

3.1 EMPIRICAL APPROACHES: FIRST PHASE

Initially, a questionnaire was proposed to analyze and identify the leadership competences that support the challenges towards Industry 4.0 context. It involved twenty-two statements (resulting from Table 2), and the respective nine challenges (from Table 1). However, after four researchers from our research group had tested the time necessary for the questionnaire to be answered (approximately 35 minutes) and verified its extension, two phases were developed for the empirical approaches of the methodology. The first prioritized the twenty-two I4.0 LC and the nine challenges towards I4.0, whereas the second phase resulted from the prioritization carried out in the first phase, considering I4.0 LC and challenges towards I4.0. Both phases followed the FDM guidelines and considered the opinions of experts from Brazil, Germany and other countries, who do research and/or work with Industry 4.0.

The first phase refers to the analysis and prioritization of I4.0 LC (Table 2) and challenges (Table 1) identified in the literature. Such prioritization also supports the verification and adaptation of theoretical findings for both groups of variables Tables 1 and 2.

Below are the descriptions of the ***four steps*** that guide FDM in the first and second phases:

3.1 a) Identification of experts who will participate in the evaluation criteria and development of questionnaires

The experts work with and research into Industry 4.0 projects. They were invited to participate and were contacted by their e-mail addresses provided in Curriculum lattes[12] or LinkedIn. Eight experts were asked to participate in I4.0 LC and eight were invited to

[12] Curriculum lattes is a platform that supports search curriculums of researchers, created by CAPES Foundation (a federal agency under the Ministry of Education of Brazil). Link< http://lattes.cnpq.br/ > Accessed April 25, 2021.

participate with the challenges towards Industry 4.0 questionnaires, respectively. Due to the delay of some experts in agreeing to participate in the I4.0 LC questionnaire, others, including those who would participate in the challenges towards I4.0 questionnaire were invited. Table 4 shows the relationship of responses for both questionnaires sent by e-mail in December 2020.

Table 4 - Relationship of responses: first phase

Relationship of responses to the questionnaires	*Questionnaire of I4.0 LC*	*Questionnaire of Challenges towards Industry 4.0*
Responses received	7	10
Complete responses	7	9
Responses considered	7	9

Source: author

Two questionnaires (MS-Excel) were created (Appendix C) - the first for the twenty-two I4.0 LC and their proposed descriptions and the second for the nine challenges towards Industry 4.0. The objective was to define the degree of importance and prioritize both groups of variables on a 5-point Likert-scale (unimportant=1 to very important=5) suggested by Cervi (2017). The result of this evaluation was denominated $R_{ik} i \epsilon S$ for every criterion (variable) i evaluated by every expert k in possible criteria set S.

3.1 b) Organization from collected data for both questionnaires, definition of triangular fuzzy numbers

The data collected from the questionnaires answered in linguistic terms were changed into numbers (1 to 5) for the definition of the triangular fuzzy numbers (TFN) for index $O_i = (L_i, M_i, U_i)$ for each criterion i. L_i is the minimum value of the evaluation, M_i is its geometric mean, and U_i is its maximum value developed by all experts in equations (I), (II) and (III). Excel functions performed the calculations.

(I) $L_i = Min(L_{ik})$

(II) $M_i = (R_{i1} \times R_{i2} \times \ldots \times R_{ik})^{\frac{1}{k}}$

(III) $U_i = Max(L_{ik})$

L_i and U_i values are taken from the terminal points of TFN, and M_i is taken as the membership degree of TFN for the achievement of the statistically unbiased effect and avoidance of the impact of extreme values (PADILLA-RIVERA et al., 2020).

3.1 c) Defuzzification for all triangular fuzzy numbers (TFN)

"Defuzzification is a method that changes fuzzy numbers into crisp real numbers" (LIN et al., 2020, p.14). Its center of area (COA), suggested by Hsieh, Lu, Tzeng (2004) and Chih-Hung; Wen-Chang (2011), defuzzifies the triangular fuzzy numbers of each evaluation criterion

to calculate the best non fuzzy performance value or crisp real value (CHIH-HUNG; WEN-CHANG, 2011). Equation (IV) calculates G_i for the defuzzification.

$$\text{(IV) } G_i = \frac{(U_i - L_i) + (M_i - L_i)}{3} + L_i$$

3.1 d) Filtering and analyses of evaluation criteria by setting a threshold value (α), i.e., if $G_i \geq \alpha$, criterion i is selected; if $G_i < \alpha$, criterion i is eliminated

A threshold or limit value (α) was defined for prioritizing the variables from both I4.0 LC and challenges towards I4.0 questionnaires, respectively. The threshold is the most important factor when all criteria are filtered and analyzed, and depends on the linguistic scale (PADILLA-RIVERA et al., 2020). The threshold may vary due to the rigor of the researchers (CERVI, 2017). Thus $\alpha = 4$ was defined, because the selected variables belong to important and very important areas, according to the 5-point Likert scale. The first phase contributes to the development of the second phase, as explained in what follows.

3.2 EMPIRICAL APPROACHES: SECOND PHASE

A new questionnaire (Appendix D) was developed in Survey Monkey[13] from the prioritization of I4.0 LC and challenges towards I4.0 in the first phase for identifying leadership competences that contribute to the dealing with the challenges. It was applied in Brazil and Germany – the latter is one of the main reference countries of Industry 4.0 context and the country where the *Industrie* 4.0 term originated (SMIT et al., 2016). As above mentioned, four steps were considered to carry out the FDM, also adopted in the first phase:

3.2 a) Identification of experts who will participate in the evaluation criteria and development of questionnaires

The respondents of the questionnaire were experts who had worked with or researched into Industry 4.0 projects from one to two years in Brazil and Germany. Their profiles were searched in Curriculum lattes, scientific articles, LinkedIn, and associations such as Platform *Industrie* 4.0[14], ABII (Brazilian Association of Industrial Internet), DWIH São Paulo (German Centre for Research and Innovation São Paulo), and VDI - Brazil (Association of German

[13] Survey Monkey is an online survey tool that supports the development of questionnaires customized towards meeting a respective objective or purpose. Link:<surveymonkey.com> Accessed April 1, 2021

[14] Platform *Industrie* 4.0 is a German network that spreads digital transformation and Industry 4.0 technologies in manufacturing, and offers publications, such as papers and reports on the themes. Link< https://www.plattform-i40.de/PI40/Navigation/EN/Home/home.html > Accessed April 7, 2021.

Brazilian Engineers). The strategies defined for contacting the experts by e-mail or LinkedIn are presented below:

- ✓ to invite the experts that participated in the first phase, when the partial results (first phase) were shared with them;
- ✓ to invite research institutions and research groups from Brazilian and German universities (e.g., professors, PhD, masters, etc.) that focus on the areas of Industry 4.0;
- ✓ to invite experts from Brazil and Germany directly by LinkedIn platform (those who work with or research into Industry 4.0 with a leadership role); and
- ✓ to invite associations, or platforms that disseminate the concepts and practices of Industry 4.0 and their technologies

The questionnaire is comprised of 16 questions and 4 sections, as shown in Appendix D The first section encompasses its introduction and objective, followed by a confidentiality agreement. The second section presents the questions on leadership competences 4.0 and challenges towards Industry 4.0 (both groups prioritized in the first phase), and I4.0 LC in four categories, namely social, methodological, personal, and technical competences. The third section provides demographic data and profile questions, and the fourth is devoted to feedback. A 5-point Likert-scale (from unimportant to very important) was adopted for the questions of the second section. The questionnaire was tested by seven research colleagues who checked time, layout and understanding of the questions, and adapted according to their suggestions. It was sent in March 2021, and was open until April 3, 2021.

Approximately, 200 questionnaires were sent via e-mail or LinkedIn for inviting experts from Brazil and Germany to participate, and a reminder was sent after fifteen days. They were also sent to experts suggested by the respondents towards inviting them to participate. Table 5 shows the list of responses, of which 43 were completed, and three were not considered in this study, because the first participant often rated questions with same level of importance, the second had no experience with I4.0, and the third had worked with or researched into I4.0 projects for less than one year. According to our criteria, the experts should have at least one or two years' experience.

Table 5 - Relationship of responses: second phase

Relationship of responses to the questionnaire	*Questionnaire of I4.0 LC regarding challenges towards Industry 4.0*
Responses received	90
Complete responses	43
Responses considered	40

Source: author

Steps 3.2 b), 3.2 c), and 3.2 d) refer to the same approaches presented in the first phase (see 3.1)

4. RESULTS

This chapter presents the results from the first and second phases described in the previous chapter. The analysis of data from the first phase was conducted by FDM (see section 3.1).

4.1 RESULTS AND ANALYSIS: FIRST PHASE

As already addressed previously, FDM involved four steps (see section 3.1).

4.1 a) Identification of experts who participated in the evaluation criteria and development of questionnaires

Table 6 shows an overview of the profiles of the experts who answered both questionnaires, i.e., challenges towards I4.0 and leadership competences, respectively. The information in Table 4 resulted from the expert's CV lattes or LinkedIn. Table 4 shows an overview of the experts´ profiles for the first phase.

Table 6 - Overview of experts´ profiles for both questionnaires: first phase

Experts' profiles for the questionnaire on challenges towards I4.0

Position	Educational background	Experience with Industry 4.0 approaches	No. of experts	Country
Professor and researcher	PhD degree	✓	1	Brazil
	PhD degree	✓	1	
	Master degree	✓	1	
Researcher	PhD student	✓	1	
	PhD student	✓	1	
Researcher and management project	Master degree	✓	2	Germany

Expert' profiles for the questionnaire on L.C 4.

Position	Educational background	Experience with Industry 4.0 approaches	Experience with leadership approaches	No. of experts	Country
Professor and researcher	PhD degree	✓	✓	3	Brazil
	PhD degree	✓	-		
	PhD degree	✓	-		
	PhD degree	✓	✓	1	Germany
Researcher	PhD student	✓	-	1	Brazil
Consultant	Engineering	✓	✓	4	Brazil

Source: author

4.1 b) Organization from collected data for both questionnaires, definition of triangular fuzzy numbers

The results from both I4.0 LC (Table 7) and challenges towards I4.0 (Table 8) questionnaires are presented below. Table 7 shows 22 I4.0 LC and the degree evaluated

by each expert (from unimportant =1 to very important=5), TFN, minimum value (Li), geometric mean (Mi), and maximum value (Ui), also shown in Table 8.

Table 7 - Results from the triangular fuzzy number-I4.0 LC questionnaire

No.	**Leadership competences in I40 context**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**Li**	**Mi**	**Ui**
1	*Agility and adaptability perspective*	4	5	4	5	5	5	3	5	5	3	4,50	5
2	*Asking big questions*	4	5	3	4	5	4	3	4	4	3	3,94	5
3	*Big-data decision-making*	4	2	4	4	5	5	4	5	5	2	4,09	5
4	*Collaborative-diverse team*	4	4	3	5	4	4	5	4	5	3	4,17	5
5	*Communication*	5	5	5	3	4	4	5	4	5	3	4,39	5
6	*Connector*	5	5	3	3	5	5	4	5	4	3	4,25	5
7	*Conflict solving*	3	4	5	2	5	5	5	3	4	2	3,84	5
8	*Deep, interdiciplinary and self-learnings*	4	4	5	3	4	4	5	5	5	3	4,28	5
9	*Digital perspective*	4	3	3	5	5	5	4	4	5	3	4,14	5
10	*Efficiency orientation*	3	3	4	4	3	5	4	2	4	2	3,45	5
11	*Emotional intelligence*	3	5	5	3	5	5	3	4	5	3	4,11	5
12	*Encourage knowledge sharing*	4	5	5	4	5	4	4	4	5	4	4,42	5
13	*Evaluation and understanding of I4.0 and Moore's law*	3	2	3	4	4	5	4	5	5	2	3,74	5
14	*Focus on customer*	3	5	3	4	5	5	5	5	5	3	4,35	5
15	*Lean approaches*	3	5	3	5	5	4	3	1	5	1	3,44	5
16	*Managing complexity*	4	5	3	5	5	5	4	3	3	3	4,01	5
17	*Massive transformative purpose (MTP)*	3	4	3	4	5	4	4	5	4	3	3,94	5
18	*Problem solving*	3	4	5	5	4	5	4	4	5	3	4,28	5
19	*Promoting of innovation*	4	5	5	5	5	5	4	5	5	4	4,76	5
20	*Rethink organizational structure*	4	3	3	3	5	4	5	3	4	3	3,70	5
21	*Technical approaches*	3	3	3	4	4	5	3	3	5	3	3,58	5
22	*Transparency*	3	5	3	3	5	5	3	5	5	3	3,98	5

Source: author

Table 8 - Results from the triangular fuzzy number-challenges towards I4.0 questionnaire

Challenges towards I40	E1	E2	E3	E4	E5	E6	E7	Li	Mi	Ui
1st. Acceptance of organizational transformation for Industry 4.0	5	4	3	4	5	4	5	3	4,22	5
2nd. Adapt/complement or develop a new business model	5	3	5	3	5	4	4	3	4,05	5
3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	4	5	4	5	5	4	4	4	4,40	5
4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	4	5	4	3	4	3	5	3	3,93	5
5th. Dealing with competitiveness and analyzing the future viability of Industry 4.0	4	4	4	4	2	5	4	2	3,74	5
6th. Having a modern IT/ICT infrastructure to meet Industry 4.0 demands	5	4	3	2	5	4	5	2	3,83	5
7th. Managing and analyzing a large quantity of data	3	4	3	2	4	3	5	2	3,31	5
8th. Qualifying and preparing employees to deal with Industry 4.0	5	5	5	4	5	3	3	3	4,19	5
9th. Stimulating collaboration and trust with key partners	4	3	4	5	5	3	5	3	4,05	5

Source: author

4.1c) Defuzzification for all triangular fuzzy numbers (TFN)

Table 9 shows the defuzzification of the Triangular Fuzzy Numbers from the 22 I4.0 LC and the 9 challenges towards I4.0.

Table 9 - Defuzzification of triangular fuzzy numbers from I4.0 LC and challenges towards I4.0

Defuzzification of I4.0 LC					Defuzzification of challenges towards I4.0				
No.	**Li**	**Mi**	**Ui**	**Defuzzification**	No.	**Li**	**Mi**	**Ui**	**Defuzzification**
1	3	4,50	5	4,17	1	3	4,22	5	4,07
2	3	3,94	5	3,98	2	3	4,05	5	4,02
3	2	4,09	5	3,70	3	4	4,40	5	4,47
4	3	4,17	5	4,06	4	3	3,93	5	3,98
5	3	4,39	5	4,13	5	2	3,74	5	3,58
6	3	4,25	5	4,08	6	2	3,83	5	3,61
7	2	3,84	5	3,61	7	2	3,31	5	3,44
8	3	4,28	5	4,09	8	3	4,19	5	4,06
9	3	4,14	5	4,05	9	3	4,05	5	4,02
10	2	3,45	5	3,48					
11	3	4,11	5	4,04					
12	4	4,42	5	4,47					
13	2	3,74	5	3,58					
14	3	4,35	5	4,12					
15	1	3,44	5	3,15					
16	3	4,01	5	4,00					
17	3	3,94	5	3,98					
18	3	4,28	5	4,09					
19	4	4,76	5	4,59					
20	3	3,70	5	3,90					
21	3	3,58	5	3,86					
22	3	3,98	5	4,0					

Source: author

4.1 d) Filtering and analysis of evaluation criteria by setting a threshold value (α), i.e., if Gi ≥ α, criterion i is selected; if Gi<α, criterion i is eliminated.

To filtering an analysis the evaluation criteria, the threshold α=4 is adopted in this study. The filtering process results when variables are eliminated because they do not meet the threshold value (PADILLA-RIVERA, et al., 2020).

Table 10 shows the I4.0 LC prioritized from the experts´ perspective (15 out of 22 I4.0 LC were prioritized), and Figure 6 displays the I4.0 LC organized from prioritized to not prioritized in relation to the threshold value. Some leadership competences' names and proposed descriptions were adapted according to the experts´ suggestions. "Technical and IT requirements" was changed to "Technical approaches", and the descriptions proposed for "Communication", "Focus on customer", "Massive transformative purpose" and "Promoting innovation" were also modified (see the website[15] shared with experts for the reporting of partial results).

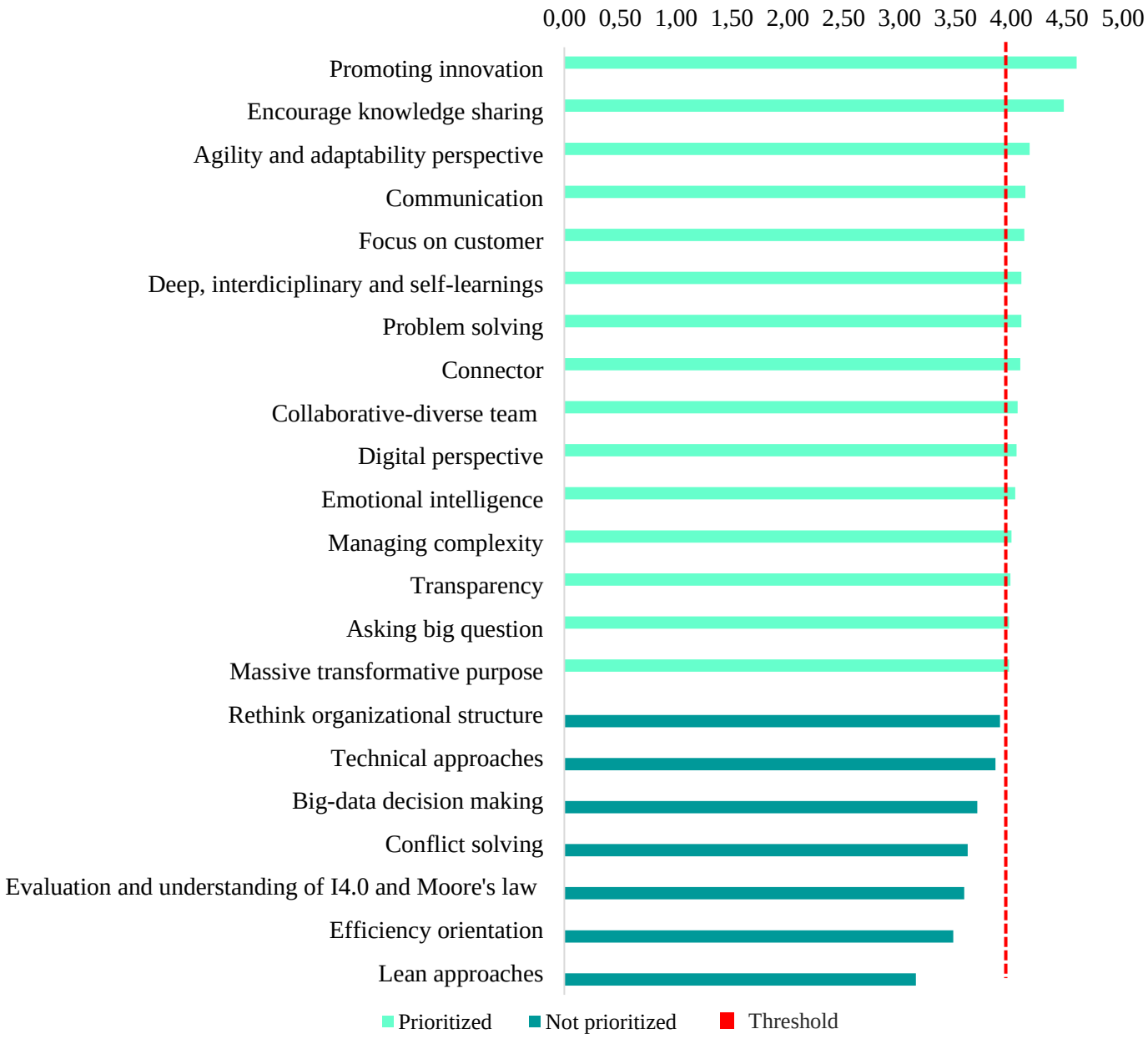
[15] A material with the topics of this study was added to the website, which also contains partial results of the first phase The website has been shared with the experts in gratitude for their contribution. Link: <https://sites.google.com/usp.br/industry4-0andleadership/home>. Accessed March 30, 2021.

Table 10 - Filtering of variables: I4.0 LC prioritized by experts

No.	**Leadership competences in I40 context**	Li	Mi	Ui	Defuzzification	If $\alpha = 4$
1	*Agility and adaptability perspective*	3	4,50	5	4,17	Prioritized
2	*Asking big questions*	3	3,94	5	3,98	Prioritized
3	*Big-data decision-making*	2	4,09	5	3,70	Not prioritized
4	*Collaborative-diverse team*	3	4,17	5	4,06	Prioritized
5	*Communication*	3	4,39	5	4,13	Prioritized
6	*Connector*	3	4,25	5	4,08	Prioritized
7	*Conflict solving*	2	3,84	5	3,61	Not prioritized
8	*Deep, interdiciplinary and self-learnings*	3	4,28	5	4,09	Prioritized
9	*Digital perspective*	3	4,14	5	4,05	Prioritized
10	*Efficiency orientation*	2	3,45	5	3,48	Not prioritized
11	*Emotional intelligence*	3	4,11	5	4,04	Prioritized
12	*Encourage knowledge sharing*	4	4,42	5	4,47	Prioritized
13	*Evaluation and understanding of I4.0 and Moore's law*	2	3,74	5	3,58	Not prioritized
14	*Focus on customer*	3	4,35	5	4,12	Prioritized
15	*Lean approaches*	1	3,44	5	3,15	Not prioritized
16	*Managing complexity*	3	4,01	5	4,00	Prioritized
17	*Massive transformative purpose (MTP)*	3	3,94	5	3,98	Prioritized
18	*Problem solving*	3	4,28	5	4,09	Prioritized
19	*Promoting innovation*	4	4,76	5	4,59	Prioritized
20	*Rethink organizational structure*	3	3,70	5	3,90	Not prioritized
21	*Technical approaches*	3	3,58	5	3,86	Not prioritized
22	*Transparency*	3	3,98	5	4,0	Prioritized

Source: author

Figure 6 - I4.0 LC organized from prioritized to not prioritized in relation to the threshold value



Source: author

15 out of the 22 I4.0 LC were prioritized. Table 11 shows the three most prioritized I4.0 LC, and the three unprioritized I4.0 LC according to some experts' comments.

Table 11 - Comments from the evaluation of the I4.0 LC prioritized and unprioritized by experts

Comments about the three most prioritized I4.0 LC	***Comments about the three not prioritized I4.0 LC***
Promoting innovation is important for constant stimulation of the experimentation in culture and consequent innovation.	*Big-data decision-making* the collection and analyses of the right information are more relevant than the collection of a large quantity of data. Leaders should have a staff for supporting them with Big-data analytics, since they cannot be experts in every tool.
Agility and adaptability perspective is a competence necessary in an environment where changes occur daily. System asap, for example, is a key to be considered by the team for a rapid learning. I4.0 LC should be considered the basis for leaders, but combined with mental health.	*Evaluation and understanding of I4.0*: leaders should encourage and understand technologies even if they do not know them in depth. However, they should have a staff for supporting them with the use and understanding of I4.0 technologies, since they cannot be experts in every tool.
Encourage knowledge sharing "they (leaders) must encourage and promote a good process for knowledge management and sharing".	*Technical approaches*: leaders should have knowledge of technical requirements, but they should hire experts to make technical decisions, for example.

Source: author

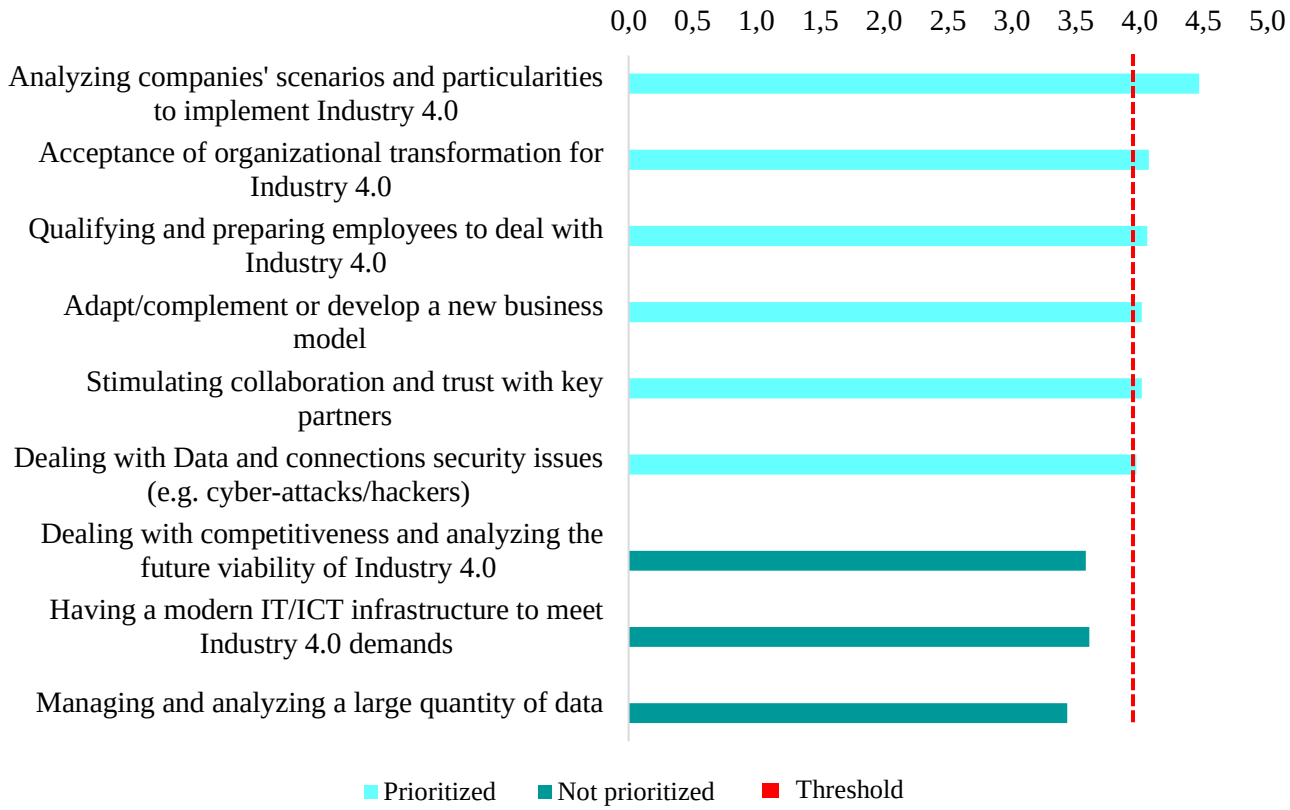
Table 12 shows the challenges towards I4.0 prioritized by experts, which were organized from prioritized to not prioritized in relation to the threshold value (see Figure 7).

Table 12 - Filtering of variables: challenges towards I4.0 prioritized by experts

Challenges towards I.40	Li	Mi	Ui	Defuzzification	If $\alpha = 4$
1st. Acceptance of organizational transformation for Industry 4.0	3	4,22	5	4,1	Prioritized
2st. Adapt/complement or develop a new business model	3	4,05	5	4,0	Prioritized
3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	4	4,40	5	4,5	Prioritized
4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	3	3,93	5	4,0	Prioritized
5th. Dealing with competitiveness and analyzing the future viability of Industry 4.0	2	3,74	5	3,6	Not prioritized
6th. Having a modern IT/ICT infrastructure to meet Industry 4.0 demands	2	3,83	5	3,6	Not prioritized
7th. Managing and analyzing a large quantity of data	2	3,31	5	3,4	Not prioritized
8th. Qualifying and preparing employees to deal with Industry 4.0	3	4,19	5	4,1	Prioritized
9th. Stimulating collaboration and trust with key partners	3	4,05	5	4,0	Prioritized

Source: author

Figure 7 - Challenges towards I4.0 organized from prioritized to not prioritized in relation to the threshold value



Source: author

Six out of the nine challenges towards I4.0 were prioritized, according to Figure 7. Table 13 shows some experts' comments on the first three challenges prioritized, and the three unprioritized challenges.

Table 13 - Comments from the evaluation of challenges towards Industry 4.0 prioritized and unprioritized by experts

Comments about the three most prioritized challenges	***Comments about the three not prioritized challenges***
Analyzing companies' scenarios and particularities to implement Industry 4.0: I4.0 is not a shelf product, therefore, the specificity of each company must be considered a first step for the transition process, which will not be the same for all companies	*Dealing with competitiveness and analyzing the future viability of Industry:* I4.0 should be considered not from a competitive view, but from a perspective that provides opportunities for the customization of products and services and availability of new technologies. Distinct changes should be adopted and occur strategically in companies, according to medium- and long-term impacts.
Acceptance of organizational transformation for Industry 4.0:"acceptance is always first", "the creation of this acceptance should not come from an effort to convince, but from a collaborative development with shared information". I4.0 knowledge must be spread in culture as a whole.	*Having a modern IT/ICT infrastructure to meet Industry 4.0 demands*: although a right infrastructure is crucial, this challenge perspective is more operational than strategic. Prior to coping with it, companies must understand what they want and need.

Qualifying and preparing employees to deal with Industry 4.0: the workforce must be upskilled and reskilled (considering technical and soft skills) for the introduction of I.40 in the company.	*Managing and analyzing a large quantity of data*: although it is a challenge for some companies and industrial areas, it is not a critical one for others.

Source: author

Some challenges towards I4.0 and their respective descriptions proposed were adapted according to the experts' suggestions. Such modifications can be found on the above-mentioned website.

The results presented in this section contributed to prioritizing variables, improving them according to the experts' comments, and achieving our main goal, i.e., identification of I4.0 LC for the dealing with challenges towards I4.0, explained in the next section.

4.2 RESULTS AND ANALYSIS: SECOND PHASE

Based on the results from first phase which presented both groups of variables prioritized, a new questionnaire was developed. This questionnaire aims to identify and prioritize I4.0 LC that better fit with challenges towards I4.0. The data analysis process of the second phase is also conducted by FDM (see section 4.1).

4.2 *a) Identification of experts who participated in the evaluation criteria and development of questionnaire;*

Table 14 shows the demographic information resulted from 40 experts that participated in the second phase. 24 responses from Brazil, 12 from Germany, and 4 from other countries (Canada (3) and Netherlands (1)).

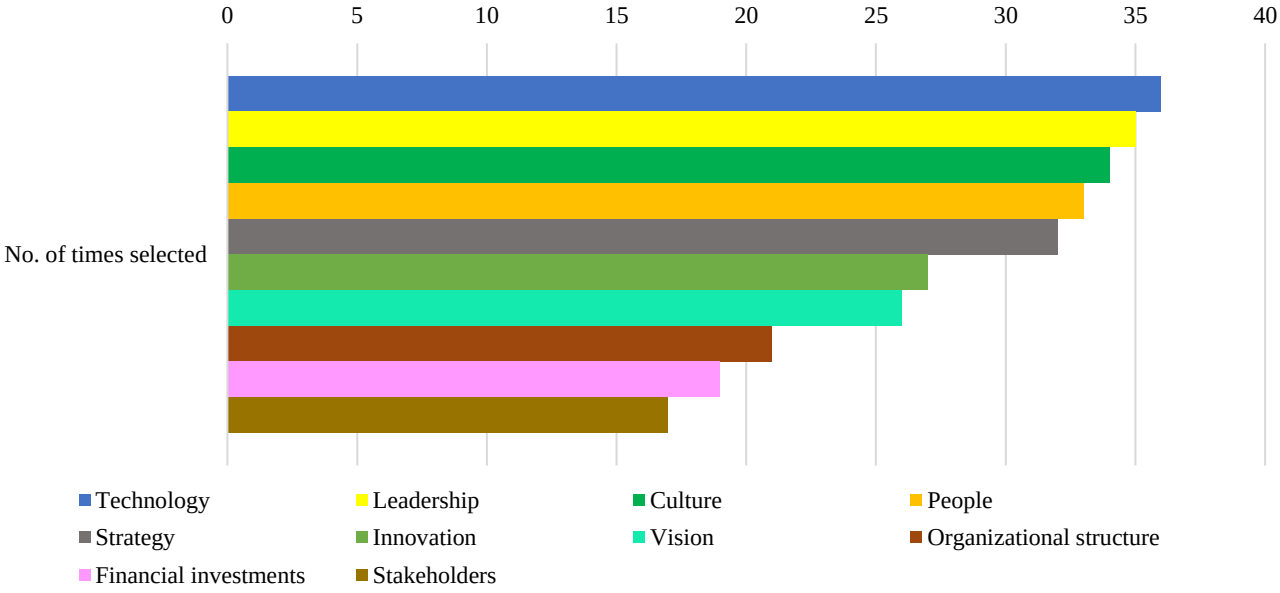
Table 14 - Demographic information and professional profile of 40 experts

Expert profile		*Frequency*	*Percent (%)*
Gender	Female	7	17,5
	Male	33	82,5
Age	20-29	4	10
	30-39	17	42,5
	40-49	9	22,5
	50-59	8	20
	60+	2	5
Expert's qualification	Professor and researcher	10	25
	Researcher (e.g., master's student, PhD student, MSc, PhD, etc)	5	12,5
	Manager	12	30
	Director	5	12,5
	Consultant	3	7,5
	Other (please specify)	5	12,5
Current place of work	Educational institution	8	20
	Research institution	8	20
	Manufacturing sector	16	40
	Consultancy	6	15
	Other (please specify)	2	5
Expert's experience with Industry 4.0 projects	Between one year and two years	3	7,5
	Between three years and four years	17	42,5
	More than four years	20	50
Leadership role experience	Yes, less than one year	3	7,5
	Yes, between one year and two years	2	5
	Yes, between three years and four years	12	30
	Yes, more than four years	19	47,5
	No, I have not exercised a leadership role	4	10
Local of work	Brazil	24	60
	Germany	12	30
	Other	4	10

Source: author

In the section of demographic and professional questions, the experts were asked about the dimensions that are more relevant towards I4.0 transition. The five dimensions with a higher evaluation were: technology, leadership, culture, people and strategy, respectively, as seen in Figure 8. One of these five dimensions is leadership, also highlighted in literature by authors such as Schneider (2018), Helming et al. (2019), Magaldi; Salibi Neto (2018).

Figure 8 - Evaluation of dimensions considered relevant towards I4.0 transition based on experts



Source: author

4.2 b) Organization from collected data, definition of triangular fuzzy numbers;

Table 15 presents the data collected from experts. The first column presents the categories of I4.0 LC. The second column shows I4.0 LC related with challenges towards I4.0 to evaluate the degree of importance (from unimportant to very important) that each of the 15 I4.0 LC contribute to support the 6 challenges towards I4.0 based on experts. The TFN includes the minimum value (Li), geometric mean (Mi) and maximum value (Ui), also shown in Table 15.

Due to the extension of data collected, the evaluation of all 40 experts has not been presented in Table 15. However, in the following steps (c and d) all results of analysis, defuzzification and filtering are presented.

Table 15 - Triangular Fuzzy number resulted from experts' perspective (continues)

Categories	*I4.0 LC and challenges towards I4.0*	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	*Sn*	*S40*	*Li*	*Mi*	*Ui*
Social competences (L.C4.0)	Collaborative-diverse team & 1st. Acceptance of organizational transformation for Industry 4.0	5	3	3	5	2	2	2	3	4	5	...	5	2	3,90	5
	Collaborative-diverse team & 2nd. Adapt/complement or develop a new business model	5	3	2	4	4	2	3	5	5	5	...	4	2	4,00	5
	Collaborative-diverse team & 3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	4	3	4	5	2	2	3	4	3	5	...	5	2	3,74	5

	Collaborative-diverse team & 4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	2	2	5	3	1	2	2	2	3	5	...	4	1	2,72	5
	Collaborative-diverse team & 5th. Qualifying and preparing employees to deal with Industry 4.0	4	4	5	4	5	2	4	5	4	5	...	5	2	4,07	5
	Collaborative-diverse team & 6th. Stimulating collaboration and trust with key partners	4	5	5	5	5	2	5	4	4	5	...	5	1	4,19	5
	...											...				
Methodological competences (L.C4.0)	Managing complexity &1st. Acceptance of organizational transformation for Industry 4.0	4	5	4	5	3	3	2	5	3	4	...	5	2	3,94	5
	Managing complexity & 2nd. Adapt/complement or develop a new business model	5	4	3	4	3	3	5	5	3	4	...	5	3	4,00	5
	Managing complexity & 3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	5	5	5	5	5	4	5	5	3	5	...	5	2	4,35	5
	Managing complexity & 4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	5	4	5	3	4	4	4	5	2	5	...	5	1	3,32	5
	Managing complexity & 5th. Qualifying and preparing employees to deal with Industry 4.0	3	3	5	5	4	2	3	4	4	5	...	5	2	3,56	5
	Managing complexity & 6th. Stimulating collaboration and trust with key partners	3	5	5	5	3	4	3	5	4	4	...	5	2	3,68	5
	...											...				
Personal competences (L.C4.0)	Asking big questions & 1st. Acceptance of organizational transformation for Industry 4.0	4	4	5	5	5	3	5	4	4	4	...	5	2	4,09	5
	Asking big questions & 2nd. Adapt/complement or develop a new business model	5	5	3	5	4	3	5	5	3	4	...	5	3	4,34	5
	Asking big questions 3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	5	4	4	4	4	4	5	5	4	4	...	5	3	4,15	5
	Asking big questions & 4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	3	2	4	4	3	2	3	4	3	5	...	5	1	3,14	5
	Asking big questions 5th. Qualifying and preparing employees to deal with Industry 4.0	1	2	5	4	5	4	2	3	4	4	...	5	1	3,56	5

	Asking big questions & 6th. Stimulating collaboration and trust with key partners	3	3	4	4	5	4	3	4	4	4	...	5	2	3,70	5
	...											...				
Technical competences (L.C4.0)	Digital perspective & 1st. Acceptance of organizational transformation for Industry 4.0	3	3	5	5	5	3	5	5	4	5	...	5	3	4,25	5
	Digital perspective & 2nd.Adapt/complement or develop a new business model	4	5	3	5	5	4	5	5	3	5	...	5	2	4,24	5
	Digital perspective & 3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	5	5	4	5	5	4	5	5	3	4	...	5	3	4,39	5
	Digital perspective & 4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	4	3	5	3	3	5	3	5	3	5	...	4	1	3,75	5
	Digital perspective & 5th. Qualifying and preparing employees to deal with Industry 4.0	4	4	5	5	4	3	4	5	4	5	...	5	2	4,12	5
	Digital perspective & 6th. Stimulating collaboration and trust with key partners	3	4	5	5	5	3	4	5	3	5	...	5	3	4,13	5

Source: author

4.2 c) Defuzzification for all TFN and 4.2 d) Filtering and analyses of evaluation criteria by setting a threshold value (α), i.e., if Gi ≥ α, criterion i is selected; if Gi < α, criterion i is eliminated.

Table 16 presents the defuzzification of all TFN resulted from the evaluation of the I4.0 LC (15) in relation to the challenges towards I4.0 (6) by all experts (40). The Defuzzification results by calculating Gi (see 3.1), considering *Li, Mi and Ui*. For the filtering and analysis of all criteria evaluated, a threshold value was adopted ($\alpha = 4$) (as well as the first phase). That means, if Gi $\geq \alpha$, then I4.0 LC is prioritized, because it is assumed that this I4.0 LC can support with at least one challenge towards I4.0. In contrast, if, Gi $< \alpha$ then I4.0 LC is not prioritized because it is assumed that this I4.0 LC cannot contribute to at least one challenge.

Table 16 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on all experts' perspective (continues)

I4.0 LC	*Challenges towards I40*	*Li*	Mi	Ui	Defuzzification	If alpha =4,0
Collaborative-diverse team	1st. Acceptance of organizational transformation for Industry 4.0	2	3,90	5	3,63	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,00	5	3,67	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,74	5	3,58	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,72	5	2,91	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,07	5	3,69	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	4,19	5	3,40	Not prioritized
Communication	1st. Acceptance of organizational transformation for Industry 4.0	2	4,51	5	3,84	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	3,97	5	3,66	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,80	5	3,60	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,99	5	3,00	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,29	5	3,76	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,57	5	4,19	Prioritized
Encourage knowledge sharing	1st. Acceptance of organizational transformation for Industry 4.0	3	4,36	5	4,12	Prioritized
	2nd.Adapt/complement or develop a new business model	2	3,80	5	3,60	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,62	5	3,54	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,96	5	2,99	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,39	5	3,80	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,03	5	3,68	Not prioritized
Focus on customer	1st. Acceptance of organizational transformation for Industry 4.0	2	3,79	5	3,60	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,64	5	4,21	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	4,26	5	3,75	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,52	5	3,17	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,77	5	3,59	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,23	5	3,74	Not prioritized
Massive transformative purpose (MTP)	1st. Acceptance of organizational transformation for Industry 4.0	3	4,53	5	4,18	Prioritized
	2nd.Adapt/complement or develop a new business model	1	3,95	5	3,32	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,74	5	3,58	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,74	5	2,91	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,89	5	3,63	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,75	5	3,58	Not prioritized

Table 16 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on all experts' perspective (continues)

I4.0 LC	*Challenges towards I40*	*Li*	Mi	Ui	Defuzzification	If alpha =4,0
Transparency	1st. Acceptance of organizational transformation for Industry 4.0	2	4,50	5	3,83	Not prioritized
	2nd.Adapt/complement or develop a new business model	1	3,54	5	3,18	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	1	3,58	5	3,19	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,95	5	2,98	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,20	5	3,73	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,21	5	3,74	Not prioritized
Managing complexity	1st. Acceptance of organizational transformation for Industry 4.0	2	3,94	5	3,65	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,00	5	4,00	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	4,35	5	3,78	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,32	5	3,11	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,56	5	3,52	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,68	5	3,56	Not prioritized
Problem solving	1st. Acceptance of organizational transformation for Industry 4.0	2	4,03	5	3,68	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,16	5	3,72	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,18	5	4,06	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,38	5	3,13	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,74	5	3,58	Not prioritized
	6th. Stimulating collaboration and trust with key	2	3,61	5	3,54	Not prioritized
Promoting innovation	1st. Acceptance of organizational transformation for Industry 4.0	2	4,17	5	3,72	Not prioritized
	2nd.Adapt/complement or develop a new business model	1	4,06	5	3,35	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	1	3,81	5	3,27	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,41	5	3,14	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	1	3,69	5	3,23	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	3,72	5	3,24	Not prioritized
Asking big questions	1st. Acceptance of organizational transformation for Industry 4.0	2	4,09	5	3,70	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,34	5	4,11	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,15	5	4,05	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,14	5	3,05	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	1	3,56	5	3,19	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,70	5	3,57	Not prioritized

Table 16 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on all experts' perspective (conclusion)

I4.0 LC	*Challenges towards I40*	*Li*	Mi	Ui	Defuzzification	If alpha =4,0
Agility and adaptability perspective	1st. Acceptance of organizational transformation for Industry 4.0	2	4,51	5	3,84	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,28	5	4,09	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	4,04	5	3,68	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,06	5	3,02	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,84	5	3,61	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,83	5	3,61	Not prioritized
Connector	1st. Acceptance of organizational transformation for Industry 4.0	2	3,98	5	3,66	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,32	5	4,11	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,28	5	4,09	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,11	5	3,04	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,82	5	3,61	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,08	5	3,69	Not prioritized
Deep, interdisciplinary and self-learning	1st. Acceptance of organizational transformation for Industry 4.0	2	4,00	5	3,67	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,37	5	3,79	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,24	5	4,08	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,38	5	3,13	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,98	5	3,66	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	3,58	5	3,19	Not prioritized
Emotional intelligence	1st. Acceptance of organizational transformation for Industry 4.0	2	4,33	5	3,78	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	3,67	5	3,56	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,64	5	3,55	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,40	5	2,80	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	1	4,06	5	3,35	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	4,11	5	3,37	Not prioritized
Digital perspective	1st. Acceptance of organizational transformation for Industry 4.0	3	4,25	5	4,08	Prioritized
	2nd.Adapt/complement or develop a new business model	2	4,24	5	3,75	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,39	5	4,13	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,75	5	3,25	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,12	5	3,71	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,13	5	4,04	Prioritized

Source: author

In addition, Table 17 illustrates a color scale of the defuzzification resulted from the evaluation of all experts (Table 16). 15 I4.0 LC (categorized in social, methodological, personal and technical competences) are related to the 6 challenges towards I4.0. Table 17 illustrates a heat map with a color scale from red, yellow to green, where the cells in or close to the green color have a defuzzification value ≥ 4 (prioritized), different than cells in or close to red or yellow color that have a defuzzification value < 4 (unprioritized).

Eleven out of the fifteen I4.0 LC were prioritized because when related to the six challenges towards I4.0, the defuzzification value was ≥4 (threshold value) for at least one challenge. However, it is important to emphasize that the prioritization of the I4.0 LC considering the threshold= 4 does not exclude the other I4.0LC (unprioritized) since they are also important in this study. The prioritization highlights the responses of all experts by the threshold adopted in this study. Despite the adopted threshold, flexibility between interval 4 and 3.75 (0.25 hundredths difference) can be considered. Thus, inclusion for the values close to the threshold and belong to important and very important areas (according to the 5-point Likert scale) would be ensured in this study. Therefore, defuzzified values within this range may also be important for the challenges.

The first five I4.0 LC prioritized in relation to the challenges towards I4.0 with a higher defuzzification value are respectively (as shown in Table 17): Focus on customer (4,21) related to the 2nd challenge; communication (4,19) related to 6th challenge, MTP (4,18) related to 1st challenge, digital perspective (4,13) related to 3rd challenge, and encourage knowledge sharing (4,12) related to 1st challenge. It can be emphasized, considering the FDM approaches. that these first five L C 4.0 with a higher defuzzification value (≥ 4) related to the challenges are the I4.0 LC that present a higher degree of importance to contribute with the respective challenge related.

Table 17 - Defuzzification: overview of the I4.0 LC related with the challenges towards Industry 4.0 from prioritized to unprioritized based on all experts

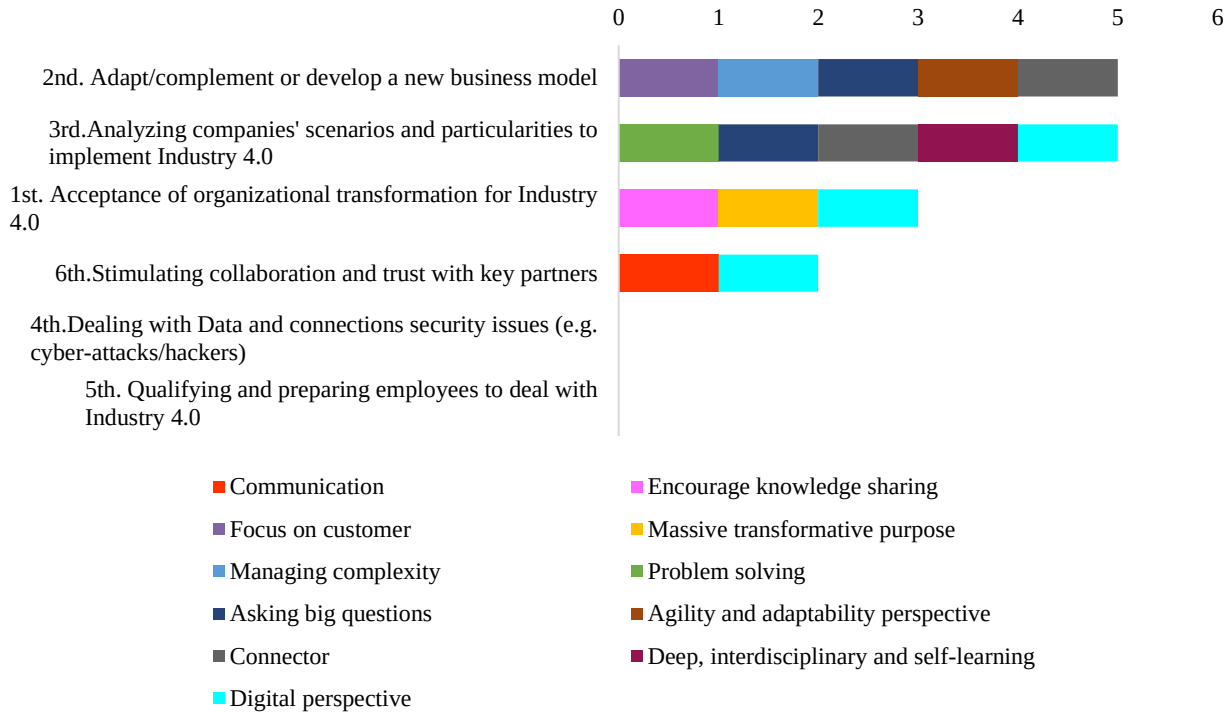
	Challenges towards I40 →	1st	2nd	3rd	4th	5th	6th	
Categories	***I4.0 LC ↓***	Acceptance of organizational transformation for Industry 4.0	Adapt/complement or develop a new business model	Analyzing companies' scenarios and particularities to implement Industry 4.0	Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	Qualifying and preparing employees to deal with Industry 4.0	Stimulating collaboration and trust with key partners	Number of challenges towards Industry 4.0 that are supported by each I4.0 LC
Social competences	Collaborative-diverse team	3,63	3,67	3,58	2,91	3,69	3,40	0
	Communication	3,84	3,66	3,60	3,00	3,76	4,19	1
	Encourage knowledge sharing	4,12	3,60	3,54	2,99	3,80	3,68	1
	Focus on customer	3,60	4,21	3,75	3,17	3,59	3,74	1
	Massive transformative purpose (MTP)	4,18	3,32	3,58	2,91	3,63	3,58	1
	Transparency	3,83	3,18	3,19	2,98	3,73	3,74	0
Methodological competences	Managing complexity	3,65	4,00	3,78	3,11	3,52	3,56	1
	Problem solving	3,68	3,72	4,06	3,13	3,58	3,54	1
	Promoting innovation	3,72	3,35	3,27	3,14	3,23	3,24	0
Personal competences	Asking big questions	3,70	4,11	4,05	3,05	3,19	3,57	2
	Agility and adaptability perspective	3,84	4,09	3,68	3,02	3,61	3,61	1
	Connector	3,66	4,11	4,09	3,04	3,61	3,69	2
	Deep, interdisciplinary and self-learning	3,67	3,79	4,08	3,13	3,66	3,19	1
	Emotional intelligence	3,78	3,56	3,55	2,80	3,35	3,37	0
Technical competences	Digital perspective	4,08	3,75	4,13	3,25	3,71	4,04	3

Source: author

It can be seen from the data in Table 17 that the main I4.0 LC that contribute to more than one challenge towards I4.0 are: digital perspective, connector and asking big questions. In contrast, two challenges towards I4.0 seem to have not benefited from the I4.0 LC prioritized, due to the defuzzification value not reaching the threshold (=4). These challenges are, respectively, 4th Dealing with Data and connections security issues (e.g. cyber-attacks/hackers) and 5th Qualification and preparation of employees to deal with I4.0. However, as mentioned above, considering a flexibility of the threshold (a difference of 0,25 hundredth of 4), then the I4.0 LC *communication* and *encourage knowledge sharing* can be relevant to support the 5th challenge. Also, *communication* would be part of the I4.0 LC that contributes to more challenges, considering the flexibility of the threshold.

Figure 9 illustrates all I4.0 LC (11) prioritized that can support the challenges towards I4.0, it is observed that for the 2nd. and the 3rd. challenge there are five I4.0 LC that were evaluated to be considered. In sequence, Table 18 presents some highlighting points of the 3 I4.0 LC (considering their theoretical approaches) prioritized that presented a higher defuzzification when related with challenges (Table 17). The I4.0 LC in bold are those that contribute with more than one challenge (Table 18).

Figure 9 - The I4.0 LC that contribute to support each challenge towards I4.0: based on all experts



Source: author

Table 18 - The I4.0 LC with higher defuzzification value related with challenges towards Industry 4.0

Challenges towards I4.0	I4.0 LC
1st. Acceptance of organizational transformation for Industry 4.0	*Massive transformative purpose (MTP)* aims to have a purpose's perspective to drive organization as a whole to achieve specific goals, in that case the acceptance and transformation towards Industry 4.0 is a process of change that need a clear MTP guided by managers and leaders through strategic actions that should involve all collaborators of the company (KIEL et al. 2017). *Encourage knowledge sharing* is about incentivizing a collaborative knowledge sharing regards to I4.0 technologies and technological trends, that are supported through networks and communication channels. Related to that, the creation of a culture convinced of I4.0 technologies benefits (KIEL et al. 2017; SCHNEIDER, 2018) can be conducted by managers and leaders, when they encourage knowledge sharing in company as a whole becoming the process of transformation more acceptable. ***Digital perspective*** is about adopting a digital mindset to explore new technologies, opportunities and strategies advantages in favor of the company. Before the transformation towards I4.0 its fundamental that managers and leaders assess the organizational readiness in companies, considering different dimensions such as the digitalization (SONY; NAIK, 2019) demanding by understand digital technologies, and tools that promote digitalization (ALLEN, 2020)
2nd.Adapt/complement or develop a new business model	*Focus on customer* is about keeping proximity with customers constantly understanding their demands and expectation, considering the fast changes in the market. In this regard, the process to develop, adapt or complement a new business model to be more innovative, service-oriented should integrate the customer demands (KIEL, 2017). ***Asking big questions*** aims to ask instigation questions to promote curiosity, leaders should align these questions with company business to meet market demands. Thus, the adaptation, complement or develop of new business model may start with a question, such as "how can I distribute movies and shows on-line?", this question was the beginning to think in a new business model that distributes movies and shows via streaming, such as Netflix[16] (MAGALDI; SALIBI NETO, 2018). ***Connector*** it is about to connect points interpreting the environment and emerging trends. Therefore, different connections can be executed considering the emerging trends of I4.0 to develop, adapt or complement a new business model (SCHNEIDER, 2018) so that it can meet and be connected to customer demands.
3rd.Analyzing companies' scenarios and particularities to implement Industry 4.0	***Digital perspective*** aims to understand, practice and adopt digitalization, for that leaders and managers should consider digital wisdom to practice and adopt digital technologies. Related with that, for the process to implement I4.0 it's important to consider different particularities designed for a specific company (MÜLLER, KIEL, VOIGT, 2018). One of these particularities are the technical requirements in a specific company (HERMAN, PENTEK, OTTO, 2016). These requirements can be contributed by a digital perspective to understand better the digital technologies to be adopted or the new technologies to be explored supporting the process of I4.0 implementation in a company. ***Connector*** it is about to connect points interpreting the environment and emerging trends in the FIR. Considering the specific particularities of a company to implement the I4.0 process, analyzing these different particularities, such as technological needs, project's goals, interfaces to other systems, projects schedules, costs and benefits should be interpreted, analyzed to be connected in a company- specific scenario. *Deep, interdisciplinary and self-learning* it refers to constantly learn in deep and interdisciplinary way applying the knowledge in different contexts to support to find solutions. There are distinct requirements for a specific company to conduct and implement the I4.0, a deep and interdisciplinary technological knowledge can contribute to define the technologies needed to be adopted and integrated into different organizational hierarchies, structures production and logistic systems (Müller, Kiel, Voigt, 2018) for example.
6th. Stimulating collaboration and trust with key partners	*Communication* is essential to allow information flow and information exchange. In this regard, stimulating collaboration and trust with partners requires openness, cross-company cooperativeness, trust and transparency through value chain (KIEL et al. 2017; AGOSTINI; FILIPPINI, 2018). For that its important increase connectivity to allow information flow and knowledge exchange (AGOSTINI; FILIPPINI 2018) adopting distinct communication tools. ***Digital perspective*** refers to understand, practice and adopt digitalization considering the use of digital technologies, as well as tools to promote digitalization, also its important to adopt a digital mindset exploring for new technologies, opportunities and strategic advantages to favor the company. In this regard, a compatibility of technologies is a high point to stimulus collaboration and trust with key partners (KIEL et al. 2017) to support that its important the alignment of all (managers, leaders, partners, customers) in a digital perspective to be able to share and exchange information supported by the compatibility of technologies, for example.

Source: author

[16] Netflix is a subscription-based on streaming service that allows people to watch movies, TV series and shows without commercials on an internet-connected device. Link< https://help.netflix.com/en/node/412>. Accessed 16 April, 2021.

For the Brazilian and international experts, an analysis similar to the one presented above (overview of all experts) was also developed (see Appendix E), which shows the analysis for both groups.

On the one hand, based on the Brazilian experts, 13 out of the 15 I4.0 LC were prioritized (collaborative diverse team and emotional intelligence were not). On the other hand, international experts, prioritized 14 out of the15 I4.0 LC (promoting innovation was unprioritized). Comparing both groups, it was observed, that the I4.0 LC prioritized, focus on customer and connector respectively, related to the 3rd. challenge and to the 2nd. challenge, are the I4.0 LC prioritized from Brazilian and international experts for its high defuzzification values. Thus, both I4.0 LC presents an important degree to contribute to the respective challenges when related.

Still comparing both groups (Brazilian and international experts), it was found a difference with the I4.0 LC (promoting innovation). For Brazilian experts, this I4.0 LC was prioritized, contributing to support the 3rd.; 5th and 6th. challenge. However, for international experts this I4.0 LC was unprioritized. It is important to emphasize that promoting innovation has been prioritized as one of the most important I4.0 LC in the first phase of the empirical approaches. This difference may be due to the cultural differences, and perspectives of both groups. Despite these differences, it is important to highlight that the literature strengthens the importance of innovation to be considered and practiced by leaders and managers in Industry 4.0 context (SHAMIM et al., 2016; MAGALDI; SALIBI NETO, 2018; MDLULI; MAKHUPE, 2017).

In second phase, the perspective of 40 experts from Brazil, Germany and other countries allowed to evaluate the role of I4.0 LC when they were related to the challenges towards I4.0. Therefore, 11 I4.0 LC were considered relevant to contribute to the challenges towards I4.0. From this 11 I4.0 LC it is emphasized the five I4.0 LC with a higher defuzzification value when related to the challenges towards I4.0, they are respectively: *Focus on customer* related to the 2nd.challenge; *communication* related to 6th.challenge, *MTP* related to 1st.challenge, *digital perspective* related to 3rd.challenge, and *encourage knowledge sharing* related to 1st.challenge. Such I4.0 LC (5) when related to the challenges towards I4.0 are those that presented a higher degree of importance to contribute to the respective challenge related.

In addition, during the analysis of the second phase, the challenge 4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers), and 5th. Qualification and preparation of employees to deal with I4.0 were not supported by I4.0 LC, because the defuzzification values when related both variables have not reached the threshold (=4).

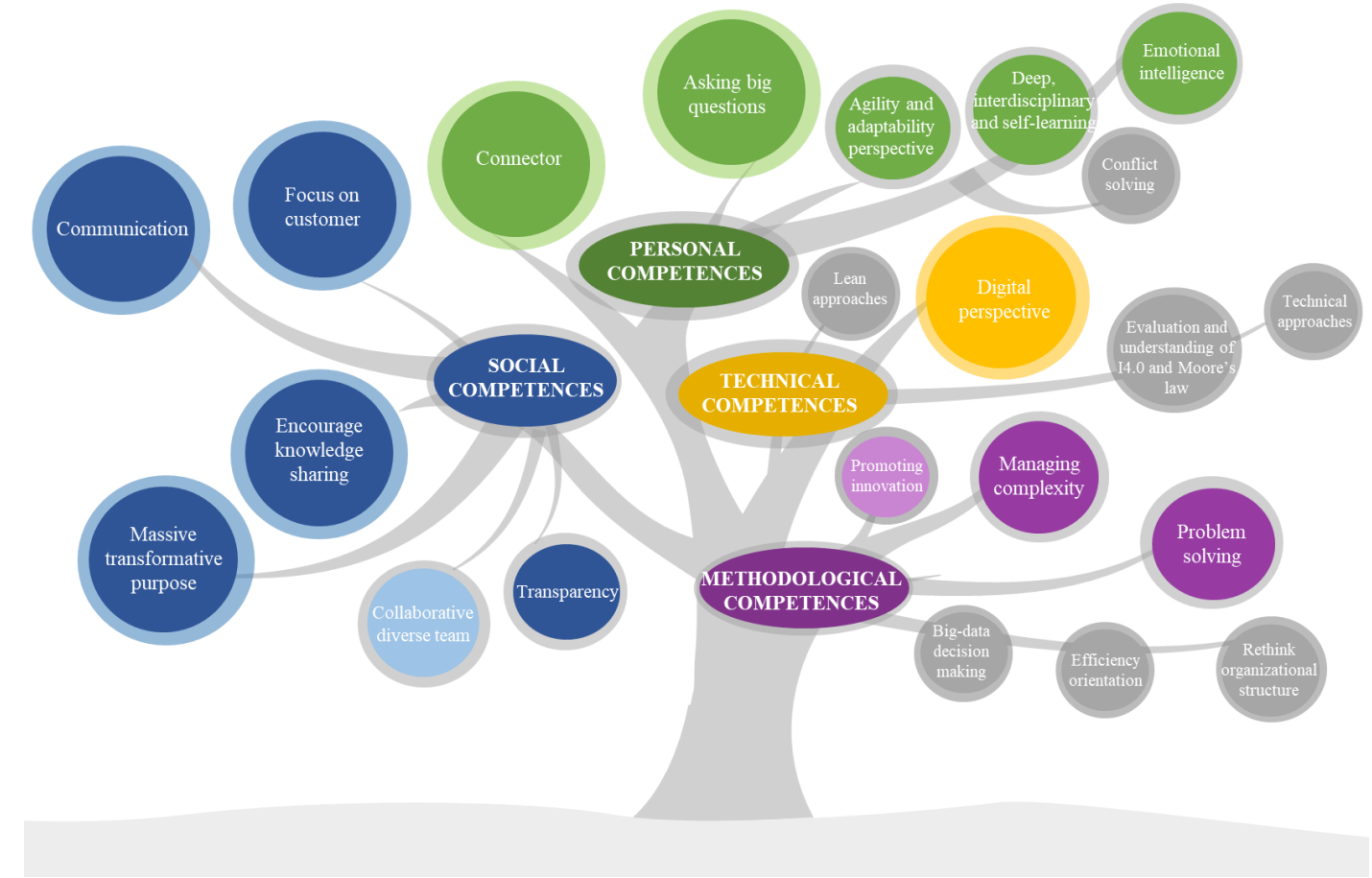
However, as mentioned previously considering the flexibility of scale between 3,75 and 4 (difference of 0,25 hundredths) regarding the threshold adopted, the I4.0 LC *communication* and *encourage knowledge sharing* can contribute to the 5th challenge.

In summary, the results presented in second phase allowed to achieve the main goal of this study to identify and prioritize the I4.0 LC that contribute to deal with challenges towards I4.0. Based on the perspective of Brazilian and international experts and the analysis of findings commented above, this study highlighted 7 out of 11 I4.0 LC that were prioritized by experts. 5 I4.0 LC presents a higher defuzzification value when related to the challenges towards I4.0 respectively: *Focus on customer*, *communication, MTP, digital perspective* and *encourage knowledge sharing*. The other 2 I4.0 LC are: *connector and asking big question* which can support to more than one challenge towards I4.0, as well as *digital perspective*. In sequence, it is presented a proposal that follow the prioritization process of the I4.0 LC from the first to the second empirical phases to identify those that contribute to the challenges.

5. I4.0 LC REGARDING CHALLENGES TOWARDS I4.0 CONTEXT BASED ON EXPERTS PERSPECTIVE

Based on experts' perspective and the results from the first and second phases of this study, it is proposed an information tree in Figure 10 showing the empirical prioritization of I4.0 LC in the first and second phases. Initially 22 I4.0 LC were proposed with their description based on the literature review. From this 22 I4.0 LC, 15 I4.0 LC were prioritized in the first phase as the leadership competences in I4.0 context. Then, for the second phase, these 15 I4.0 LC were related to six challenges towards I4.0 (prioritized) identifying 11 out of 15 I4.0 LC that can support the challenges towards I4.0, still in this second phase, some I4.0 LC were highlighted, contributing to more challenges.

Figure 10 - Overview of the prioritization of I4.0 LC: an information tree



Legend

Categories of competences

Overview of the I4.0 LC (example for the social competences category)

Prioritized in 2nd phase and highlighted

Prioritized in 2nd phase

Prioritized in 1st phase

Identified in the literature (not prioritized)

Note: There are four areas in the information tree, that represent the categories: Social competences (blue color), Personal competences (green color), Technical competences (yellow color).and Methodological competences (purple color). Into the four categories are presented circles that refer to the 22 I4.0 LC. As observed in the legend, there are four circles types in the information tree: the colored bigger circles (blue, green, yellow, and purple) that represent the 7 I4.0 LC that were prioritized and highlighted in the second phase due to the higher defuzzification value, supporting more challenges. The colored medium circles (blue, green, yellow and purple) are also part of the prioritized I4.0 LC in the second phase. The medium circles in light colors (blue, green, yellow and purple) are the prioritized I4.0 LC in the first phase. Finally, the medium circles in grey are the I4.0 LC that were not prioritized by the experts, but were identified in the literature, as well as the other I4.0 LC.

Source: author (the information tree has been designed using resources from PoweredTemplate.com)

As shown in Figure 10, there are 7 I4.0 LC that were highlighted. These 7 I4.0 LC are: *asking big questions, connector, focus on customer, communication, MTP, encourage knowledge sharing and digital perspective*. There were highlighted because presented a higher defuzzification value (> 4) when related to the challenges (see Table 18).

The 3 I4.0 LC that contribute with more than one challenge are: *asking big question, connector, and digital perspective*. Asking big question contributes to 2nd. challenge because of the adaptation, complement or develop of a new business model may start with a question (MAGALDI; SALIBI NETO, 2018). Also, this I4.0 LC supports to 3rd. challenge, because the process to analyze and define particularities required to implement I4.0 can be supported by asking questions such as: which are the technical requirements to guarantee the full connection of systems in real time of the shop floor?, or which are the technologies that can guarantee the digitalization and a ICT infrastructure in the different areas of the company?

Connector can contribute to 2nd. challenge because the process to adapt, complement, or develop new business model can be supported by connecting the points to interpret the environment, emerging trends in I4.0 context, and future demands of customers, for example. Also, this I4.0 LC supports to 3rd. challenge connecting the different particularities (such as, technological needs, costs, projects schedules, among others) of the company to be considered before the process to implement I4.0.

Digital perspective supports to 1st. challenge because leaders and manager should assess the organizational readiness in companies, considering the digitalization dimension before the transformation towards I4.0.In addition, this I4.0 LC supports to 3rd.challenge because during the process to implement I4.0 it’s important to consider distinct particularities designed for a specific company, such the technical requirements, a digital perspective can contribute to understand which digital technologies are best suited for a specific area, for example. Also, this I4.0 LC supports to 6th. challenge by the compatibility of technologies to stimulate collaboration and trust with partners.

6. CONCLUSION AND FINAL CONSIDERATIONS

It was presented in the literature review the role that leadership plays to guide the successful change process to I4.0 context (HELMING et al., 2019) handling the requirements resulted from I4.0 technologies and its challenges (HELMING et al., 2019; SCHNEIDER, 2018). The FIR scenario demands workers qualified and prepared with the respective competence and skills demanded in Industry 4.0 (EROL et al., 2016). Although, there are studies proposing competences required in I4.0, there are still few studies that propose competences required by leaders and managers in the FIR.

The main goal of the current study was to prioritize the leadership competences that contribute to leaders and managers handling the challenges towards Industry 4.0. To support this main goal, three specific goals respectively were developed: I) to identify challenges towards Industry 4.0; II) to identify leadership competences in Industry 4.0, and III) to analyze leadership competences and challenges in Industry 4.0 context. The I) and II) are specific goals identified in the literature resulted in nine challenges towards I.40 and twenty-two leadership competences in Industry 4.0 context (I4.0 LC), respectively. The specific goal III) was developed empirically carrying out the FDM that considers the outputs of I) and II).

The FDM conducted two phases, initially for the first phase, 6 out of 9 challenges towards I4.0 and 15 out of 22 I4.0 LC were prioritized by experts who have experience with Industry 4.0 approaches. For the second phase a new FDM was carried out to prioritize the I4.0 LC (15) that can fit better with the challenges towards I4.0 (6), for that each I4.0 LC was related to the six challenges to identify the degree of importance of the I4.0 LC with the respective challenges. This prioritization process was executed by a total of 40 experts from Brazil, Germany and other countries.

For the analysis based on all experts 11 out of 15 I4.0 LC were prioritized to contribute to the challenges towards I4.0, for Brazilian and international experts 13 and 14 out of 15 I4.0 LC respectively were prioritized. Such differences may have resulted due to the cultures differences between the countries. A positive point comparing the analysis of all experts and both groups separately was that the majority of I4.0 LC (from first phase) were prioritized also to support the challenges in the second phase.

This study emphasized 7 out of the 11 I4.0 LC prioritized, because 5 of them have a higher defuzzification value when related with the challenges towards I4.0 respectively: *Focus on customer* related to the 2nd.challenge, *communication* related to 6th., *MTP* related to 1st.challenge, *digital perspective* related to 3rd.challenge and *encourage knowledge sharing* related to 1st.challenge. The other 2 I4.0 LC are: *connector and asking big question* which can

support to more than one challenge towards I4.0, including the *digital perspective* as a I4.0 LC that support to more than one challenge.

Regarding the limitations of this study there are three points to be highlighted, firstly, although the results presented in this research are based on expert's perspective from Brazil, Germany and other countries, the number of experts should be larger for the next applications. Secondly, the study considered the challenges towards I4.0 based on the literature from 2014 to 2018, mainly because of the authors' approaches to these challenges (cited by at least two authors), and the resulting extension list when it would be empirically analyzed.

Thirdly, this study proposed 11 I4.0 LC to contribute to at least four of the six challenges towards I4.0. However, no relevant relationship was found for the prioritized I4.0 LC to contribute to the challenges (considering the threshold (4) in the FDM of the second phase): 4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers) and 5th. Qualifying and preparing employees to deal with Industry 4.0, being a limitation to be considered. This may emphasize two points: firstly, the flexibility considered with the threshold (difference of 0,25 hundredths), then the I4.0 LC *communication* and *encourage knowledge sharing* can support the 5th challenge. Secondly, other leadership competences need to be explicitly proposed to meet the 4th challenge.

Further studies should analyze and identify learning and training methods to qualify managers and leaders with the I4.0 LC proposed in this study. The I4.0 LC proposed also can be developed in maturity models supporting leaders and managers during the transition process towards Industry 4.0. In addition, it is suggested constant literature reviews regarding the challenges towards I4.0, including more recent articles on this approach and analyzing them empirically in future studies. Also, it is suggested to explore in the literature specifically the I4.0 LC *digital perspective* because it has resulted as the more prominent I4.0 LC than the others, supporting more challenges, and because such I4.0 LC may be the niche that encompasses other relevant competences for leaders and managers in I4.0 context. Furthermore, future studies should consider a relationship map (DEMATEL - Decision Making Trial and Evaluation Laboratory) to analyze and understand the relationship of all variables resulted in this study. Finally, it is suggested to evaluate these I4.0 LC proposed with the talent management and HR in companies to develop leadership competences model aligned with the specific scenario of the company.

REFERENCES

AGOSTINI, L.; FILIPPINI, R. Organizational and managerial challenges in the path toward Industry 4.0. **European Journal of Innovation Management**, v. 22, n. 3, p. 406–421, 2019.

AKDERE, M.; HICKMAN, L.; KIRCHNER, M. Developing Leadership Competencies for STEM Fields: The Case of Purdue Polytechnic Leadership Academy. **Advances in Developing Human Resources**, v. 21, n. 1, p. 49–71, 2019.

ALLEN, S. J. On the Cutting Edge or the Chopping Block? Fostering a Digital Mindset and Tech Literacy in Business Management Education. **Journal of Management Education**, 2020.

ASSANTE, D. et al. Smart education in the context of industry 4.0. **IEEE Global Engineering Education Conference, EDUCON**, v. April-2019, p. 1140–1145, 2019.

BAARTMAN, L. K. J.; DE BRUIJN, E. Integrating knowledge, skills and attitudes: Conceptualizing learning processes towards vocational competence. **Educational Research Review**, v. 6, n. 2, p. 125–134, 2011.

BAUER, W. et al. Transforming to a Hyper-connected Society and Economy – Towards an "Industry 4.0". **Procedia Manufacturing**, v. 3, n. Ahfe, p. 417–424, 2015.

BATTILANA, Julie et al. Leadership competencies for implementing planned organizational change. **The leadership quarterly**, v. 21, n. 3, p. 422-438, 2010.

BIANCO, D. et al. Unlocking the Relationship Between Lean Leadership Competencies and Industry 4.0 Leadership Competencies: An ISM/Fuzzy MICMAC Approach. **IEEE Transactions on Engineering Management**, 2021.

BOLTE, Sophia; DEHMER, Joanna; NIEMANN, Jörg. DIGITAL LEADERSHIP 4.0. **ACTA TECHNICA NAPOCENSIS-Series: APPLIED MATHEMATICS, MECHANICS, and ENGINEERING**, v. 61, n. 4, 2018.

BORGES, L. et al. Desenvolvimento de modelagem de liderança para a Revolução 4.0. **FTT Journal of Engineering and Business**, v. 1, n. 5, 2020.

BOYATZIS, R. E. Managerial and Leadership Competencies : A Behavioral Approach to Emotional , Social and Cognitive Intelligence ∗. v. 28, n. 9, 2011.

BOYATZIS, R.; BOYATZIS, R. E. **Competencies in the 21st centuryJournal of Management Development**, 2008.

BOLDEN, Richard; GOSLING, Jonathan. Leadership competencies: time to change the tune?. **Leadership**, v. 2, n. 2, p. 147-163, 2006.

BRETTEL, M. et al. How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. **FormaMente**, v. 12, 2017.

CAMPION, M. A. et al. Doing competencies well: Best practices in competency modeling. **Personnel psychology**, v. 64, n. 1, p. 225-262, 2011.

CASINO, F.; DASAKLIS, K.; PATSAKIS, C. A systematic literature review of blockchain-based applications: Current status, classification and open issues. **Telematics and informatics**, v. 36, p. 55-81, 2019.

CANALS, J.; HEUKAMP, F. **The Future of Management in an AI World**. Palgrave Macmillan, 2020.

CERVI, A. F. **Fazer ou comprar: proposta de uma estrutura para o processo decisório e aplicação de métodos de decisão multicritério**. 2017. Tese. (Doutorado em Engenharia de Produção). Universidade de São Paulo.

CHEN, M. K.; WANG, S. C. The use of a hybrid fuzzy-Delphi-AHP approach to develop global business intelligence for information service firms. **Expert Systems with Applications**, v. 37, n. 11, p. 7394–7407, 2010.

CHIH-HUNG, W.; WEN-CHANG, F. Combining the Fuzzy Analytic Hierarchy Process and the fuzzy Delphi method for developing critical competences of electronic commerce professional managers. **Quality & Quantity**, v. 45, n. 4, p. 751-768, 2011.

CHOI, Y. W. et al. Effects of interdisciplinary courses on engineering students' competencies. In: **TENCON 2018-2018 IEEE Region 10 Conference.** IEEE, 2018. p. 0793-0797.

CIMINI, C. et al. How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs. **Journal of Manufacturing Technology Management**, 2020.

COLLI, Michele et al. A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. **Annual Reviews in Control**, v. 48, p. 165-177, 2019.

CONGER, Jay A.; READY, Douglas A. Rethinking leadership competencies. **Leader to leader**, v. 2004, n. 32, p. 41, 2004.

CROFT, L.; SEEMILLER, C. Developing Leadership Competencies. **New directions for student leadership**, v. 156, p. 7-18, 2017.

CULOT, G. et al. Addressing Industry 4.0 Cybersecurity Challenges. **IEEE Engineering Management Review**, v. 47, n. 3, p. 79–86, 2019.

DANGLOT, B. et al. A snowballing literature study on test amplification. **Journal of Systems and Software**, v. 157, p. 110398, 2019.

DAY, J.; BOBEVA, M. A generic toolkit for the successful management of delphi studies. **Electronic Journal of Business Research Methods**, v. 3, n. 2, p. 103–116, 2005.

DE SOUSA JABBOUR, A. B. L. et al. When titans meet – Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. **Technological Forecasting and Social Change**, v. 132, n. October 2017, p. 18–25, 2018.

DELOITTE. Industry 4.0 Challenges and solutions for the digital transformation and use of exponential technologies. **Finance, Audit Tax Consulting Corporate: Zurich, Swiss**, p. 1-30, 2015.

DELOITTE DEVELOPMENT LLC (FIRM). The Fourth Industrial Revolution: at the intersection of readiness and responsibility. 2020. Available at< https://www2.deloitte.com/content/dam/Deloitte/de/Documents/humancapital/Deloitte_Review_26_Fourth_Industrial_Revolution.pdf>. Accessed July 10, 2020.

ELKINGTON, R. Leadership Decision-Making Leveraging Big Data in Vuca Contexts. **Journal of Leadership Studies**, v. 12, n. 3, p. 66-70, 2018.

ENKE, J. et al. Industrie 4.0–Competencies for a modern production system: A curriculum for learning factories. **Procedia manufacturing**, v. 23, p. 267-272, 2018.

EROL, S. et al. Tangible Industry 4 . 0 : a scenario-based approach to learning for the future of production. **Procedia CIRP**, v. 54, p. 13–18, 2016.

EROL, S.; SCHUMACHER, A.; SIHN, W. Strategic guidance towards Industry 4 . 0 – a three-stage process model Strategic guidance towards Industry 4 . 0 – a three-stage process model. n. December 2015, 2016.

FIRJAN. **Panorama da Inovação: Indústria 4.0.** Publicações FIRJAN: Cadernos SENAI de Inovação. 2016

FLORES, E.; XU, X.; LU, Y. Human Capital 4.0: a workforce competence typology for Industry 4.0. **Journal of Manufacturing Technology Management**, v. 31, n. 4, p. 687–703, 2020.

FRANK, A. G.; DALENOGARE, L. S.; AYALA, N. F. Industry 4.0 technologies: Implementation patterns in manufacturing companies. **International Journal of Production Economics**, v. 210, n. January, p. 15–26, 2019.

GRANGEL-GONZÁLEZ, I. et al. Towards a semantic administrative shell for industry 4.0 components. In: **2016 IEEE Tenth International Conference on Semantic Computing (ICSC)**. IEEE, 2016. p. 230-237.

GRZYBOWSKA, K.; ŁUPICKA, A. Key competencies for Industry 4.0. **Economics and Management Innovations (ICEMI)**, v. 1, n. October, p. 250–253, 2017.

GUZMÁN, V. E. C. et al.. Leadership competences in industry 4.0 context: a qualitative analysis based on the literature review.. In: **Anais** do Simpósio de Engenharia, Gestão e Inovação. Anais...Juazeiro do Norte(CE) URCA, 2021. Available at: < https//www.even3.com.br/anais/sengi2021/352668-LEADERSHIP-COMPETENCES-IN-INDUSTRY-40-CONTEXT--A-QUALITATIVE-ANALYSIS-BASED-ON-THE-LITERATURE-REVIEW>. Accessed August 19, 2021.

HAY GROUP. Building the new leader. **Leadership challenges of the future revealed**, 2011b. 12p. Available at: < https://issuu.com/fredforum/docs/hay_group_leadership_2030_whitepaper/10>. Accessed August 30, 2020.

HAY GROUP. Emotional and social competency inventory (ESCI): **A user guide for accredited practitioners**, 2011a. 36p. Available at < http://www.eiconsortium.org/pdf/ESCI_user_guide.pdf >. Accessed March 30, 2021.

HEAVIN, C.; POWER, D. J. Challenges for digital transformation–towards a conceptual decision support guide for managers. **Journal of Decision Systems**, v. 27, p. 38–45, 2018.

HECKLAU, F. et al. Holistic Approach for Human Resource Management in Industry 4.0. **Procedia CIRP**, v. 54, p. 1–6, 2016.

HECKLAU, F. et al. Human resources management: Meta-study-analysis of future competences in Industry 4.0. In: **Proceedings of the International Conference on Intellectual Capital, Knowledge Management & Organizational Learning**. 2017. p. 163-174.

HELMING, S. et al. Development of a training concept for leadership 4.0 in production environments. **Procedia Manufacturing**, v. 31, p. 38–44, 2019.

HERCEG, A V. et al. Challenges and Driving Forces for Industry. **Sustainability**, v. 12, n. 4208, p. 1–22, 2020.

HERMANN, M.; PENTEK, T.; OTTO, B. Design principles for industrie 4.0 scenarios. **Proceedings of the Annual Hawaii International Conference on System Sciences**, v. 2016- March, p. 3928–3937, 2016.

HERMANN, MARIO PENTEK, TOBIAS* OTTO, B. Design Principles for Industrie 4.0 Scenarios: A Literature Review. **Technische Universitat Dortmund**, v. 514, n. 01, p. 172–181, 2015.

HERNEZ-BROOME, G.; HUGHES, R.J. Leadership development: Past, present, and future. **Human resource planning**, v. 27, n. 1, 2004.

HIRSCH-KREINSEN, H. Smart production systems : a new type of industrial process innovation. **DRUID Society Conference 2014**, n. June 2014, p. 1–21, 2014.

HSIEH, T. Y.; LU, S. T.; TZENG, G. H. Fuzzy MCDM approach for planning and design tenders selection in public office buildings. **International Journal of Project Management**, v. 22, n. 7, p. 573–584, 2004.

HSU, Y. L.; LEE, C. H.; KRENG, V. B. The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection. **Expert Systems with Applications**, v. 37, n. 1, p. 419–425, 2010.

ISHIKAWA, A. The Max-Min Delphi method and fuzzy Delphi method via fuzzy integration *. v. 55, p. 241–253, 1993.

JERMAN, A.; PEJIĆ BACH, M.; ALEKSIĆ, A. Transformation towards smart factory system: Examining new job profiles and competencies. **Systems Research and Behavioral Science**, v. 37, n. 2, p. 388–402, 2020.

KAGERMANN, H.; WAHLSTER, W.; HELBIG, J. Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0. **Final Report of the Industrie 4.0 Working Group**, n. April, p. 1–84, 2013.

KASAPOĞLU, Ö. A. Leadership and Organization for the Companies in the Process of Industry 4.0 Transformation. **International Journal of Organizational Leadership**, v. 7, p. 300–308, 2018.

KAUFFELD, S. Self-directed work groups and team competence. **Journal of Occupational and Organizational Psychology**, v. 79, n. 1, p. 1–21, 2006.

KELLY, R. **Constructing Leadership 4.0. Swarm Leadership and the Four Industrial Revolution**. Springer Nature Switzerland, 2018.

KIEL, D. What do we know about " Industry 4 . 0 " so far ? [rewarded with IAMOT Best Student Paper Award]. **International Association for Management of Technology**, n. May, p. 0–22, 2017.

KOHL, K.; SWARTZ, J. Building Industry 4.0 Talent. In: **Thriving in Digital Workspaces**. Springer, Cham, 2019. p. 15-39.

KOMAROVA, N. V.; ZAMKOVOI, A. A.; NOVIKOV, S. V. The Fourth Industrial Revolution and Staff Development Strategy in Manufacturing. **Russian Engineering Research**, v. 39, n. 4, p. 330–333, 2019.

KOTTER, J. P. What leaders really do. **Harvard business review**, v. 79, n. 11, 2001.

KUO, Y.; CHEN, P. Constructing performance appraisal indicators for mobility of the service industries using Fuzzy Delphi Method. v. 35, p. 1930–1939, 2008.

LESKIW, S. L.; SINGH, P. Leadership development: Learning from best practices. **Leadership and Organization Development Journal**, v. 28, n. 5, p. 444–464, 2007.

LIN, C. Application of fuzzy Delphi method (FDM) and fuzzy analytic hierarchy process (FAHP) to criteria weights for fashion design scheme evaluation. **International Journal of Clothing Science and Technology**, v. 25, n. 3, p. 171–183, 2013.

MAGALDI, S.; SALIBI NETO, J. **Gestão do Amanhã: Tudo o que você precisa saber sobre gestão, inovação e liderança para vencer na 4a Revolução Industrial**. Editora Gente Liv e Edit Ltd, 2018.

MARTÍNEZ-GONZÁLEZ, M.; OLID, C. S.; CRESPO, J. L. Evolution of HR competences in organizations immersed in the fourth industrial revolution. **Quadernos de Psicologia**, v. 21, n. 1, p. 1–16, 2019.

MCAFEE, A.; BRYNJOLFSSON, E. Big Data : The Management Review. **Harvard Business Review**, n. October, p. 1–12, 2012.

MCMILLAN, S.; KING, M.; TULLY, P. How to use the nominal group and Delphi techniques. **International journal of clinical pharmacy**, v. 38, n. 3, p. 655-662, 2016.

MDLULI, S.; MAKHUPE, O. Defining leadership competencies needed for the fourth industrial revolution: leadership competencies 4.0. **Africa Expansion Project**, 2017.

MOEUF, Alexandre et al. Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. **International Journal of Production Research**, v. 58, n. 5, p. 1384-1400, 2020.
MOHAMED, M. Challenges and Benefits of Industry 4.0: An overview. **International Journal of Supply and Operations Management**, v. 5, n. 3, p. 256–265, 2018.

MÜLLER, J. M. Assessing the barriers to Industry 4.0 implementation from a workers' perspective. **IFAC-PapersOnLine**, v. 52, n. 13, p. 2189–2194, 2019.

MÜLLER, J. M.; KIEL, D.; VOIGT, K.. What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. **Sustainability**, v. 10, n. 1, p. 247, 2018.

MÜLLER-FROMMEYER, L. C. et al. Introducing Competency Models as a Tool for Holistic Competency Development in Learning Factories: Challenges, Example and Future Application. **Procedia Manufacturing**, v. 9, p. 307–314, 2017.

NEL et al. Trend 9: Leadership in an Industry 4.0 world. Preparing to manage the mining workforce of the future. **Tracking the trends 2020 Leading from the front**. Deloitte Insights, 2020. Available at <https://www2.deloitte.com/content/dam/insights/us/articles/tracking-the-trends-2020/DI_Tracking-the-trends-2020.pdf >. Accessed March 30, 2021.

O*NET CONTENT MODEL. Occupational Information Network. O*Net Resource Center. Available at https://www.onetcenter.org/content.html#cm2. Accessed August 20, 2020.

OBERER, B.; ERKOLLAR, A. Leadership 4.0: Digital Leaders in the Age of Industry 4.0. **International Journal of Organizational Leadership**, v. 7, p. 404–412, 2018.

OKOLI, C.; PAWLOWSKI, S. D. The Delphi method as a research tool: An example, design considerations and applications. **Information and Management**, v. 42, n. 1, p. 15–29, 2004.

OLSEN, T. L.; TOMLIN, B. Industry 4.0: Opportunities and challenges for operations management. **Manufacturing and Service Operations Management**, v. 22, n. 1, p. 113–122, 2020.

PADILLA-RIVERA, A. et al. Social circular economy indicators: Selection through fuzzy delphi method. **Sustainable Production and Consumption**, v. 26, p. 101–110, 2021.

PEREIRA, A. C.; ROMERO, F. A review of the meanings and the implications of the Industry 4.0 concept. **Procedia Manufacturing**, v. 13, p. 1206–1214, 2017.

PICCAROZZI, M.; AQUILANI, B.; GATTI, C. Industry 4.0 in management studies: A systematic literature review. **Sustainability (Switzerland)**, v. 10, n. 10, p. 1–24, 2018.

PRICE WATER HOUSE COOPERS. Industry 4.0: Building the digital enterprise Metals key findings. **Global Industry 4.0 Survey** – Industry key findings, 2016. Available at < https://www.pwc.com/gx/en/industries/industrial-manufacturing/publications/assets/pwc-building-digital-enterprise.pdf>. Accessed April 10, 2021.

PRODROMOS C. et al. The relationship between leadership competencies and successful organisational change. In: **10th Annual Conference of the EuroMed Academy of Business**. 2017.

QI, Q.; TAO, F. Digital twin and big data towards smart manufacturing and industry 4.0: 360 degree comparison. **Ieee Access**, v. 6, p. 3585-3593, 2018.

RASCA, L. et al. Employee Experience – an Answer To the Deficit of Talents ,. v. 19, n. October, p. 9–15, 2018.

RICHERT, A. et al. Educating engineers for industry 4.0: Virtual worlds and human-robot-teams: Empirical studies towards a new educational age. **IEEE Global Engineering Education Conference, EDUCON**, v. 10-13-Apri, n. April, p. 142–149, 2016.

ROBBINS, S. P. Comportamento Organizacional. Tradução técnica de Reynaldo Marcondes. **Comportamento Organizacional. 9.ed, São Paulo: Prentice Hall**, v. 2, 2005.

ROWE, G.; WRIGHT, G. The delphi technique as a forecasting tool. **International Journal of Forecasting**, v. 2070, n. 99, p. 353–375, 1999.

RÜßMANN, M. et al. Industry 4.0: The future of productivity and growth in manufacturing industries. **Boston Consulting Group**, v. 9, n. 1, p. 54-89, 2015.

SAFFIE, N. A. M.; SHUKOR, N. M.; RASMANI, K. A. Fuzzy delphi method: Issues and challenges. p. 1–7, 2017.

SCHMIDT, R. C. Managing Delphi surveys using nonparametric statistical techniques. **Decision Sciences**, v. 28, n. 3, p. 763–774, 1997.

SCHNEIDER, P. Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field. **Review of Managerial Science**, v. 12, n. 3, p. 803-848, 2018.

SCHRAGE, M. et al. "Leadership's Digital Transformation: Leading Purposefully in an Era of Context Collapse," ***MIT Sloan Management Review and Cognizan***t, January 2021.

SCHUMACHER, A.; EROL, S.; SIHN, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. **Procedia CIRP**, v. 52, p. 161–166, 2016.

SCHWAB, K. **A Quarta Revolução Industrial**. Trad. Daniel Moreira, São Paulo: Edipro, 2016.

SHAMIM, S. et al. Management approaches for Industry 4.0: A human resource management perspective. **2016 IEEE Congress on Evolutionary Computation, CEC 2016**, p. 5309–5316, 2016.

SHEN, Yung-Chi et al. A hybrid selection model for emerging technology. **Technological Forecasting and Social Change**, v. 77, n. 1, p. 151-166, 2010.

SHET, Sateesh V.; PATIL, S. V.; CHANDAWARKAR, Meena R. Framework for methodical review of literature on leadership competencies. **Cogent Business & Management**, v. 4, n. 1, p. 1309123, 2017.SIDDOO, V. et al. An exploratory study of digital workforce competency in Thailand. **Heliyon**, v. 5, n. 5, p. e01723, 2019.

SMIT, J. et.al. **Industry 4.0.** London: European Parliament, 2016. Available at < https://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf>. Accessed March 30, 2021.

SONG, J.; SUN, Y.; JIN, L. PESTEL analysis of the development of the waste-to-energy incineration industry in China. **Renewable and Sustainable Energy Reviews**, v. 80, p. 276-289, 2017.

SONY, M.; NAIK, S. S. Ten Lessons for Managers while Implementing Industry 4.0. **IEEE Engineering Management Review**, v. 47, n. 2, p. 45–52, 2019.

STAFFEN, S.; SCHOENWALD, L. Leading in the Context of the Industrial Revolution: The Key Role of the Leader 4.0. **Capgemini Group: Paris, France**, 2016.

STEFANO, N. M.; CASAROTTO FILHO, N.; DUARTE, M. DO C. F. Proposta De Um Instrumento De Pesquisa Para Avaliar a Gestão De Periódicos Científicos : Utilizando O Método Fuzzy Delphi Proposal of a Research Instrument To Evaluate the Management of Scientific Journals : Using of Fuzzy. **Iberoamerican Journal of Project Management**, v. 5, n. 2, p. 39–69, 2014.

SULTANA, I.; AHMED, I.; AZEEM, A. An integrated approach for multiple criteria supplier selection combining Fuzzy Delphi, Fuzzy AHP and Fuzzy TOPSIS. **Journal of Intelligent and Fuzzy Systems**, v. 29, n. 4, p. 1273–1287, 2015.

TAHRIRI, F. et al. The application of fuzzy Delphi and fuzzy inference system in supplier ranking and selection. **Journal of Industrial Engineering International**, v. 10, n. 3, 2014.

THUN, S. et al. Industry 4.0: Whose revolution? The digitalization of manufacturing work processes. **Nordic Journal of Working Life Studies**, v. 9, n. 4, p. 39–57, 2019.

TOOR, S. R. Differentiating leadership from management: An empirical investigation of leaders and managers. **Leadership and Management in Engineering**, v. 11, n. 4, p. 310-320, 2011.

TRENTIN, Alessio et al. Operations managers' individual competencies for mass customization. **International Journal of Operations & Production Management**, 2019.

TUROFF, M.; LINSTONE, H. A. The Delphi method-techniques and applications. 2002.

VAFADARNIKJOO, A. et al. Assessment of consumers' motivations to purchase a remanufactured product by applying Fuzzy Delphi method and single valued neutrosophic sets. **Journal of Cleaner Production**, v. 196, p. 230–244, 2018.

VAIDYA, S.; AMBAD, P.; BHOSLE, S. Industry 4.0 - A Glimpse. **Procedia Manufacturing**, v. 20, p. 233–238, 2018.

VAN ECK, N. J.; WALTMAN, L. VOSviewer manual. **Leiden: Univeristeit Leiden**, v. 1.6.16, p. 1-52, 2020.

WANG, S. et al. Implementing Smart Factory of Industrie 4.0: An Outlook. **International Journal of Distributed Sensor Networks**, v. 2016, 2016.

WANG, X.; DURUGBO, C. Analysing network uncertainty for industrial product-service delivery: A hybrid fuzzy approach. **Expert Systems with Applications**, v. 40, n. 11, p. 4621–4636, 2013.

WHYSALL, Z.; OWTRAM, M.; BRITTAIN, S. The new talent management challenges of Industry 4.0. **Journal of Management Development**, v. 38, n. 2, p. 118–129, 2019.

WOODRUFFE, C. What is meant by a competency?. **Leadership & organization development journal**, 1993.

WORDNET. **Creativity**. Princeton: Princeton University, 2020c. Available at: < http://wordnetweb.princeton.edu/perl/webwn?s=creativity&sub=Search+WordNet&o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&h=000>. Accessed August 20, 2020.

WORDNET. **Innovation**. Princeton: Princeton University, 2020b. Available at:< http://wordnetweb.princeton.edu/perl/webwn?s=innovation&sub=Search+WordNet&o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&h=000>. Accessed August 20, 2020.

WORDNET. **Transparency**. Princeton: Princeton University, 2020a Available at: http://wordnetweb.princeton.edu/perl/webwn?s=transparency&sub=Search+WordNet&o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&h= . Accessed August 20, 2020.

WORLD ECONOMIC FORUM. The Future of Jobs Report 2020 | World Economic Forum. **The Future of Jobs Report**, n. October, p. 1163, 2020.

WORLD ECONOMIC FORUM. Leading through the Fourth Industrial Revolution Putting People at the Centre, January. 2019.

WORLD ECONOMIC FORUM. **The future of jobs report: Centre for the new economy and society**. *Insight Report.* 2018.

XU, Li Da; XU, Eric L.; LI, Ling. Industry 4.0: state of the art and future trends. **International Journal of Production Research**, v. 56, n. 8, p. 2941-2962, 2018.

XU, M.; DAVID, J. M.; KIM, S. H. The fourth industrial revolution: Opportunities and challenges. **International Journal of Financial Research**, v. 9, n. 2, p. 90–95, 2018.

ZANGIACOMI, A. et al. Moving towards digitalization: a multiple case study in manufacturing. **Production Planning and Control**, v. 31, n. 2–3, p. 143–157, 2020.

ZALEZNIK, Abraham. Managers and leaders: are they different?. **Harvard Business Review**, v. 70, n. 2, p. 126-135, 1992.

ZHOU, K.; LIU, T.; ZHOU, L. Industry 4.0: Towards future industrial opportunities and challenges. **2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015**, p. 2147–2152, 2016.

Appendix A - An analysis of databases results (abstracts and key words) in VOSviewer

Here an analysis is presented based on VOSviewer tool[17] that supports to verify the density visualization to understand keywords that could be considered for future research, as well as, the interpretation of main terms related to a specific subject that is analyzed. For this study, the abstracts, titles, and keyword of the articles found in WoS and Scopus in two rounds are related to leadership approaches in Industry 4.0 context, and were analyzed in VOSviewer. Firstly, the results of first round found in WoS and Scopus are presented in Figure 11 and 12, respectively. Secondly, for the second round, the new results found in WoS and Scopus are presented in Figure 13 and 14, respectively.

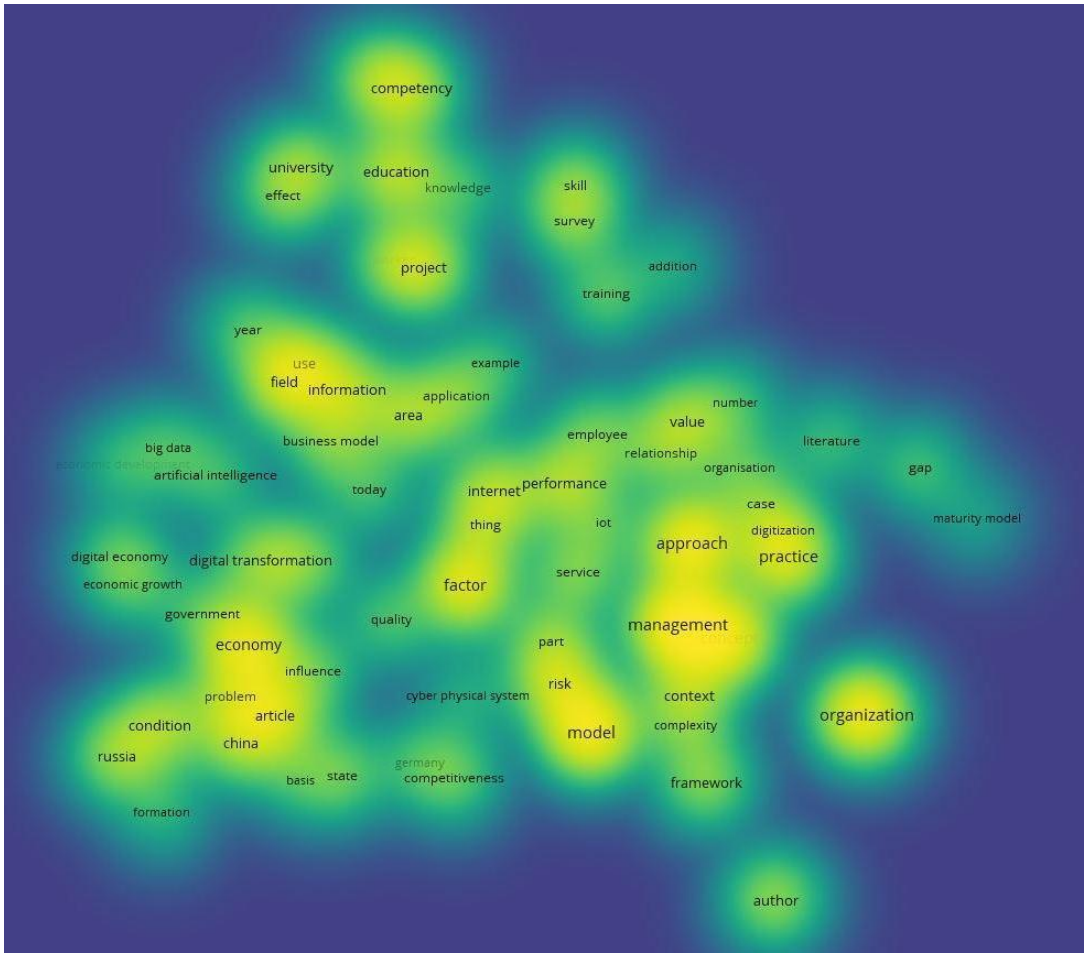
Figure 11 and 12 respectively present the density visualization from the literature review in WoS and Scopus based on VOSviewer tool. The respective figures present the density of items regarding the abstract and titles from WoS and Scopus. Each item in the density visualization presents a color range that indicates their density from blue to green to yellow (VAN ECK; WALTMAN, 2020) as seen in Figure 11 and 12.

These items represent terms that are mapped by VOSviewer with more occurrences (VAN ECK; WALTMAN, 2020). On the one hand, the items that were mapped with more weight represent a density closer to the yellow color (VAN ECK; WALTMAN, 2020) that is, items that appear more in papers. On the other hand, the items that were mapped with less weight represent a density closer to the blue color (VAN ECK; WALTMAN, 2020) that is, items that appear less in papers.

Its observed in Figure 11 the terms leadership and Industry 4.0 do not appear. This may be explained due to the low numbers of scientific papers in WoS that connect the Industry 4.0 or FIR with the approaches of leadership or leadership competences. This evidence may highlight the relevance to develop an explore research in such topics. However, the term management, and competency appeared in the density visualization. Although the competency term appears in Figure 11, there is not a relation of this term with leadership in Industry 4.0 context. The papers that explore competency term are referring to workforce competences or competences for specific role, such as IT or HR.

Figure 11 - Density visualization of WoS, first round

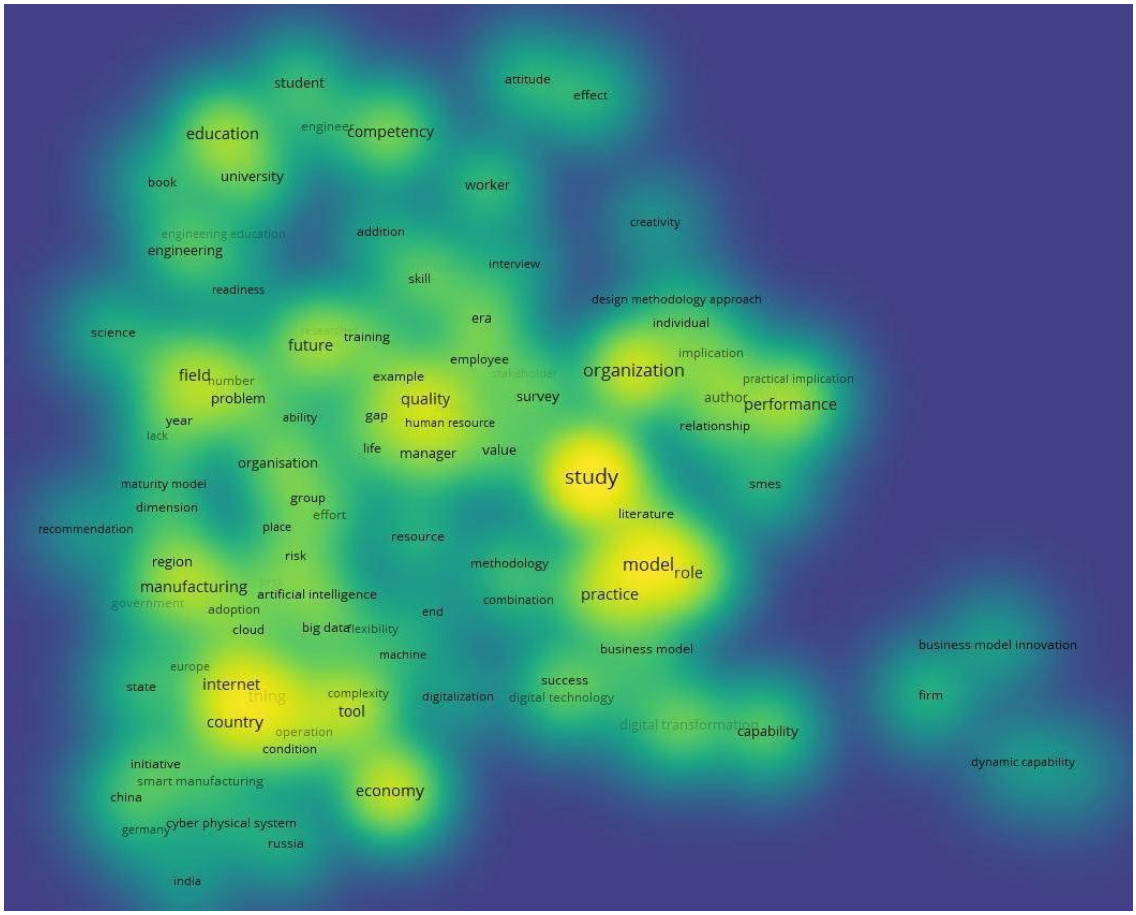
[17] VOSviewer, "is a software tool for creating maps based on network data and for visualizing and exploring these maps (VAN ECK; WALTMAN, 2020, p.3)". Available at: <https://www.vosviewer.com/getting-started>. Accessed June 30, 2020.



Source: VOSviewer, 2020

It is observed in Figure 12 that the terms Industry 4.0, FIR and leadership do not appear either, as mentioned above this may highlight the relevance to develop and explore studies in such topics. However, terms such as manager and competency are presented in the density visualization of Figure 12 close to the terms of Figure 11. The term Industry 4.0 and FIR does not appear, however artificial intelligence, big data, internet of things, smart manufacturing and digitalization among others related with Industry 4.0 are observed on density visualization.

Figure 12 - Density visualization of Scopus, first round

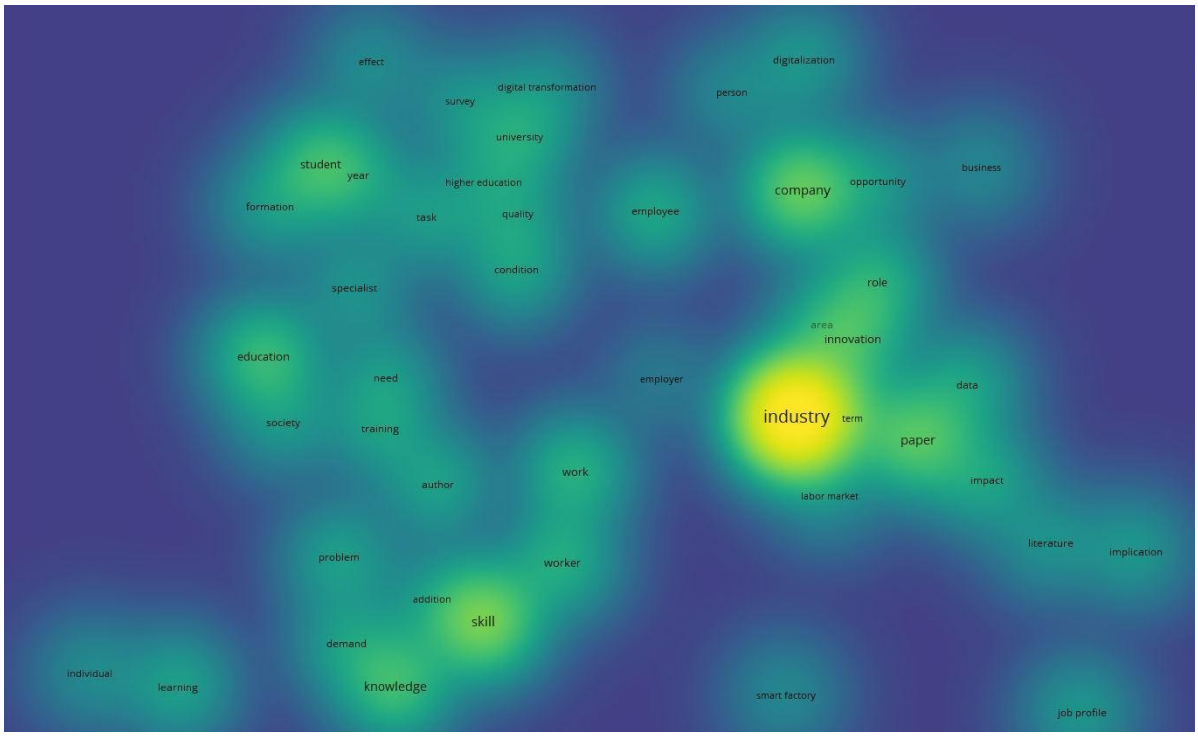


Source: VOSviewer, 2020

Considering the first round in databases and the few research results regarding leadership and leadership competences with Industry 4.0 context, as observed in density visualization (Figure 11 and 12), a second round was executed in WoS and Scopus, adding the "manager" as a keyword because this term appeared in the previous density visualization figures.

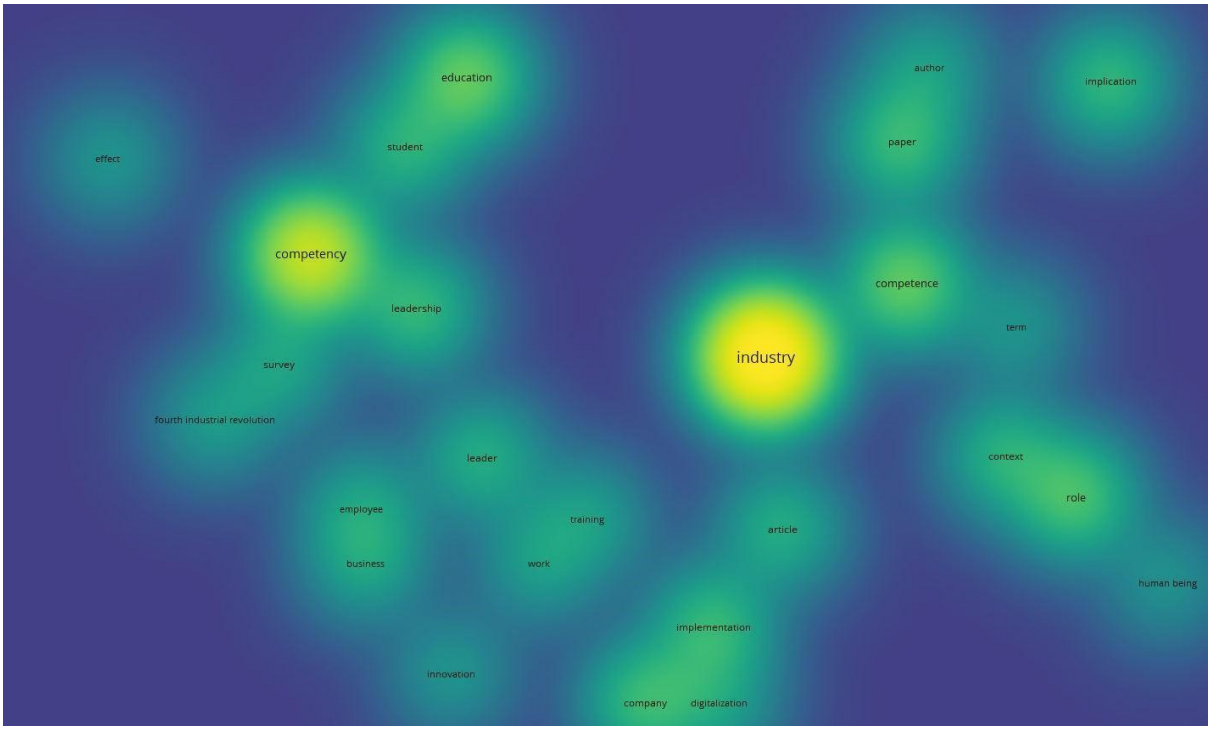
Figures 13 and 14 respectively present the density visualization based on VOSviewer of WoS and Scopus according to what was found in second round. Figure 13 does not present a term related with leader or manager and competency. Nevertheless, Figure 14 shows the term leadership, leader, and competency, different than Figure 13. These differences may be due to results from WoS and Scopus respectively and the low number of articles exploring leadership competences and Industry 4.0.

Figure 13 - Density visualization of WoS, second round



Source: VOSviewer, 2020

Figure 14 - Density visualization of Scopus, second round



Source: VOSviewer, 2020

Appendix B - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) analyzed with the support of NVivo

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (continues)

No.	Leadership competences	Approaches from the literature
1	Agility and adaptability	Leader 4.0 acts as an agile networker and a coach of the agile team to explore and use the knowledge available within and outside a company (STAFFEN; SCHOENWALD, 2016). Leaders must be able to adapt to changes, while involving employees on a journey towards an uncertain future (STAFFEN; SCHOENWALD, 2016), and ensure organizations become more responsive to market changes, resilient to unpredicted technological disruptions, and adaptive to unanticipated modifications from expected norms (MDLULI; MAKHUPE, 2017). Moreover, they must show high tolerance to ambiguity, identify opportunities, define the corresponding priorities, and make decisions in a dynamic environment (STAFFEN; SCHOENWALD, 2016). Agile leaders are fast and have a keen sense of how long-term plans are developed, and cannot keep a silo mentality (SCHWAB, 2016). “The approach to problems, issues and challenges must be holistic, flexible, and adaptable, continuously integrating different interests and opinions” (SCHWAB, 2016, p. 112). “Experimenting and managing new ideas and projects is essential for adaptive leadership” (WORLD ECONOMIC FORUM, 2020).
2	Analytical thinking	"Analytical skills are the thought processes required to evaluate information effectively. Analytical skills are the ability to visualize, gather information, articulate, analyze, solve complex problems, and make decisions (GRZYBOWSKA; ŁUPICKA, 2017, p.251)." "The capability to break a problem down into smaller pieces, whether parts of an object or parts of a process. It involves analyzing a problem by making evaluations, developing solutions, considering alternatives, and carrying out plans to address the problem" (AKDERE; HICKMAN; KIRCHNER, 2019, p.60)."Both managers and workers require strong analytical skills and ability to find domain-specific and practicable solutions without losing the overall goal” (SIMIC; NEDELKO, 2019, p.1294).
3	Asking of big questions	"The 'owner of reason' does not match the current dynamics of the business society. Leaders need to learn to unlearn and detach themselves from certainties" (MAGALDI; SALIBI NETO, 2018). The possibility of creating new paradigms and exploring the business potential that the Fourth Industrial Revolution represents may be associated with the competence of asking big questions. Leaders must prepare to be more questioning, creating a restless and curious corporate culture to understand and constantly align the questions with the company's business given the new business environment (MAGALDI; SALIBI NETO, 2018).

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (continues)

No.	Leadership competences	Approaches from the literature
4	Big data-decision-making	Data decision-making supports how data contribute to making a decision (ELKINGTON, 2018). Leaders should consider the relevant information from big-data to understand possible resulting challenges (ELKINGTON, 2018). Supported by big data, managers can measure and know more about their business using such knowledge in improved decision-making and performance (MCAFEE; BRYNJOLFSSON, 2012). Decision-making is based on the use of the right information and interpretation for avoiding intuition or expertise (MCAFEE; BRYNJOLFSSON, 2012). Big data stimulates directors to make immediate decisions and shape their capabilities towards handling the environmental changes (MERENDINO et al., 2018). A leadership team should interpret data, set goals, ask the right questions, and consider data for decision-making (MCAFEE; BRYNJOLFSSON, 2012). Tools such as software, platforms, or other technologies that support the volume, velocity and variety of Big data must be considered for their use (MCAFEE; BRYNJOLFSSON, 2012). "To leverage emerging data insights, for instance, leaders will likely need digital fluency, data visualization skills, and an understanding of cognitive and AI-driven technologies (NEL et al.,2020, p.55)." Big data provides a large amount of data created to be interpreted and support managers in making better decisions (CORDEIRO; DESCHAMPS; PINHEIRO DE LIMA, 2017).
5	Collaborative work	"Interdepartmental collaboration in organizations is the norm, and frequently, this is combined with inter-organizational collaboration. Information technology has given us the ability to collaborate with hundreds, even thousands, of people around the world on a given day" (AKDERE; HICKMAN; KIRCHNER, 2019, p. 62). "Working in virtual environments with teams spread all over the world becomes more and more common (RICHERT et al., 2016, p. 142). “The ubiquity of virtual communication technologies has facilitated a collaborative approach to work as teams " (MDLULI; MAKHUPE, 2017, p. 11). "Another aspect we need to prepare for and educate is the collaboration within teams of humans and robots” (RICHERT et al., 2016, p. 145). "Leaders will also have to manage robotic workers, such as AI assistants" (NEL et al., 2020, p.53). “Human-robot-collaboration, which is going to define new rules for the future partnership of work" (BAUER et al., 2018, p.7). The nature of cooperation is more flexible, dynamic and agile with many different and changing stakeholders and within a global context (BAUER; VOCKE, 2019). Leaders must also create new levels of intra-and-inter-company collaboration to stimulate teamwork instead of individual solutions (HAY GROUP, 2011b). “By bringing together and working in collaboration with leaders from business, government, civil society, religious, academic and the younger generation it will be possible to have a holistic perspective on what is happening” (SCHWAB, 2016 p.112).
6	Communication	“Active listening requires empathy, which is being open to and sensitive of the values and feelings of other people, understanding the other person’s perspective, and being willing to discuss your own thoughts in an open manner" (AKDERE; HICKMAN; KIRCHNER, 2019, p.60). “For a digital communication, attention must therefore be paid to a target-oriented and meaningful communication since the agility and openness that it often entails can also lead to chaos and unnecessary data exchange” (HELMING et al., 2019, p.41). Digital communication should also be considered in a company as a whole to sharing information (THUN et al., 2019). “Social media plays a key role as a supporting technology (EROL et al., 2016). "Knowledge of the science and art of delivering information. Knowledge of media production, communication, and dissemination techniques and methods. This includes alternative ways to inform and entertain via written, oral, and visual media" (O*NET CONTENT MODEL, 2020).

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (continues)

No.	Leadership competences	Approaches from the literature
7	Conflict solving	"Resolving conflict is a key part of a manager's role. Managing and resolving conflict requires emotional maturity, self-control, and empathy. Resolving conflict in a positive manner is a skill that can be developed and practiced" (GRZYBOWSKA ; ŁUPICKA, 2017, p. 251).
8	Connector	The leader is a manager of experts, mainly a point connector. A connection of points is possible when all relations among several apparently disconnected elements are perceived. A leader should connect the points by properly interpreting the environment, and must integrate all company's efforts (e.g., areas, departments, silos and experts of the organization) towards a same central objective (MAGALDI; SALIBI NETO, 2018). Leaders must understand the context, anticipating trends and connecting the points (SCHWAB, 2016), and value networks (SCHWAB, 2016). Decision-makers must be willing to get involved with those interested in a current issue. Leaders must aspire to be more connected and inclusive towards a more holistic perspective on a current scenario (SCHWAB, 2016).
9	Creativity	Leaders must be creative for innovating and, consequently, implementing new business models that meet market demands (MDLULI; MAKHUPE, 2017). “Creativity is the ability to create” (Wordnet, 2020c). "Creativity is becoming a key focus area for employers looking for the 21st century employee. Creativity is characterized by the ability to perceive the world in new ways, to find hidden patterns, to make connections between seemingly unrelated phenomena, and to generate solutions (GRZYBOWSKA; ŁUPICKA, 2017, p. 250)."
10	Critical thinking	"It is a way of judging information by analyzing, applying standards (about what constitutes quality information), discriminating, seeking new information, logical reasoning, predicting, and transforming knowledge (AKDERE; HICKMAN; KIRCHNER, 2019, p.61). Critical thinking is based on logic and objectivity, strategic problem solving and planning (AKDERE; HICKMAN; KIRCHNER, 2019). "Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems" (O*NET CONTENT MODEL, 2020).
11	Decision-making	“Decision making is the process of making choices by identifying a decision, gathering information, and assessing alternative resolutions. Decision- making is an integral part of modern management” (GRZYBOWSKA ; ŁUPICKA, 2017, p.251).
12	Deeper and interdisciplinary learning	Deeper learning involves the application of experts´ knowledge to new situations and innovative applications, showing although a certain context has been learned, the knowledge can be applied to others (AKDERE; HICKMAN; KIRCHNER, 2019, p.60). Deeper learning also requires mapping facts and concepts for supporting prior knowledge, enabling the connection of ideas, application of knowledge across content areas, and solution of real-world problems (AKDERE; HICKMAN; KIRCHNER, 2019, p.60). "Being an expert or expert on certain subjects is less important than the ability of global thinking, interdisciplinary knowledge and a holistic understanding of organizations" (RICHERT et al., 2016, p.143). "For workers and managers alike a strong interdisciplinary “out-of-the-box” orientation is likely to facilitate solution finding in complex environments" (EROL et al., 2016, p. 15).

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (continues)

No.	Leadership competences	Approaches from the literature
13	Digital perspective	Experienced digital leaders drive rapid adaptation and transformation by injecting digital insight and mindset into an organization's strategy (MDLULI; MAKHUPE, 2017). Leaders must explore and embrace digital ecosystems and digital platforms, and understand emergent technologies and use of information as a resource (MDLULI; MAKHUPE, 2017). They must also equip a 'digital wisdom', clear, transparent and practical guidance for the use of digital technologies, incentivize openness, integrity and sincerity for protecting corporate reputation (HAY GROUP, 2011b), and consider tech literacy a base for the understanding of tools that facilitate digitization (ALLEN, 2020). A digital mindset depends on emotional intelligence, and can institutionalize inter-functional collaboration, flattening hierarchies and also building environments that stimulate new ideas (SCHWAB, 2016). “A digital mindset reframes how people think about and conduct business” (ALLEN, 2020 p.8). “Managers with a digital mindset understand that digitization is one strategy that can add value, improve customer experience, save time, increase productivity, and improve margins” (ALLEN, 2020 p.8). “An additional focus should be on digital competencies. Additional modules might deal with topics such as digital engagement or digital governance such as conveying a digital vision” (STAFFEN; SCHOENWALD, 2016, p.15). Managers must understand the level of digitization in their company (SONY, NAIK, 2019).
14	Efficiency orientation	"An 'efficiency' approach is one that stresses the efficient use of resources as the main determinant of decision and action"(GRZYBOWSKA ; ŁUPICKA, 2017, p.251).
15	Emotional intelligence	Emotional intelligence is the ability to sense, understand, and effectively apply the power of emotions to facilitate collaboration and productivity (MDLULI; MAKHUPE, 2017). Emotionally intelligent leaders must consider self-awareness, self-regulation, motivation, empathy, and social skills (MDLULI; MAKHUPE, 2017). "A leader with enough emotional intelligence can overcome difficult leadership challenges" (MDLULI; MAKHUPE, 2017, p. 8). Institutions with leaders with high emotional intelligence will be more creative and better equipped to be more agile and resilient (SCHWAB, 2016). Emotional intelligence is necessary for leaders to become more innovative and act as agents of change (SCHWAB, 2016)." Emotional intelligence is the capacity for recognizing our feelings and those of others, for motivating ourselves and for effectively managing emotions in ourselves and others" (HAY GROUP, 2011a, p.4). "Without emotional balance, the leaders cannot enter in a state of serenity that allows them to reflect on alternatives to contribute to the project or business in a state of crisis (MAGALDI; SALIBI NETO, 2018).
16	Encourage knowledge sharing	Leaders must consider inter-corporate knowledge exchange, collaboration and cross-sector partnerships to use nano, bio and information technologies and cognitive sciences. They must also incentivize innovation and collaboration (HAY GROUP, 2011b). Knowledge-sharing supports the dissemination of knowledge regarding I4.0 technologies (connectivity and collaboration are key points) (ZANGIACOMI et al. 2019). The creation of a partnership stimulates the network and the sharing of knowledge with the local ecosystem (innovation centers and service and technology providers) that have a huge concentration of knowledge in digital technologies (ZANGIACOMI et al. 2019). The definition of collaboration between research centers and Industry must provide a clear strategy regarding the service offered. Communication channels and process alignment, for example, must be considered (SCHWAB, 2016).

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (continues)

No.	Leadership competences	Approaches from the literature
17	Entrepreneurial thinking	"Entrepreneurial thinking skills refer to the ability to identify marketplace opportunities and discover the most appropriate ways and time to capitalize on them. It is more like a state of mind that opens your eyes to new opportunities (GRZYBOWSKA; ŁUPICKA, 2017, p.251)." "Leadership during the Fourth Industrial Revolution requires an entrepreneurial state of mind" (WORLD ECONOMIC FORUM, 2019, p. 9). “As an entrepreneur within the company, the Leader 4.0 connects with other departments and develops overall innovative and integrative solutions for products and services and pushes trials and errors of ideas" (STAFFEN; SCHOENWALD, 2016, p.10).
18	Evaluation of I4.0 technologies	Business transformation cannot occur if decisions on technology are not made (HEAVIN; POWER, 2018). Managers must focus on new technologies to develop a digital technology capability aligned with the transformation strategy of business (HEAVIN; POWER, 2018). A deep understanding of core technologies is, therefore, required for an alignment with specific business and company´s needs (ZANGIACOMI et al. 2019). Moreover, both implications and future changes in a business model due to the adoption of I4.0 technologies must be examined (ZANGIACOMI et al. 2019). The execution and implementation of small pilot projects can support the evaluation of feasibility regarding a specific technological choice and their respective opportunities (ZANGIACOMI et al. 2019).
19	Focus on the customer	Leaders must understand the prospect of increasing the value connection with the consumer by building greater proximity. Empowering customers is empowering business (MAGALDI; SALIBI NETO, 2018). Customer approaches can be supported by systems that enable electronic devices such as cell phones to connect to the Internet, maintaining customer communication and providing customer convenience (MAGALDI; SALIBI NETO, 2018).
20	Future creator	Leaders should think about building engines 1 and 2 for the growth of the company. Engine 1 should focus on the day-to-day initiatives of the company, oriented towards short- and medium-terms, whereas engine 2 should focus on long-term disruptive initiatives. Therefore, leaders must learn to unlearn, and force themselves to look for new formulas and more promising methods to handle the changing environment. Exponential, rather than limited, thinking/mentality must be encouraged in a mutation environment towards transformations. (MAGALDI; SALIBI NETO, 2018).
21	Innovation	Leaders must be creative for innovating and implementing new business models that meet market demands (MDLULI; MAKHUPE, 2017). "The Leader 4.0 need to be an active driver of innovation and serves as a role model when it comes to trying, testing and using new technologies. Leader need to be experimental and unafraid to fail" (MDLULI; MAKHUPE, 2017, p.12). A leader is oriented toward the outside, encouraging experimentation to promote innovation in organizational culture (MAGALDI; SALIBI NETO, 2018). Leaders need to continuously innovate to be able to handle the business disruptions (SCHAWB, 2016)". "Innovation is the process of adapting an existing idea to new uses, improving an existing product or process, or inventing a new product. Innovation should create value for society. Successful innovation may require a combination of cognitive-behavioral, and technical skills" (AKDERE; HICKMAN; KIRCHNER, 2019, p.63). "The rapid pace of technology and business model innovation requires a culture of experimentation that tolerates failure and links innovation to a new purpose (WORLD ECONOMIC FORUM, 2019, p.10). Nurturing these capacities of creativity, innovation, and entrepreneurship are essential to moving forward" (CANALS; HEUKAMP, 2020 p. 199)."
22	Lean approaches	The adoption of lean management should be considered prior to investments in I4.0 technologies. The approach is endorsed by companies as an important prerequisite and an enabler for the implementation of new solutions (ZANGIACOMI et al. 2019). Lean and Industry 4.0 approaches increase a company´s productivity, since lean tools can contribute to Industry 4.0 technologies (ENKE et al., 2018). The integration of I4.0 technologies and lean production management practices can improve operational performance (FETTERMANN, 2018). Companies that aim to apply I4.0 technologies also have more widely adopted lean principles and practices (TORTORELLA; FETTERMANN, 2018).

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (continues)

No.	Leadership competences	Approaches from the literature
23	Management of complexity	"Explaining complex entities involves multiple layers of analysis, including breaking entities down into their constituent parts and demonstrating the interactions between the parts. Complexity management can include delayering, decentralizing (or centralizing), streamlining processes, and creating stronger processes that ensure alignment. Big data and advanced analytics are emerging techniques for managing complexity, allowing us to monitor large numbers of variables to see how they develop and interact over time (AKDERE; HICKMAN; KIRCHNER, 2019, p.61)." Dealing with complex problems requires their analyses, development of solutions, and application of plans (AKDERE; HICKMAN; KIRCHNER, 2019).
24	Massive Transformative Purpose	The massive transformative purpose considers the current scenario of possibilities generated from technologies. When leaders adopt MTP, they provide people in the organization with a clear future to be achieved, thus impacting society through strategic actions. The stimulus of MTP will help the organization to offer an external trend to both market and consumers. Leaders must integrate the vision of purpose into the company's execution system (MAGALDI; SALIBI NETO, 2018), and encourage a common purpose within the organization, so that an environment of trust is essential for the teamwork and all stakeholders collaboratively contribute with innovations aimed at the common good (SCHWAB, 2016).
25	Understanding of Moore's Law, platforms and New Technologies	Leaders must deeply experience and understand technological trends towards being familiar with them. Regardless of their area of expertise, they must be familiar with technology, its implications and potentials (MAGALDI; SALIBI NETO, 2018), and know programming, since it is the basis for the construction of applications and systems. They must also consider the effects of Moore's Law due to the speed of technological changes in relation to market demands, and adapt to the use of platforms for the creation of value through interaction between participants (producers and consumers in a single environment) (MAGALDI; SALIBI NETO, 2018).
26	Problem-solving	"Solving problems involves both analytical and creative skills. Analytical or logical thinking includes skills such as comparing, evaluating and selecting. It provides a logical framework for problem solving" (GRZYBOWSKA-; ŁUPICKA, 2017, p.251). "Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions"(O*Net content model, 2020).
27	Research skills	"Use reliable sources for continuous learning in changing environments. Being able to provide in depth information and advice on a given topic is an important skill " (GRZYBOWSKA; ŁUPICKA, 2017, p.251). “Systematic investigation to establish facts” (WordNet, 2020). Increased demands for creative technological development and scientific research services, as innovation (key focus of businesses), will require analytical, research and design skills (Z_PUNKT THE FORESIGHT COMPANY, 2014, p.79).
28	Rethink of organizational structure	The design of an organizational structure regarding Industry 4.0 environment must be taken into account (HELMING et al., 2019). An organic and flexible design structure should be considered by managers in an environment such as I4.0 (SHAMIM et al., 2016), according to their needs and situations (SHAMIM et al., 2016). The nature of the organizational structure should be rethought, and the hierarchy should be more flexible (SCHWAB, 2016). Successful companies will move from a hierarchical structure to a more flexible one, characterized as collaborative and networking, thus facilitating the exchange of information and data on tasks in progress (SCHWAB, 2016).
29	Risk-taker	Leaders must expose the organization and live with the risk of failure, since there is no longer an organization formed; they are all in constant and continuous formation (MAGALDI; SALIBI NETO, 2018).

Table 19 - Approaches from the literature regarding the 34 Leadership Competences (I4.0 LC) (conclusion)

No.	Leadership competences	Approaches from the literature
30	Self-directed learning	Self-directed learning can be achieved through goal setting, progress tracking, reflections on strengths and weaknesses, and turning of setbacks into opportunities for growth (AKDERE; HICKMAN; KIRCHNER, 2019, p.62). Formulation of learning goals, identification of resources for learning, and implementation of learning strategies are important for evaluations of the learning outcomes (AKDERE; HICKMAN; KIRCHNER, 2019). "The leader's ability to continually learn, adapt and challenge his own successful conceptual and operational models is what will distinguish the next generation of successful business leaders" (SCHWAB, 2016, p.59). "The fourth industrial revolution will require and emphasize the ability of workers to adapt continuously and learn new skills and approaches within a variety of contexts" (SCHWAB, 2016, p.54).
31	Social culture awareness	"Leaders need to constantly understand and adapt as they work across diverse cultures, dealing with project-based, virtual and multi-generational teams and with a global customer base"(MDLULI; MAKHUPE, 2017, p.11). "Developing cultural awareness also develops self-awareness, a foundational skill for effective leadership. Cultural awareness is necessary for effective communication as norms of behavior change from culture to culture" (AKDERE; HICKMAN; KIRCHNER, 2019, p.63)."In the future, it will be perfectly normal to work in teams that are mixed according to age, gender, origin and attitudes/approaches. This could potentially unleash major improvements in creativity and productivity but also poses an increased risk of conflicts. The design of the interactions, the orchestration of diversity, will become one of the defining skills of successful leadership" (BAUER et al., 2015 p.423). Managers must consider teams of the future will be diverse regarding culture, education and geographical location (EROL et al., 2016; Nel et al., 2020), and leaders must be able to lead them and be flexible and culturally sensitive, besides find new ways to stimulate personal loyalty among workers (HAY GROUP, 2011b).
32	Technical and IT requirments	Competences related to ICT (Information and Communication Technology), and also new technical knowledge of new technologies are required; therefore, continuous learning becomes relevant for the human labor (JERMAN; BACH; ALEKSIC, 2019), and the competence of ICT system and digitization based on Industry 4.0 vision will become relevant for managers (THUN et al., 2019). "Among the technical competences, efficient and advanced use of IT devices – such as computers, mobile devices and automation devices (i.e. PLC) – is required. Additionally, knowledge and use of software, such as ERPs, MESs and specific IT tools, are crucial for effective factory management. Data analysis skills are also increasingly necessary for performance control and benchmarking, and technicians dealing with new production machines must be familiar with high-level programming languages" (CIMINI et al., 2019, p.14). Technical competences must consider technical skills, process understanding, media skills, and understanding of IT security (HECKLAUetal.,2016). Leaders should also consider the knowledge of artificial intelligence towards its wider application to management with the development of algorithms that offer predictive business analyses that support decision-making in critical issues (MAGALDI; SALIBI NETO, 2018).
33	Think bold	"Bold thinking demands a radical change in the leader's mentality" (MAGALDI; SALIBI NETO, 2018). Leaders should change their mental and conceptual structures, as well as the principles of organization (SCHWAB, 2016). Silo thinking and a fixed vision of the future are not priorities, due to the need for intellectual agility of leaders in the Fourth Industrial Revolution (SCHWAB, 2016).
34	Transparency	The guarantee of transparency to all workers will involve them with the overall production and distributions of tasks (HELMING et al., 2019), motivating them and improving their potential (HELMING et al., 2019). "Transparency is the quality to be clear and transparent" (Wordnet, 2010a). "Deep, data-driven insights and enhanced transparency across the full value chain call for leadership" (NEL et al., 2020, p.53).

Source: author

Appendix C - Questionnaires of the first and second phase (empirical approaches)

Questionnaire1: Challenges towards Industry 4.0

NOTE: The table below shows the challenges towards Industry 4.0 (I4.0) context that resulted from the application of Industry 4.0 technologies in companies. These nine challenges towards Industry 4.0 context have been cited at least twice by authors in the literature. The objective of the experts who participate and answer this questionnaire is to define the degree of importance of the main challenges towards Industry 4.0 to prioritize them. For that, it is presented a Likert scale from 1 to 5 (1=Unimportant, 2=Low importance, 3=Medium importance, 4=Important, 5=Very important) to define the degree of importance of each challenge towards Industry 4.0. Consequently, we will use the challenges prioritized in this Table by the experts in a new questionnaire to be related to the leadership competences in the context of Industry 4.0.

***Please, feel free in case that you have any suggestions for us, you can use the box "Comments".**

No.	Challenges towards Industry 4.0	Descriptive approach	References	5-Likert scale	*Comments
1st. Challenge	Acceptance of organizational transformation for Industry 4.0	The incentive to create an adaptable corporate culture convinced of the applications of I4.0 technologies being favorable to the company, to avoid resistance. The acceptance of transformation processes with I4.0 solutions and their technologies must be stimulated in the company as a whole, counteracting organizational inertia.	Kiel et al. (2017); Schneider (2018); Hirsch-Kreinsen (2014)		
2nd. Challenge	Adapt/complement or develop a new business model	The implications for the business model should be reflected considering the introduction of I4.0 context. These implications refer to defining whether the business model needs to be adapted, complemented, and/or be replaced by a new business model. Also, it is important to consider changes in the current business models to be more innovative, service-oriented and integrated with customer demands.	Kiel et al. (2017); Schneider (2018)		
3rd. Challenge	Analyzing scenarios and particularities of companies to implement Industry 4.0	The I4.0 implementation needs to be designed specifically for different organizational production scenarios. "Firms need to be shaped at all levels to reach high levels of implementation of I4.0 technologies" (Agostini, Filippini, 2018, p. 417). Thus, the complexity to retrofit companies should be considered to adopt the new paradigm of I4.0, integrating their technologies into different organizational hierarchies, structures, production, as well as logistic systems . Also, it is important to define the scenarios of the company for I4.0 implementation, considering, for example, current situation, project's goals, interfaces to other systems, technical requirements, project schedule, estimations for cost and benefits. Characteristics and requirements from different companies regarding I4.0 are not similar, since the scenarios for each company are distinct.	Müller, Kiel, Voigt (2018); Herman, Pentek, Otto (2016); Kiel (2017)		

4th. Challenge	Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	In Industry 4.0 context, privacy protection and an increasing degree of information security are demanded. The connection of different devices and networks increases the risk of data and the vulnerability of networks connected which can be accessed by hackers and cyber-terrorist . Also, cyber-attacks and viruses can interfere in the shutdown of networks and smart production systems. The risk of data also manifests itself across the entire value chain with the connection/exchange open of data. So, it is recommended to consider requirements in terms of data protection.	Xu, Xu, Li (2018); Deloitte (2015); Kiel et al.(2018); Kiel (2017); Xu, David, Kim (2018)	
5th. Challenge	Dealing with competitiveness and analyzing the future viability of Industry 4.0	The Industry 4.0 introduction reshapes companies' boundaries, creates new industries, and carries established manufacturing to deal with new competitive challenges. Thus, competitive dynamics increase makes companies change and adapt their environments in a competitive context. In the dynamic market, many companies have adjusted to meet the demands of customers because of the competition of product quality and production costs. Also, companies should analyze the viability of I4.0 technologies adoption for their competition in the market, considering positive and negative effects.	Müller, Kiel, Voigt (2018); Kiel et al. (2017); Brettel et al.(2017)	
6th. Challenge	Having a modern IT/ICT infrastructure to meet Industry 4.0 demands	Incorporation and development of a modern IT/ICT infrastructure should be ensured in companies, or the current IT infrastructure should be adapted to meet the demands of Industry 4.0. The modern IT infrastructure supports the intra-firm (the connection between different components that can facilitate production) and inter-firm (connection throughout the entire supply and value chain, ensuring cross-company interactions) connections. Besides, cost implications are factors to be considered by companies with the IT infrastructure.	Kiel et al. (2017); Xu, Xu, Li (2018); Agostini, Filippini (2018); Deloitte (2015)	
7th. Challenge	Managing and analyzing a large quantity of data	There is a need to analyze and manage large quantities and complex data connected in real-time generated by networks, machines, productions, equipment, products, applications and services. Efficient real-time integration and analysis in the industrial production process should be guaranteed to optimize resources in the production chain. Big data should be considered, since it offers enterprise information protection and privacy issues, such as information security. Data science and data analytics techniques will have relevant roles to deal with huge quantities of connected data.	Zhou, Liu, Zhou (2015); Xu, Xu, Li (2018); Deloitte (2015)	
8th. Challenge	Qualifying and preparing employees to deal with Industry 4.0	"The existing tasks such as simpler machine operation, handling materials and materials-linked machine settings, as well as various monitoring and regulating functions, will be automated in the future" (Hirsch-Kreinsen, 2014, p.9). For that, qualifying and preparing employees with the development of competences and skills to deal with I4.0 technologies is fundamental. New technical skills and competences must be developed considering the digitalization increase in companies.	Xu, David, Kim (2018); Müller, Kiel, Voigt (2018); Kiel (2017); Agostini, Filippini (2018); Schneider (2018); Deloitte (2015)	

9th. Challenge	Stimulating collaboration and trust with key partners	Guaranteeing collaboration and cooperation requires openness, cross-company cooperativeness, a high degree of trust and compatibility of technologies. This collaboration should consider different partners that have to be integrated more closely into value creation (e.g. customers, suppliers). One of the obstacles to achieving a close collaboration between companies is the lack of trust since some managers are not comfortable to share critical information with companies. Thus, collaboration should ensure vertical and horizontal integration through the value chain, to improve and increase the connectivity and exchange of knowledge and information flow.	Kiel et al. (2017); Brettel et al.(2017); Agostini, Filippini (2018)	

Questionnaire 2: Leadership competences in Industry 4.0 context

NOTE: The following table shows leadership competences in Industry 4.0 context that were identified in the literature. These 22 leadership competences resulted after a qualitative analysis, in order to synthesize and make some complementation between them with the support of NVivo, a software that supports content analysis through the identification of codes. The objective of collecting the opinion from the experts is to define the degree of importance of leadership competences in Industry 4.0 context identified in the literature. For that, a Likert scale from 1 to 5 (1=Unimmportant, 2= Low importance, 3= Medium importance, 4=Important, 5=Very important) is presented to define the degree of importance for all leadership competences in the context of Industry 4.0. Consequently, we will use the leadership competences prioritized by the experts in a new questionnaire to be associated with the challenges towards Industry 4.0.

***Please, feel free in case that you have any suggestions for us, you can use the box "Comments".**

No.	Leadership competences	Description proposal	Author references	5-Likert scale	*Comments
1	Agility and adaptability perspective	This competence comprehends: having intellectual agility, responding quickly to the changing requirements, and being adaptive and resilient to unpredictable technological disruption of the future. Leaders should keep an open mind, stimulate and integrate different ideas, and opinions. For that, experimentation, failure and risking to explore new opportunities and innovations in the company must be practiced by leaders.	Mdluli, Makhupe (2017); Schwab (2016); STAFFEN; SCHOENWALD, 2016 (2018); Magaldi; Salibi Neto (2018)		
2	Asking big question	This competence relates to ask instigation questions to stimulate curiosity and create a curious corporate culture. Leaders should give incentive to the practice of questions, understanding and constantly aligning the questions with the company's business considering market demands.	Magaldi; Salibi Neto (2018)		
3	Big-data decision making	This competence is the process of making decisions based on data. The decision-making should use the right and relevant information and interpretation of Big-data avoiding intuition or expertise. Leaders need to consider critical thinking (judging and reasoning information), analytical thinking (evaluate, visualize, gather information), research skills (providing in-depth information and advice on a topic), digital	McAfee; Brynjolfsson (2012); Elkington (2018); Akdere, Hickman, Kirchner (2019); O*Net		

		fluency, and data visualization skills. Tools, such as software, platform and other technologies to support volume, velocity and variety of Big-data are essential.	Content Model (2020); Grzybowska ; Łupicka (2017)		
4	Collaborative-diverse team	This competence is the ability to practice intra-inter company collaboration, value diversity in physical and virtual environments. Team diversity should be valued in terms of culture, education and geographical location. Also, human-machine collaboration must be practiced by leaders, managing robotic workers, such as AI assistants.	Akdere, Hickman, Kirchner (2019); Bauer et al. (2015); Hay Group (2011b); Mdluli, Makhupe (2017); Nel et al.(2020); Richert et al. (2016); Schwab (2016)		
5	Communication	This competence is about listening and understanding others, and the knowledge of the science and art of delivering information. The media production, communication, and dissemination techniques and methods to inform and entertain via written, oral, and visual media are required. Managers and leaders should have literacy with different technical communication and cooperation systems, adopting social media as a key role to support technology.	Akdere; Hickman; Kirchner (2019); O*Net Content Model (2020); Erol et al.(2016)		
6	Connector	This competence is the ability to connect points interpreting the environment and emerging trends. Being able to integrate all company's efforts (e.g., areas, departments, experts) for the central objective of the organization. Leaders should be prepared with different sources of knowledge and value the network being connected with those who have a similar interest to understand the trends.	Magaldi; Salibi Neto (2018); Schwab (2016)		
7	Conflict solving	This competence should be developed and practiced by managers, to manage and resolve conflicts. For conflict solving it is necessary to consider emotional maturity, self-control and empathy.	Grzybowska, Łupicka (2017)		
8	Deep, interdiciplinary and self-learnings	This competence is the ability to learn continuously in a deep and interdisciplinary way. Goals, resources and strategies of new learning need to be practiced and developed contributing to the continuous self-learning of leaders. A deep and interdisciplinary knowledge also should be considered to supports connecting ideas and applying the knowledge for different contexts to find solutions.	Akdere, Hickman, Kirchner (2019); Richert et al.(2016); Schwab (2016)		
9	Digital perspective	This competence gives incentive to a digital perspective to be adopted. Managers must understand the level of digitalization in their organization. The digitalization strategy in business can add value, improve customer experience, save time, increase productivity and improve margins. To support digitalization is necessary to consider digital wisdom (practical guidance for the use of digital technologies), tech literacy (general understanding about tools that promote digitalization), and adopt a digital mindset to explore new business models, opportunities and strategic advantages in favor of the company.	Mdluli; Makhupe (2017); Allen (2020); Hay Group (2011b); Sony, Naik (2019)		
10	Efficiency orientation	This competence is the ability to assess input-output relationships to guarantee the efficient use of resources to support decisions and action.	Grzybowska, Łupicka (2017); Boyatzis et al. 1995 apud Trentin et al. 2019		

11	Emotional intelligence	This competence is the ability to sense, understand, and effectively apply the power of emotions. The capacity of people to recognize their feelings and those of others, managing their own emotions and those of others. Leaders need to consider self-awareness, self-regulation, motivation, empathy, and social skills. Emotional intelligence keeps the balance in unstable situations allowing leaders to reflect on alternatives in favor of business.	Mdluli, Makhupe (2017); Schwab (2016); Magaldi; Salibi Neto (2018); Hay Group (2011)		
12	Encourage knowledge sharing	This competence refers to give incentive a collaborative knowledge sharing regarding I4.0 technologies considering external sources (e.g. universities, research centers, service and technology providers). Also, it is important the create a partnership to stimulate knowledge sharing with the use of networks and communication channels.	Zangiacomi et al. (2019); Hay Group (2011b); Schwab (2016)		
13	Evaluation and understanding of I4.0 and Moore's law	This competence is about evaluating the use of I4.0 technologies. Leaders should experience and understand in-depth these technologies, their implications and potentials, choosing technologies aligned with specific business and company needs. The adoption of I4.0 technologies must consider the effects of Moore's Law (speed of technologies changes) regarding the market demand and future changes of the business model. The execution of small pilot projects can support the feasibility of the technologies adopted.	Magaldi; Salibi Neto (2018); Zangiacomi et al. (2019)		
14	Focus on customer	This competence is about understanding the expectation of customers based on the fast consumer market responses to companies. Leaders should increase the value of connecting with customers to build major proximity. The use of systems that connect electronic devices, such as cell phones to the internet could maintain communication, connection and offer comfort to customers.	Magaldi; Salibi Neto (2018)		
15	Lean approach	This competence is about introducing the Lean approaches in favor of Industry 4.0. Managers should consider the use of Lean tools, practices and principles to contribute with I4.0 technologies adopted. The integration of I4.0 technologies and Lean production management practices could improve operational performance.	Zangiacomi et al. (2019); Enke et al. (2018)		
16	Managing complexity	This competence is about understanding complex entities based on their constituent parts. Complexity management can include delayering, decentralizing (or centralizing), streamlining processes and creating processes to ensure alignment. To manage the complexity it is important to analyze the problem and consequently to break down the complex problem into smaller parts, verifying their interactions to finally develop solutions, and carry out plans to drive them.	Akdere, Hickman, Kirchner (2019)		
17	Massive transformation process	This competence is adopted by the Massive Purpose Transformation, as a purpose's perspective about the contribution of technologies to global problem solving those impact individuals. The purpose's perspective should be executed through strategic actions based on the respective business. Leaders need to consider external orientation to market and consumer involving all stakeholders to contribute collaboratively for the common purpose's perspective.	Magaldi; Salibi Neto (2018)		
18	Problem solving	This competence refers to use analytical or logical thinking and creativity to identify, evaluate, compare and select respective solutions.	Grzybowska, Łupicka (2017); O*Net content model (2020)		

19	Promoting innovation	This competence is the process of adapting an existing idea to new uses, improving an existing product or process, or inventing a new one to practice innovation. For this, leaders need to consider creativity (ability to create), research skills (provide in-depth information on a given topic), entrepreneurial thinking (ability to identify marketplace opportunities) and stimulate the experimentation (tolerating failure) in corporate culture for the development of new business models that meet market demands.	Mdluli; Makhupe (2017); Canals; Heukamp (2020); Word Net (2020); Grzybowska, Łupicka (2017); Akdere, Hickman, Kirchner (2019); Rasca (2018)		
20	Rethink organizational structure	This competence is about considering the design of the organizational structure in Industry 4.0 environment. Rethought the organizational structure to be a flexible structure and to be more collaborative and networked, facilitating information and data exchange than a hierarchical structure. The design of a flexible structure should be following the needs and situations of the respective company.	Helming et al. (2019), Shamim et al. (2016), Schwab (2016)		
21	Technical and IT requirements	This competence is about considering technical requirements to deal with I4.0 technologies. The know-how of IT devices (e.g. computers, mobile devices, and automation devices), software such as ERPs, MESs, understanding of artificial intelligence (to the support decision-making process), programming codes (the basis for building applications and systems), IT and data security issues are some requirements needed to be considered by leaders.	Cimini et al. (2019); Magaldi; Salibi Neto (2018); Hecklau et al. (2016); Thun et al. (2019)		
22	Transparency	This competence is about being clear and transparent. Leaders should ensure transparency to involve all workers with the overall production, across the entire value chain, and with the distribution of tasks.	Helming et al. (2019); (Word Net, 2010); Nel et al.(2020)		

Appendix D – Questionnaire for the second phase to analyze and identify the leadership competences that supports to the challenges towards Industry 4.0

An analysis of leadership competences in Industry 4.0 context

1. Introduction and goal

This questionnaire aims to gather information from specialists that have know-how in leadership and Industry 4.0 context to identify leadership competences that contribute to deal with challenges towards Industry 4.0.

Consider approximately 15-20 minutes to answer this questionnaire.

The data collected in this questionnaire will be used exclusively for academic and scientific purposes. Your participation is voluntary and anonymous. In case that you are uncomfortable during the collection of data, you can cancel the questionnaire completion at any moment, interrupting your participation in this research.

Note: the experience is usually better when the questionnaire is answered on the computer.

We appreciate your collaboration!

For any question, please contact:

Prof. Mateus C. Gerolamo, University of São Paulo (EESC-USP)
e-mail: gerolamo@sc.usp.br
Phone: +55 (16) 3376-8643

* 1. Confidentiality:
Your identification will be confidential during the data collection and analysis of this research. The data will be presented in a grouped form after the analysis, and only summary data may be published in scientific articles, for example.

After I have been informed about the objective of this research and before proceeding to the next section, I affirm that I have read the text carefully and agree to participate in this research:

- ◯ Yes, I agree to participate
- ◯ No, I disagree to participate

An analysis of leadership competences in Industry 4.0 context

2. Leadership competences and challenges towards Industry 4.0

This section presents questions regarding fifteen leadership competences in Industry 4.0 context (L.C 4.0) with their respective statements and six challenges towards Industry 4.0 (I4.0). We divide these questions into four blocks to be evaluated (the four blocks are: social competences, methodological competences, personal competences and technical competences)

For the following questions (2 to 5), please define the degree of importance of the fifteen leadership competence (L.C 4.0) in the rows contributing to deal with the six challenges towards Industry 4.0 in the columns, on a 5-point Likert scale (from unimportant=1 to very important=5).

***For example, for the first competence (row) and the first challenge (column), if you select "*very important*", that means that the first L.C 4.0 contributes on a "very important" degree to deal with the first challenge towards I4.0.**

***In case that you need more detail about the L.C 4.0, you can open a new page through this link, or for the challenges towards I4.0 through this other link.**

* 2. Please define the degree of importance of the following L.C 4.0 (this block represent the social competences):

	1. Acceptance of organizational transformation for Industry 4.0	**2.** Adapt/complement or develop a new business model	**3.** Analyzing scenarios and particularities of companies to implement Industry 4.0	**4.** Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	**5.** Qualifying and preparing employees to deal with Industry 4.0	**6.** Stimulating collaboration and trust with key partners
Collaborative-diverse team: Leaders practice intra-intercompany collaboration, valuing team diversity.						
Communication: Leaders listen, understand others and have the knowledge to deliver information.						

	1. Acceptance of organizational transformation for Industry 4.0	**2.** Adapt/complement or develop a new business model	**3.** Analyzing scenarios and particularities of companies to implement Industry 4.0	**4.** Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	**5.** Qualifying and preparing employees to deal with Industry 4.0	**6.** Stimulating collaboration and trust with key partners
Encourage knowledge sharing: Leaders incentive a collaborative knowledge sharing regarding I4.0 technologies.						
Focus on customer: Leaders value the connection with customers to increase proximity and satisfaction.						
Massive transformative purpose: Leaders adopt a purpose's perspective aligned into the company as a whole, applying strategic actions to carry out this purpose.						
Transparency: Leaders ensure transparency with all workers and across the entire value chain.						

* 3. Please define the degree of importance of the following L.C 4.0 (this block represent the methodological competences):

	1. Acceptance of organizational transformation for Industry 4.0	**2.** Adapt/complement or develop a new business model	**3.** Analyzing scenarios and particularities of companies to implement Industry 4.0	**4.** Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	**5.** Qualifying and preparing employees to deal with Industry 4.0	**6.** Stimulating collaboration and trust with key partners
Managing complexity: Leaders use analytical thinking and break down complex problems to evaluate solutions						
Problem solving: Leaders use analytical thinking and creativity to evaluate solutions.						
Promoting innovation: Leaders create new devices or processes resulted from study and experimentation.						

* 4. Please define the degree of importance of the following L.C 4.0 (this block represent the personal competences):

	1. Acceptance of organizational transformation for Industry 4.0	**2.** Adapt/complement or develop a new business model	**3.** Analyzing scenarios and particularities of companies to implement Industry 4.0	**4.** Dealing with Data and connections security issues(e.g. cyber-attacks/hackers)	**5.** Qualifying and preparing employees to deal with Industry 4.0	**6.** Stimulating collaboration and trust with key partners
Asking big questions: Leaders ask instigating questions, aligning them with the company's business and needs.						
Agility and adaptability perspective: Leaders respond quickly and adapt to change. Keep an open mind to experiment, failure and risk.						
Connector: Leaders connect points, interpreting the environment and emerging trends.						
Deep, interdisciplinary and self-learning: Leaders learn continuously in an in-depth and interdisciplinary way, applying knowledge in different situations.						
Emotional intelligence: Leaders effectively manage emotions.						

* 5. Please define the degree of importance of the following L.C 4.0 (this block represent the technical competences):

	1. Acceptance of organizational transformation for Industry 4.0	**2.** Adapt/complement or develop a new business model	**3.** Analyzing scenarios and particularities of companies to implement Industry 4.0	**4.** Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	**5.** Qualifying and preparing employees to deal with Industry 4.0	**6.** Stimulating collaboration and trust with key partners
Digital perspective: Leaders have a digital perspective understanding the level of digitalization in a company to explore opportunities.						

An analysis of leadership competences in Industry 4.0 context

3. Profile questions and demographic information

We would like to know more about your professional profile

* 6. How long have you been working (acting or researching) with Industry 4.0 projects?

- ◯ Less than one year
- ◯ Between one year and two years
- ◯ Between three years and four years
- ◯ More than four years
- ◯ I have not worked with Industry 4.0 projects

* 7. Have you ever exercised a leadership role?

- ◯ Yes, less than one year
- ◯ Yes, between one year and two years
- ◯ Yes, between three years and four years
- ◯ Yes, more than four years
- ◯ No, I have not exercised a leadership role

* 8. In your perspective, which dimensions below are relevant towards the transition process of Industry 4.0?

- [ ] Technology
- [ ] Strategy
- [ ] Culture
- [ ] Leadership
- [ ] People
- [ ] Organizational structure
- [ ] Stakeholders
- [ ] Innovation
- [ ] Financial investments
- [ ] Vision
- [ ] Other (please specify)

* 9. Where do you currently work?

- ( ) Educational institution
- ( ) Research institution
- ( ) Manufacturing sector
- ( ) Consultancy

Other (please specify)

* 10. My current professional position is:

- ( ) Professor and researcher
- ( ) Researcher (e.g., master's student, PhD student, MSc, PhD, etc)
- ( ) Manager
- ( ) Director
- ( ) Consultant
- ( ) Other (please specify)

* 11. Currently, I work in:

Brazil Germany

Other (please specify)

* 12. Gender

Female Male I prefer not to say

* 13. Which category below includes your age?

20-29 30-39 40-49 50-59 60+

An analysis of leadership competences in Industry 4.0 context

4. Feedbacks

Finally, we would like to ask for feedbacks (this section is optional)

14. Would you like to add any comment (suggestion) about this research/questionnaire?

15. Can you recommend someone who has the profile to answer this questionnaire? (If you can recommend, please add her/his name or e-mail)

16. If you wish to receive a final report with the main results of this research, please add your e-mail:

Appendix E – Analysis of data resulted from Brazilian and international experts' perspective based on FDM

Experts' perspective: from Brazilian and international experts

In this second phase, there were also analyzed the experts' perspective in two groups: from Brazilian experts and from international experts (German & other nationalities). For this analysis we adopted the FDM (specifically the steps *c* and *d*, see 3.3), the steps *a* and *b* embraced the analysis from both groups in section 4.2 where it was presented the overview of all experts. Initially it was presented the Brazilian experts' perspective followed by the international experts' perspective.

c) Defuzzification for all triangular fuzzy numbers (TFN) and d) Filtering and analyzing all evaluation criteria by setting the threshold value (α)***. That is, if*** $G_i \geq \alpha$***, the*** i ***criterion is selected; if*** $G_i < \alpha$***, the*** i ***criterion is eliminate***

Table 20 presents the defuzzification of all TFN (Li, Mi, Ui) resulted from the evaluation of the I4.0 LC (15) in relation to the challenges towards I4.0 (6) executed by Brazilian experts (24). The Defuzzification results by calculating Gi (see 3.1). For the filtering and analysis of all criteria evaluated, a threshold value was defined ($\alpha = 4$). That means if Gi is $\geq \alpha$, then the I4.0 LC is prioritized, if, Gi $< \alpha$ then the I4.0 LC is not prioritized as explained above. Therefore, 13 I4.0 LC were considered as those that contribute to at least one challenge towards I4.0, and two were not considered.

Table 20 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of Brazilian experts (continues)

I4.0 LC	*Challenges towards I4.0*	*Li*	*Mi*	*Ui*	*Defuzzification*	*If* $\alpha = 4$
Collaborative-diverse team	1st. Acceptance of organizational transformation for Industry 4.0	2	3,99	5	3,66	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,01	5	3,67	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	2	3,81	5	3,60	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,10	5	3,03	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,00	5	3,67	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,29	5	3,76	Not prioritized

Table 20 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of Brazilian experts (continues)

I4.0 LC	*Challenges towards I4.0*	*Li*	*Mi*	*Ui*	*Defuzzification*	*If* $\alpha = 4$
Communication	1st. Acceptance of organizational transformation for Industry 4.0	3	4,54	5	4,18	Prioritized
	2nd.Adapt/complement or develop a new business model	2	4,03	5	3,68	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,22	5	4,07	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,23	5	3,08	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,37	5	3,79	Not prioritized
	6th. Stimulating collaboration and trust with key partners	4	4,56	5	4,52	Prioritized
Encourage knowledge sharing	1st. Acceptance of organizational transformation for Industry 4.0	3	4,50	5	4,17	Prioritized
	2nd.Adapt/complement or develop a new business model	2	3,78	5	3,59	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	2	3,51	5	3,50	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,09	5	3,03	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,40	5	3,80	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,06	5	4,02	Prioritized
Focus on customer	1st. Acceptance of organizational transformation for Industry 4.0	2	3,85	5	3,62	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,49	5	4,16	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,50	5	4,17	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,54	5	3,18	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,88	5	3,63	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,17	5	3,72	Not prioritized
Massive transformative purpose	1st. Acceptance of organizational transformation for Industry 4.0	3	4,54	5	4,18	Prioritized
	2nd.Adapt/complement or develop a new business model	1	3,99	5	3,33	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	2	3,73	5	3,58	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,03	5	3,01	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,86	5	3,62	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,83	5	3,61	Not prioritized

Table 20 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of Brazilian experts (continues)

I4.0 LC	*Challenges towards I4.0*	*Li*	*Mi*	*Ui*	*Defuzzification*	*If* $\alpha = 4$
Transparency	1st. Acceptance of organizational transformation for Industry 4.0	2	4,31	5	3,77	Not prioritized
	2nd.Adapt/complement or develop a new business model	1	3,61	5	3,20	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	1	3,58	5	3,19	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,47	5	3,16	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,27	5	4,09	Prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,34	5	3,78	Not prioritized
Managing complexity	1st. Acceptance of organizational transformation for Industry 4.0	2	4,02	5	3,67	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,01	5	4,00	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	2	4,27	5	3,76	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,32	5	3,11	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,77	5	3,59	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	3,72	5	3,91	Not prioritized
Problem solving	1st. Acceptance of organizational transformation for Industry 4.0	2	4,31	5	3,77	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,14	5	3,71	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,34	5	4,11	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	2	3,67	5	3,56	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,03	5	3,68	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,71	5	3,57	Not prioritized
Promoting innovation	1st. Acceptance of organizational transformation for Industry 4.0	2	4,36	5	3,79	Not prioritized
	2nd.Adapt/complement or develop a new business model	1	3,96	5	3,32	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,16	5	4,05	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	3	3,88	5	3,96	Prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,07	5	4,02	Prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,23	5	4,08	Prioritized

Table 20 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of Brazilian experts (continues)

I4.0 LC	*Challenges towards I4.0*	*Li*	*Mi*	*Ui*	*Defuzzification*	*If* $\alpha = 4$
Asking big questions	1st. Acceptance of organizational transformation for Industry 4.0	2	4,11	5	3,70	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,21	5	4,07	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,27	5	4,09	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	2	3,25	5	3,42	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,03	5	3,68	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,88	5	3,63	Not prioritized
Agility and adaptability perspective	1st. Acceptance of organizational transformation for Industry 4.0	2	4,36	5	3,79	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,26	5	4,09	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,27	5	4,09	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,43	5	3,14	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,23	5	4,08	Prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,96	5	3,65	Not prioritized
Connector	1st. Acceptance of organizational transformation for Industry 4.0	2	3,91	5	3,64	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,18	5	4,06	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,35	5	4,12	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	2	3,46	5	3,49	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,20	5	4,07	Prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,12	5	4,04	Prioritized
Deep, interdisciplinary and self-learning	1st. Acceptance of organizational transformation for Industry 4.0	2	3,99	5	3,66	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,28	5	3,76	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,18	5	4,06	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	2	3,58	5	3,53	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,16	5	3,72	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	3,81	5	3,27	Not prioritized

Table 20 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of Brazilian experts (conclusion)

I4.0 LC	*Challenges towards I4.0*	*Li*	*Mi*	*Ui*	*Defuzzification*	*If* $\alpha = 4$
Emotional intelligence	1st. Acceptance of organizational transformation for Industry 4.0	2	4,18	5	3,73	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	3,87	5	3,62	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	2	3,89	5	3,63	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,92	5	2,97	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,25	5	3,75	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	4,10	5	3,37	Not prioritized
Digital perspective	1st. Acceptance of organizational transformation for Industry 4.0	3	4,26	5	4,09	Prioritized
	2nd.Adapt/complement or develop a new business model	2	4,07	5	3,69	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0.0	3	4,31	5	4,10	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	2	3,90	5	3,63	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,22	5	4,07	Prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,15	5	4,05	Prioritized

Source: author

In sequence, Table 21 illustrates a color scale of the defuzzification resulted from the evaluation of all experts (Table 20) for the 15 I4.0 LC (categorized in social, methodological, personal and technical competences) related to the 6 challenges towards I4.0. The matrix in Table 21 illustrates a colors scale from red, white to blue, where the cells in or close to the blue color have a defuzzification value ≥ 4 (prioritized), while the cells in or close to red or white color that have a defuzzification value < 4 (not prioritized). 13 out of the 15 I4.0 LC were prioritized because they can contribute to or support at least one challenge towards I4.0, and 2 were not prioritized (collaborative diverse team and emotional intelligence).

5 out of the 13 I4.0 LC were highlighted, because they have a higher defuzzification value related to the challenges towards I4.0 (as observed in Table 21), respectively are: communication (4,52) related to 6th.challenge; MTP (4,18) related to 1st.challenge; encourage knowledge sharing (4,18) related to 1st.challenge; Focus on customer (4,17) related to 3rd.challenge and connector (4,12) also related to 3rd.challenge. Therefore, these I4.0 LC with a higher defuzzification value (≥ 4) related to the challenges towards I4.0 are the I4.0 LC that present a higher degree of importance to contribute with the respective challenge related.

Table 21 - Defuzzification: overview of the I4.0 LC related with the challenges towards Industry 4.0 to illustrate from prioritized to not prioritized based on Brazilian experts'

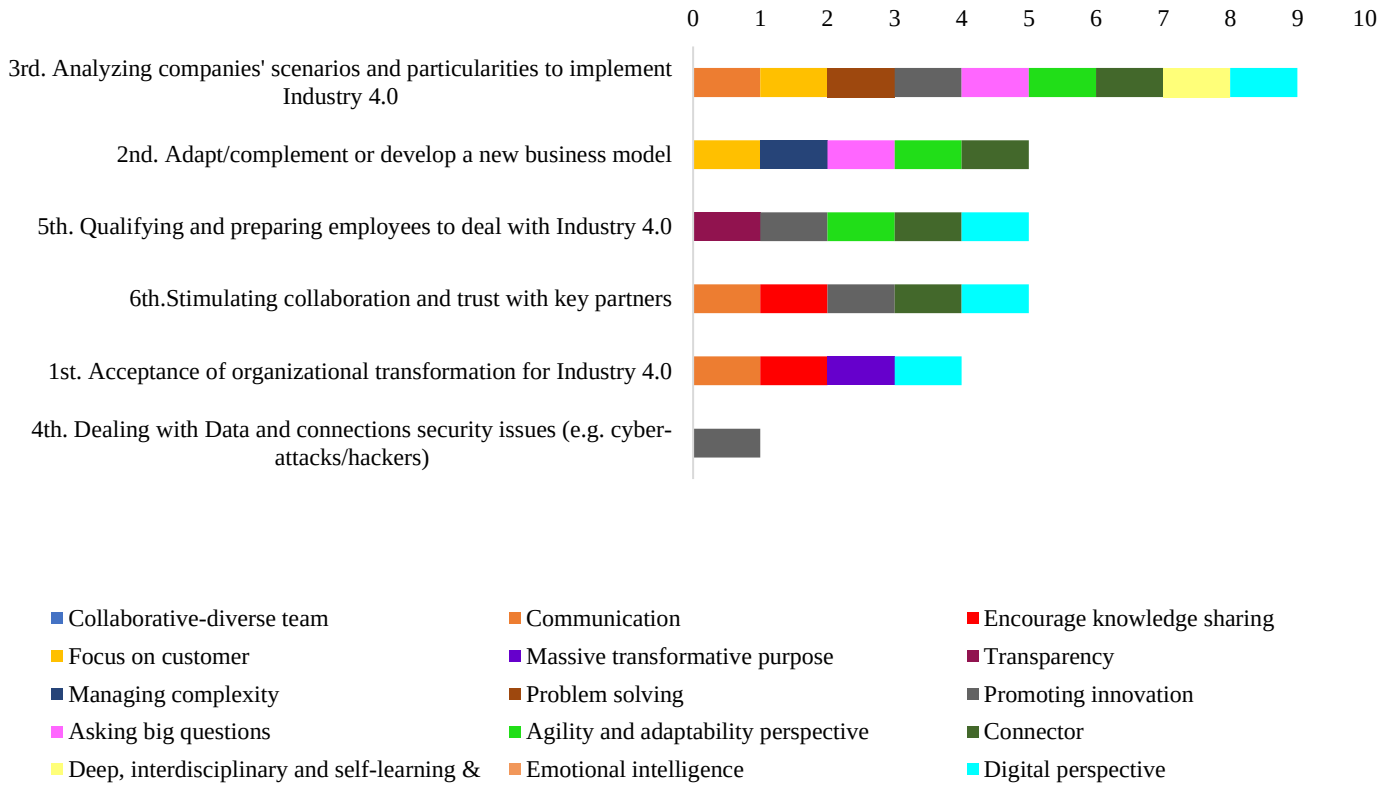
	Challenges towards I40 →	1st.	2nd.	3rd.	4th.	5th.	6th.	Number of challenges towards Industry 4.0 that are supported by each I4.0 LC
Categories	***I4.0 LC*** ↓	Acceptance of organizational transformation for Industry 4.0	Adapt/complement or develop a new business model	Analyzing companies' scenarios and particularities to implement Industry 4.0	Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	Qualifying and preparing employees to deal with Industry 4.0	Stimulating collaboration and trust with key partners	
Social competences	Collaborative-diverse team	3,66	3,67	3,60	3,03	3,67	3,76	0
	Communication	4,18	3,68	4,07	3,08	3,79	4,52	3
	Encourage knowledge sharing	4,17	3,59	3,50	3,03	3,80	4,02	2
	Focus on customer	3,62	4,16	4,17	3,18	3,63	3,72	2
	Massive transformative purpose (MTP)	4,18	3,33	3,58	3,01	3,62	3,61	1
	Transparency	3,77	3,20	3,19	3,16	4,09	3,78	1
Methodological competences	Managing complexity	3,67	4,00	3,76	3,11	3,59	3,91	1
	Problem solving	3,77	3,71	4,11	3,56	3,68	3,57	1
	Promoting innovation	3,79	3,32	4,05	3,96	4,02	4,08	4
Personal competences	Asking big questions	3,70	4,07	4,09	3,42	3,68	3,63	2
	Agility and adaptability perspective	3,79	4,09	4,09	3,14	4,08	3,65	3
	Connector	3,64	4,06	4,12	3,49	4,07	4,04	4
	Deep, interdisciplinary and self-learning	3,66	3,76	4,06	3,53	3,72	3,27	1
	Emotional intelligence	3,73	3,62	3,63	2,97	3,75	3,37	0
Technical competences	Digital perspective	4,09	3,69	4,10	3,63	4,07	4,05	4

Source: author

It can be seen from the data in Table 21 that the main I4.0 LC contributing to more than one challenge towards I4.0 are: digital perspective, promoting innovation, connector, agility and adaptability, focus on customer, encourage knowledge sharing and communication. Based on Brazilian experts, the 4th. challenge and 5th.challenge were contributed by at least one I4.0 LC, different than on the perspective of all experts (Table 17), when such challenges were not contributed by any I4.0 LC.

Figure 15 illustrates all the I4.0 LC (13) prioritized that can support the challenges towards I4.0, it is observed that for the 3rd. challenge there are nine I4.0 LC that were evaluated based on experts to be considered.

Figure 15 - The I4.0 LC that contribute to each challenge towards I4.0: based on Brazilian experts



Source: author

Experts' perspective: from international experts

c) Defuzzification for all triangular fuzzy numbers (TFN) and 4.2.2 d) Filtering and analyzing all evaluation criteria by setting the threshold value (α)***. That is, if*** $G_i \geq \alpha$***, the*** i ***criterion is selected; if*** $G_i < \alpha$***, the*** i ***criterion is eliminate***

Table 22 presents the defuzzification of all TFN resulted from the evaluation of the I4.0 LC (15) in relation to the challenges towards I4.0 (6) executed by international experts (16). The Defuzzification results by calculating Gi (see 3.1). For the filtering and analysis of all criteria evaluated, a threshold value of 4 was defined ($\alpha = 4$). That means if Gi is $\geq \alpha$, then the I4.0 LC is prioritized, if, Gi $< \alpha$ then the I4.0 LC is not prioritized as explained above. Therefore, 14 I4.0 LC were prioritized as those that contribute to supporting at least one challenge towards I4.0, and one was not prioritized (promoting innovation).

Table 22 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of international experts (continues)

LC 4.0	*Challenges towards I40*	*Li*	Mi	Ui	Defuzzification	If alpha =4,0
Collaborative-diverse team	1st. Acceptance of organizational transformation for Industry 4.0	2	3,76	5	3,59	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	3,99	5	4,00	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,65	5	3,55	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,25	5	2,75	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,18	5	4,06	Prioritized
	6th. Stimulating collaboration and trust with key partners	1	4,04	5	3,35	Not prioritized
Communication	1st. Acceptance of organizational transformation for Industry 4.0	2	4,47	5	3,82	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	3,88	5	3,96	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,24	5	3,41	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,68	5	2,89	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,17	5	3,72	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,58	5	4,19	Prioritized
Encourage knowledge sharing	1st. Acceptance of organizational transformation for Industry 4.0	3	4,16	5	4,05	Prioritized
	2nd.Adapt/complement or develop a new business model	2	3,82	5	3,61	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,79	5	3,60	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,76	5	2,92	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	4,37	5	4,12	Prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,99	5	3,66	Not prioritized
Focus on customer	1st. Acceptance of organizational transformation for Industry 4.0	2	3,70	5	3,57	Not prioritized
	2nd.Adapt/complement or develop a new business model	4	4,86	5	4,62	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,92	5	3,64	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,50	5	3,17	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,61	5	3,54	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,31	5	4,10	Prioritized

Table 22 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of international experts (continues)

LC 4.0	*Challenges towards I40*	*Li*	Mi	Ui	Defuzzification	If alpha =4,0
Massive transformative purpose	1st. Acceptance of organizational transformation for Industry 4.0	3	4,52	5	4,17	Prioritized
	2nd.Adapt/complement or develop a new business model	2	3,91	5	3,64	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,75	5	3,58	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,35	4	2,45	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,95	5	3,65	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,64	5	3,55	Not prioritized
Transparency	1st. Acceptance of organizational transformation for Industry 4.0	4	4,80	5	4,60	Prioritized
	2nd.Adapt/complement or develop a new business model	2	3,45	5	3,48	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,57	5	3,52	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,31	5	2,77	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	4,08	5	3,69	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,02	5	3,67	Not prioritized
Managing complexity	1st. Acceptance of organizational transformation for Industry 4.0	2	3,83	5	3,61	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	3,98	5	3,99	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	4,47	5	3,82	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,31	5	3,10	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,26	5	3,42	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,64	5	3,55	Not prioritized
Problem solving	1st. Acceptance of organizational transformation for Industry 4.0	2	3,65	5	3,55	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,19	5	3,73	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	3,94	5	3,98	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,98	5	2,99	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,33	5	3,44	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,46	5	3,49	Not prioritized
Promoting innovation	1st. Acceptance of organizational transformation for Industry 4.0	2	3,90	5	3,63	Not prioritized
	2nd.Adapt/complement or develop a new business model	2	4,21	5	3,74	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	1	3,35	5	3,12	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,82	4	2,61	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	1	3,19	5	3,06	Not prioritized
	6th. Stimulating collaboration and trust with key partners	1	3,06	5	3,02	Not prioritized
Asking big questions	1st. Acceptance of organizational transformation for Industry 4.0	3	4,06	5	4,02	Prioritized
	2nd.Adapt/complement or develop a new business model	4	4,53	5	4,51	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	3,98	5	3,99	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,97	5	2,99	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	1	2,95	5	2,98	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	3,45	5	3,82	Not prioritized

Table 22 - Defuzzification and filtering of the I4.0 LC (15) regarding challenges towards I4.0 (6): based on the perspective of international experts (conclusion)

LC 4.0	*Challenges towards I40*	*Li*	Mi	Ui	Defuzzification	If alpha =4,0
Agility and adaptability perspective	1st. Acceptance of organizational transformation for Industry 4.0	4	4,73	5	4,58	Prioritized
	2nd.Adapt/complement or develop a new business model	3	4,31	5	4,10	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,71	5	3,57	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,57	5	2,86	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,31	5	3,44	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,64	5	3,55	Not prioritized
Connector	1st. Acceptance of organizational transformation for Industry 4.0	2	4,07	5	3,69	Not prioritized
	2nd.Adapt/complement or develop a new business model	4	4,53	5	4,51	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,18	5	4,06	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	2,65	5	2,88	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,31	5	3,44	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,01	5	3,67	Not prioritized
Deep, interdisciplinary and self-learning	1st. Acceptance of organizational transformation for Industry 4.0	2	4,02	5	3,67	Not prioritized
	2nd.Adapt/complement or develop a new business model	3	4,50	5	4,17	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,31	5	4,10	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,11	5	3,04	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	3	3,73	5	3,91	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	3,26	5	3,42	Not prioritized
Emotional intelligence	1st. Acceptance of organizational transformation for Industry 4.0	3	4,56	5	4,19	Prioritized
	2nd.Adapt/complement or develop a new business model	2	3,38	5	3,46	Not prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	2	3,29	5	3,43	Not prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	1,78	4	2,26	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	1	3,79	5	3,26	Not prioritized
	6th. Stimulating collaboration and trust with key partners	2	4,13	5	3,71	Not prioritized
Digital perspective	1st. Acceptance of organizational transformation for Industry 4.0	3	4,22	5	4,07	Prioritized
	2nd.Adapt/complement or develop a new business model	3	4,52	5	4,17	Prioritized
	3rd. Analyzing companies' scenarios and particularities to implement Industry 4.0	3	4,52	5	4,17	Prioritized
	4th. Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	1	3,53	5	3,18	Not prioritized
	5th. Qualifying and preparing employees to deal with Industry 4.0	2	3,96	5	3,65	Not prioritized
	6th. Stimulating collaboration and trust with key partners	3	4,10	5	4,03	Prioritized

Source: author

In sequence, Table 23 illustrates a color scale of the defuzzification resulted from the international experts (Table 22) for the 15 I4.0 LC (categorized in social, methodological, personal and technical competences) related to the 6 challenges towards I4.0. The matrix in Table 23 illustrates a colors scale from red, white to green, where the cells in or close to the green color have a defuzzification value ≥ 4 (prioritized), different than cells in or close to red or white color that have a defuzzification value < 4 (not prioritized).

Table 23 - Defuzzification: overview of the I4.0 LC related with the challenges towards Industry 4.0 to illustrate from prioritized to not prioritized based on international experts'

	Challenges towards I40 →	1st	2nd	3rd	4th	5th	6th	
Categories	***I4.0 LC ↓***	Acceptance of organizational transformation for Industry 4.0	Adapt/complement or develop a new business model	Analyzing companies' scenarios and particularities to implement Industry 4.0	Dealing with Data and connections security issues (e.g. cyber-attacks/hackers)	Qualifying and preparing employees to deal with Industry 4.0	Stimulating collaboration and trust with key partners	Number of challenges towards Industry 4.0 that are supported by each I4.0 LC
Social competences	Collaborative-diverse team	3,59	4,00	3,55	2,75	4,06	3,35	2
	Communication	3,82	3,96	3,41	2,89	3,72	4,19	2
	Encourage knowledge sharing	4,05	3,61	3,60	2,92	4,12	3,66	2
	Focus on customer	3,57	4,62	3,64	3,17	3,54	4,10	2
	Massive transformative purpose	4,17	3,64	3,58	2,45	3,65	3,55	1
	Transparency	4,60	3,48	3,52	2,77	3,69	3,67	1
Methodological competences	Managing complexity	3,61	3,99	3,82	3,10	3,42	3,55	1
	Problem solving	3,55	3,73	3,98	2,99	3,44	3,49	1
	Promoting innovation	3,63	3,74	3,12	2,61	3,06	3,02	0
Personal competences	Asking big questions	4,02	4,51	3,99	2,99	2,98	3,82	3
	Agility and adaptability perspective	4,58	4,10	3,57	2,86	3,44	3,55	2
	Connector	3,69	4,51	4,06	2,88	3,44	3,67	2
	Deep, interdisciplinary and self-learning	3,67	4,17	4,10	3,04	3,91	3,42	2
	Emotional intelligence	4,19	3,46	3,43	2,26	3,26	3,71	1
Technical competences	Digital perspective	4,07	4,17	4,17	3,18	3,65	4,03	4

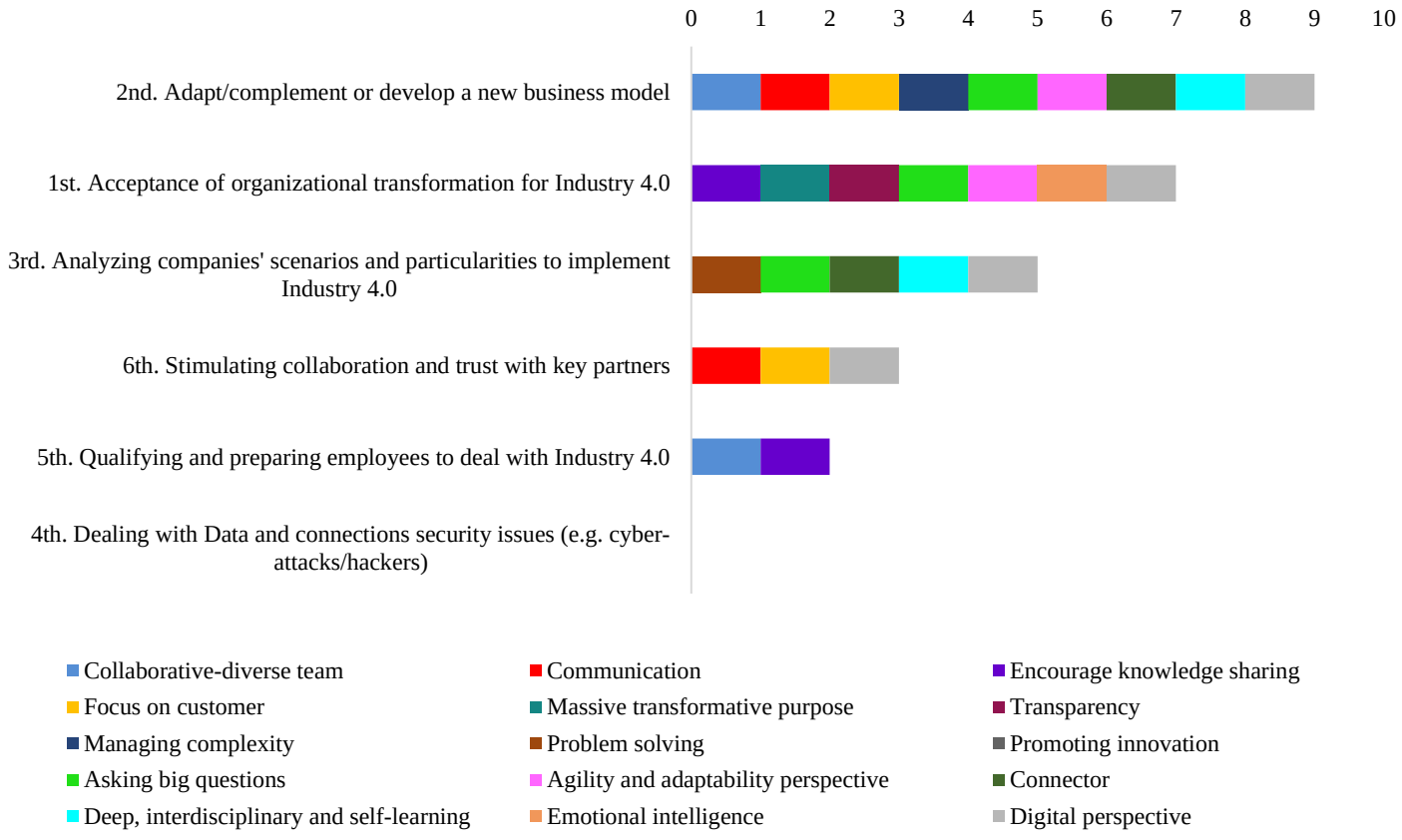
Source: author

5 out of the14 I4.0 LC prioritized by international experts were highlighted, because they have a higher defuzzification value related to the challenges towards I4.0 (as observed in Table 23), respectively are: Focus on customer (4,62) related to 2nd.challenge; transparency (4,60) related to 1st.challenge; agility and adaptability (4,58) related to 1st.challenge; asking big questions (4,51) related to 2nd.challenge; and connector (4,51) also related to 2nd.challenge.

Table 23 also illustrates the I4.0 LC that contribute to support more than one challenge respectively are: digital perspective, followed by asking big questions, connector, agility and adaptability, focus on customer, encourage knowledge sharing, communication, and collaborative diverse team. In sequence, Figure 16 illustrates all I4.0 LC (14) prioritized that can contribute to the challenges towards I4.0, the 2nd. challenge is one of the most contributed by 9 I4.0 LC.

In addition, it can be seen from the data in Table 23 and Figure 16 that the 4th. challenge was not contributed by any I4.0 LC, also observed in the evaluation of all experts commented above.

Figure 16 - The I4.0 LC that contribute to each challenge towards I4.0: based on international experts



Source: author