Authors: Dashi Nazarov
Dr. Anton Klarin

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Title: Taxonomy of Industry 4.0 research: Mapping scholarship and industry insights

Abstract:

A systems perspective of an emergent field such as Industry 4.0 requires combining and analysing the entire multi-disciplinary scholarship under one map. Recent developments in scientometric analysis allow researchers to carry out complex co-citation bibliometric analyses coupled with an unstructured ontological discovery made available through thematic and ensuing semantic analyses to gain a holistic outlook on the ecosystem of Industry 4.0. The state-of-the-art review of the entire scholarship of Industry 4.0 demonstrates three broad clusters – the implications of automation on industry, the integration of technologies, and technological advancements driving the Fourth Industrial Revolution. The scholarship output is, for the first time, compared to the leading industrial and policy-making institutional reports to highlight similarities and discrepancies. This allows to propose a previously unavailable definition of Industry 4.0 which is much needed to progress the research further. The three highly discrepant areas between academic literature and industry insights are – lack of research into return on investment, lack of research involving policy-making, and the implications of technological development on the workforce, firms, and countries. It is imperative to drive research into the existent, as well as the highlighted, themes in advancing the knowledge and aligning the academic scholarship with the interests of practitioners.

Keywords: Industry 4.0; Fourth Industrial Revolution; science mapping; systematic review; industry insights; bibliometrics; scientometrics; systems thinking

1. Background and introduction to understanding Industry 4.0

Technology develops at an exponential rate as a phenomenon of accelerating change, and so does the technological adoption. It took over a century for landline telephone technology to reach saturation, however, it took around five years for smartphone, social media, tablets, and other modern technologies to become mainstream (Desjardins, 2018). Moore's Law (Moore, 1965) that observed that the number of transistors in semiconductors doubles every two years has been expanded to explain the exponential advancement of mainstream technologies (see, for example, Kurzweil, 1990).

The development of industrial production which depends on technological progress shows similar exponentially evolving trends. As such, the first industrial revolution, as noted by a British historian, Arnold Toynbee, to have begun in 1760 in Britain, which was characterised by the move from production by hand to the use of machines that were powered by steam and water to create mechanised factory systems that utilised machine tools (Deane, 1965). While it took millennia for people to go through learning the use of tools and the domestication of plants and animals to machine production, the Second Industrial Revolution happened in a little over a century where steam power had become mainstream and steel production allowed for such breakthroughs as rail systems. The era is also known for the introduction of electricity, telegraph, and oil (Atkeson & Kehoe, 2001; Mokyr, 1998). The Third Industrial Revolution emerged yet faster, rooting itself in 1950s with the development of semiconductors, that gave rise to the computerisation, the subsequent internet, and the mobile phone technologies. These technologies dramatically increased the rate of information processing and diffusion, higher productivity, global interconnectedness and integration (Rifkin, 2011). Only half a century into the Third Industrial Revolution, otherwise known as the Digital Revolution or the Information Age, the German government unveiled Industry 4.0 (I4) or the 'Internet of things (IoT) to the Fourth Industrial Revolution (4IR)' with the aim to become the leading supplier of Industrial IoT (IIoT) globally by 2020 (Kagermann, Lukas, & Wahlster, 2011). The peak of attention to the 4IR came in 2016 at the World Economic Forum (WEF) meeting in Davos named 'Mastering the Fourth Industrial Revolution' (Pfeiffer, 2017). I4 proposes smart factories that rely on the IoT through smart machines communicating with each other with little or no human involvement. The use of these machines is not only within reach but is already in place for some companies and even industries. Amazon is replacing repetitive tasks done by humans by robots, Foxconn is cutting tens of thousands of jobs due to automation and is heavily investing in artificial intelligence (AI) in a bid to create production efficiencies. Industries including shipbuilding, warehousing, car manufacturing, among others are increasingly utilising automation, with the majority of tasks dependent on robots (McKinsey&Company, 2017; World Bank, 2018). True to the technological progress of accelerating change, there are discussions of succession of I4 by the first steps towards the Fifth Industrial Revolution driven by developments in AI and deep learning (Namaki, 2018; Petrillo, De Felice, Cioffi, & Zomparelli, 2018; Serrano, 2018; Valenduc, 2018). It is too early to judge whether the I4 theme is on its way to saturation levels in the academic discussion, however, we can provide an illustration of the research outputs in regards to the topic of I4 and the 4IR, Figure 1.

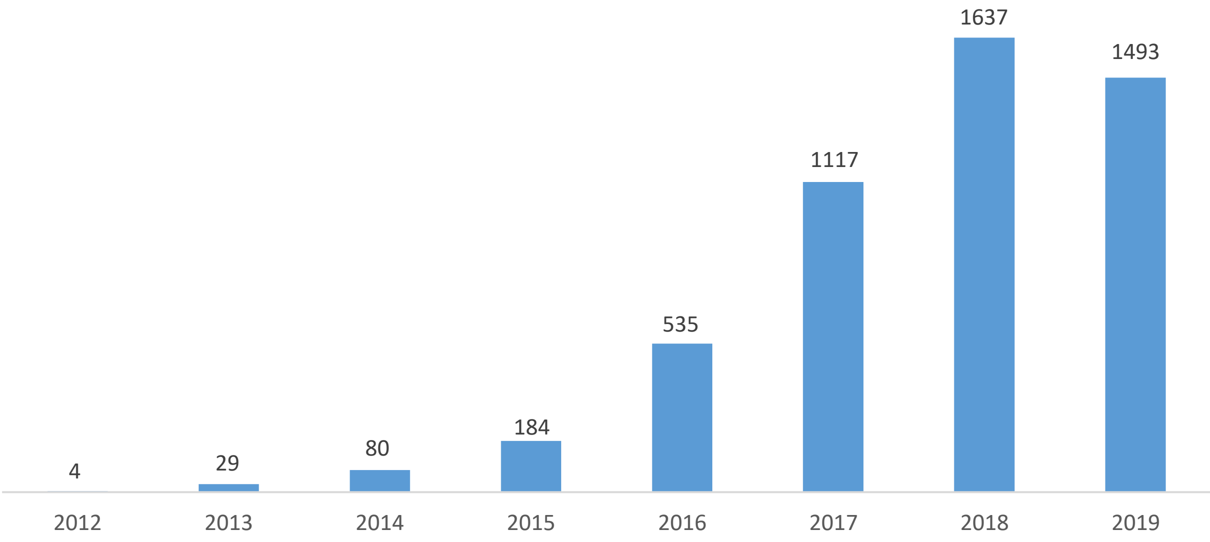

Figure 1. Total number of published articles on I4 and the 4IR, Web of Knowledge yearly to 14/12/2019

Much research and application has been conducted in the field of I4 since the coining of the term in 2011. To best gain an understanding of the holistic nature of I4 from a systems perspective, we believe that a comprehensive review of the I4 scholarship and industry insights should be carried out to offer an understanding of the I4 system and propose future research directions of this important field.

A holistic understanding of how a structure's integral parts are interrelated and how the processes are run is best analysed through a systems perspective. Systems science explores the nature of complex systems in natural ecosystems (ones created by nature), designed systems (ones created by humans), and societal affairs (Checkland, 1999a). Thus, it is safe to say that the I4 concept is a social construct therefore it is a designed system. A designed system by default should exhibit the properties of emergence, holism, and openness (Suseno & Standing, 2018). Emergence perspective assumes the whole is larger than its parts and that the system is a single (separable from its environment) entity (Checkland, 1999b: 50). Holism infers interactions through communication and control between parts/sub-systems of the entire system. It is crucial to consider the comprehensiveness of all these interactions rather than concentrating on several features or a part/some parts of a system (Jackson, 2003, 2006). Finally, systems ought to be open – such systems affect, and are influenced by, the environments (Emery, 2000, 2004, 2010; Standing, Mavi, Suseno, & Jackson, 2018; von Bertalanffy, 1950). It is indeed Ludwig von Bertalanffy (1968) that suggested that systems research integrates holism and reductionism approaches, meaning an analysis through the study of the interactions between sub-systems/components and the study of a subject as a whole, which we attempt in this study.

In this paper, our aim is to explore and map the data that is available on the majority of academic literature on I4 and the 4IR through provision of a comprehensive bibliometric and thematic results. We further demonstrate the perspectives of the major advisory and policy-making transnational and supranational institutions, and compare them to the entire academic scholarship on this highly important topic. This will not only provide a systems perspective on I4 and the 4IR, but also enable us to collate the findings of the academic scholarship and the practitioners' knowledge to propose a definition of I4 that will assist in driving the research further. The study aims to provide valuable insights into the possibilities of further advancement of the academic scholarship.

The paper is organised as follows. Section 2 proposes advanced methods of review used in this study that have a number of advantages over the previous review studies. Section 3 describes the process of the comprehensive literature survey to provide state-of-the art outlook on I4. Section 4 provides the clustered output results of the I4 scholarship with a comprehensive discussion. Section 5 compares the results of the I4 scholarship to practitioner-oriented sources to highlight the areas of divergence and proposes a much needed definition of I4. Finally, Section 6 concludes and offers future directions for research.

2. Existing reviews of I4 and the value added of scientometric review

A thorough investigation of the literature on I4 and 4IR identified several existing literature review studies as shown in Table 1. There is a large number of studies that provide narrative and systematic reviews of specific technologies that underpin I4 and the 4IR, it is outside the scope of this paper to investigate the various technologies that driver the 4IR. Thus, we abstained from reviewing the technological factor studies and instead focused on the systems view of the scholarship and industry insights.

Table 1. I4 review studies

Review	Type	Key topic(s)	Research area	Methodology remarks
Pereira and Romero (2017)	Traditional narrative	I4 and its implications	Manufacturing	No methodology provided, potentially biased.
Roger and Antonella (2017)	Traditional narrative	I4 technologies' implications on global value chains	International Business	No methodology provided, potentially biased.
Bahrin, Othman, Azli, and Talib, (2016)	Traditional narrative	I4 and its implications	Engineering	No methodology provided, potentially biased.
Trappey, Trappey, Govindarajan, Sun, and Chuang (2016)	Traditional narrative	Technology standards and patent portfolios of cyber physical systems (CPS)	Engineering	No methodology provided, potentially biased.
Zhong, Xu, Klotz, and Newman (2017)	Traditional narrative	I4 technologies review	Engineering	No methodology provided, potentially biased.
Liao et al. (2017)	Manual systematic	I4 and 4IR	Operations management	Results up to mid-2016, 224 studies analysed, search criteria could be expanded, manual collection and interpretation could be subject to bias.
Galati and Bigliardi (2019)	Mapping, state-of-the art	I4	Operations management	Limited search criteria, 1025 studies, search results up to 2017.
Piccarozzi, Aquilani, and Gatti (2018)	Manual systematic	I4	Management	Limited search criteria, methodology is not clarified, only 68 studies, search results up to mid-2018.

While the reviews represented in Table 1 provide valuable insights into SE literature, there are a number of limitations to the existing review studies. First, a large part of the reviews tends to be narrative in nature with limited information on the scientific methodology (Bahrin et al., 2016; Pereira & Romero, 2017; Roger & Antonella, 2017; Trappey et al., 2016; Zhong et al., 2017). Second, existing review studies were conducted using limited search criteria, which subsequently limits the number of results incorporated in the studies. For example, Galati and Bigliardi (2019) and Piccarozzi, Aquilani, and Gatti (2018) searched for 'Industry 4.0', ignoring the original 'Industrie 4.0', and the variations of the 4IR terms. Consequently, the total body of literature they generated could potentially be incomplete. Third, existing review studies in majority ignore the bulk of the literature that was published since 2018, amounting to over three quarters of all studies on I4 and 4IR. Last but not least, a comprehensive analysis of an emergent topic requires a comparison between scientific studies and the practitioners' insights to best inform research and the practical application of science especially that of industrial evolution that is transforming the society and is currently missing from the literature.

More recently, advancements in technology brought forth algorithm-based scientometric mapping that allows a holistic visualisation of a particular research domain (Petticrew & Roberts, 2006; Tranfield, Denyer, & Smart, 2003). The rationale for employing scientometric mapping reviews is four-fold. First, scientometric review utilises objective, consistent, transparent, and reproducible results for the audience (van Eck & Waltman, 2014). Compared to traditional reviews that are prone to type II bias of subjective presentation and interpretation of data, this method relies on complex algorithms that allows for an unbiased outlook of the research topic. Second, scientometric review enables the search of the entire academic publications of the topic, facilitating a more comprehensive understanding of the chosen research domain. Moreover, the use of the thousands of scholarship literature allows the bridging of crucial gaps between disparate disciplinary boundaries (Hu & Zhang, 2017; Rafols, Leydesdorff, O'Hare, Nightingale, & Stirling, 2012). Third, this review, with its visual representations, not only enables the identification of the existing research domains but also the trends of the scholarship domains over time. Finally, this method allows scholars to objectively analyse how scholarship can be organised in a systematic manner, and also provides a semantic analysis of the topic, including for example the provision of top trending and top impact articles. Overall, the systems perspective of a topic is best facilitated through carrying out a comprehensive inclusive analysis of the majority of scholarship which is best carried out through a scientometric analysis offered through this study.

The identified clusters/research domains of the scholarship provide a taxonomy of the studied topic. The term taxonomy derives from the Greek language, where taxis translates as an 'arrangement' and nomos translates as 'law'. Taxonomy is, therefore, the methodology and principles of systematic classification of a studied topic and sets up arrangements of the kinds of sub-systems into a system. The optimal way to create this systems taxonomy is through systematically feeding the holistic outlook on a particular topic (for example the entire WoS database) through algebraic clustering techniques that integrates closely related themes into clusters based on advanced algorithms (van Eck & Waltman, 2010, 2014). I4 and 4IR are driving the future of production, to this date, as far as we know, there has been no attempt to classify this immensely important topic into a unified taxonomy. A systems view of the topic offered through this study will allow to create this taxonomy and drive the research forward.

Indeed, I4 is the top priority of industrialised nations that aim to gain the efficiencies stemming from the technological advancements. Much research of this emergent topic covers the vision, the technologies, applications of these technologies, and the design principles of

I4. Surprisingly, there is no uniform definition of I4 available in the literature (Castelo-Branco, Cruz-Jesus, & Oliveira, 2019; Hermann, Pentek, & Otto, 2016; Mrugalska & Wyrwicka, 2017). This constrains scientific research due to the lack of the basic terminological foundation. Some rather vague definitions have been provided that fail to specify the nature of I4 in comparison to other industrial revolutions. An example of such definition may include 'a collective term for technologies and concepts of value chain organization' (Hermann, Pentek, and Otto (2015), p. 11). After a careful examination of Germany's Industry 4.0 working group report (Kagermann, Wahlster, & Helbig, 2013) we courteously disagree with using this report being considered as 'the citation and guidance for identifying the definition of Industry 4.0' (Liao et al. (2017), p. 16). Although the report does elaborate on the design principles of I4 in detail, it does not provide a definition of I4, apart from a 'continuous resource productivity and efficiency gains to be delivered across the entire value network. It allows work to be organised in a way that takes demographic change and social factors into account.' (Kagermann et al., 2013, p. 5). These type of definitions have little value in identifying the premises of the 4IR.

3. Scientometric review process of I4 scholarship

Science mapping through the use of innovative scientometric techniques is becoming an increasingly popular method of visualising academic research. Creating maps based on a complete scholarship of a topic provides a holistic understanding of the topic that allows to connect diverse knowledge domains. Scholars in varied disciplines may utilise science maps to overcome the boundaries between knowledge domains and create value through collaboration in knowledge advancement (Hu & Zhang, 2017; Rafols et al., 2012).

This study is a mixed methods systematic review of the literature that is consistent of a systematic search criteria, mapping review that categorizes current literature, and a state-of-the-art review (Grant & Booth, 2009) that evaluates not only the current scholarship but also industry insights into I4 and the 4IR. The mixed methods systems review was necessary to provide a robust, comprehensive, and breakthrough evaluation of the literature on this current and emergent theme.

Systematic reviews apply scientific methods that explicitly aim to limit systematic errors or bias through identifying, appraising and synthesizing all relevant studies (dependent on the design) in order to deal with a question or a set of questions (Schlosser, Wendt, & Sigafoos, 2007). Tranfield, Denyer, and Smart (2003) proposed three stages of conducting a through, transparent and a reliable systematic review – planning and outlining a review protocol, execution of the protocol, and reporting.

In the planning stage we have identified the value of the research in providing a holistic understanding of the interdisciplinarity of the topic and proposing future development of the domain. We have also developed a protocol for selection, search strategies, methods of the review, and accompanying data and information. In this stage we chose to use the entire Web of Knowledge database (WoS) as it is considered one of the largest scientific knowledge databases (Crossan & Apaydin, 2010; Podsakoff, MacKenzie, Podsakoff, & Bachrach, 2008), and has major overlaps with its closest contestant database – Scopus, meaning the results to have marginal divergences between the two databases especially if looking to compare large volumes of articles (Vieira & Gomes, 2009).

In the second stage of the execution of the protocol we followed the procedures set out in the planning stage of identification of search terms, selection of studies, studying the quality assessment, data extraction and synthesis. The dates of the document search were deliberately set from 2011 (proposition of I4 as a concept – Kagermann et al., 2011) until 28/01/2019 when the initial comprehensive list of documents was extracted. The search criteria was set as follows: '*Industry 4.0' or 'industrie 4.0' or 'Fourth Industrial Revolution' or '4th industrial revolution' or 'Industrial Revolution 4*'* using Boolean search of the WoS. The search returned 2,986 documents that contain either of these terms within the titles and abstracts of the original works. For mapping and identifying clusters of research, we have decided to use all of the collected sources in our analysis regardless of the language (as long as the title and abstract are in English), the publication type (including editorials, letters, book chapters, proceedings, etc.) as a large-sample thematic study of the entire scholarship requires a semantic analysis of noun terms regardless of the mentioned criteria (Justeson & Katz, 1995; van Eck & Waltman, 2014).

The mapping and state-of-the art reviews are done using innovative science mapping software that utilises co-citation analysis that demonstrates relationships between scientometric indicators in a visual map. We have combined the bibliometric analysis that provides results for identification of author, document, organisation, keywords, sources, countries of publication with advanced methods of thematic analysis made available by extracting commonly occurring noun phrases. This method maps the content of the entire extracted literature (2,986 documents) on I4 and the 4IR according to clusters. We have further removed generic noun phrases that relate to purely academic articles including 'practical implications', 'in-depth interviews', 'paper', 'research limitations', and others. These terms commonly occur universally across the corpus of the research and provide no value in data analysis. We have also abbreviated some commonly occurring terms, both, specific to the research (e.g., 'cyber physical system' to 'CPS') and generic terms (e.g., 'small and medium enterprise' to 'SME'). British spelling terms were combined with American spelling nouns (e.g. 'organisation' to 'organization'). Finally, the terms 'industry' and 'industrie' were excluded from the results due to being the key search criteria and occurring indiscriminately throughout the fields of research. Upon running the analysis, cluster alignment occurs when terms that are strongly associated with each other are placed in the same cluster thereby providing an emergent taxonomy of the literature.

4. Systems perspective on I4 and 4IR

To gain the state-of-the-art systems view of the scholarship we utilised VOSviewer clustering software which is based on identifying high similarity terms and placing on a map close to each other. The software, then, allows to create clusters which occur as a result of assigning nodes in a network on the basis of relationship between terms. Publications that are assigned to the same clusters are likely to have a theme in common (for a more detailed technical explanation please see Korom, 2019; van Eck & Waltman, 2010, 2014).

In our study the software identified three clear clusters of I4 research: blue cluster – *technology requirements and the evolution of the industrial environment*; red cluster – *opportunities and challenges presented by the 4IR*; and green cluster – *integration of technologies to the current systems and processes*. To provide a thorough investigation of the areas of research, each cluster is analysed according to the themes that are presented within each cluster. The results of the thematic analysis are represented visually in Figure 2. In the map, the frequency of occurrences is represented by the size of the noun phrase, i.e. larger circles represent higher number of occurrences of the term.

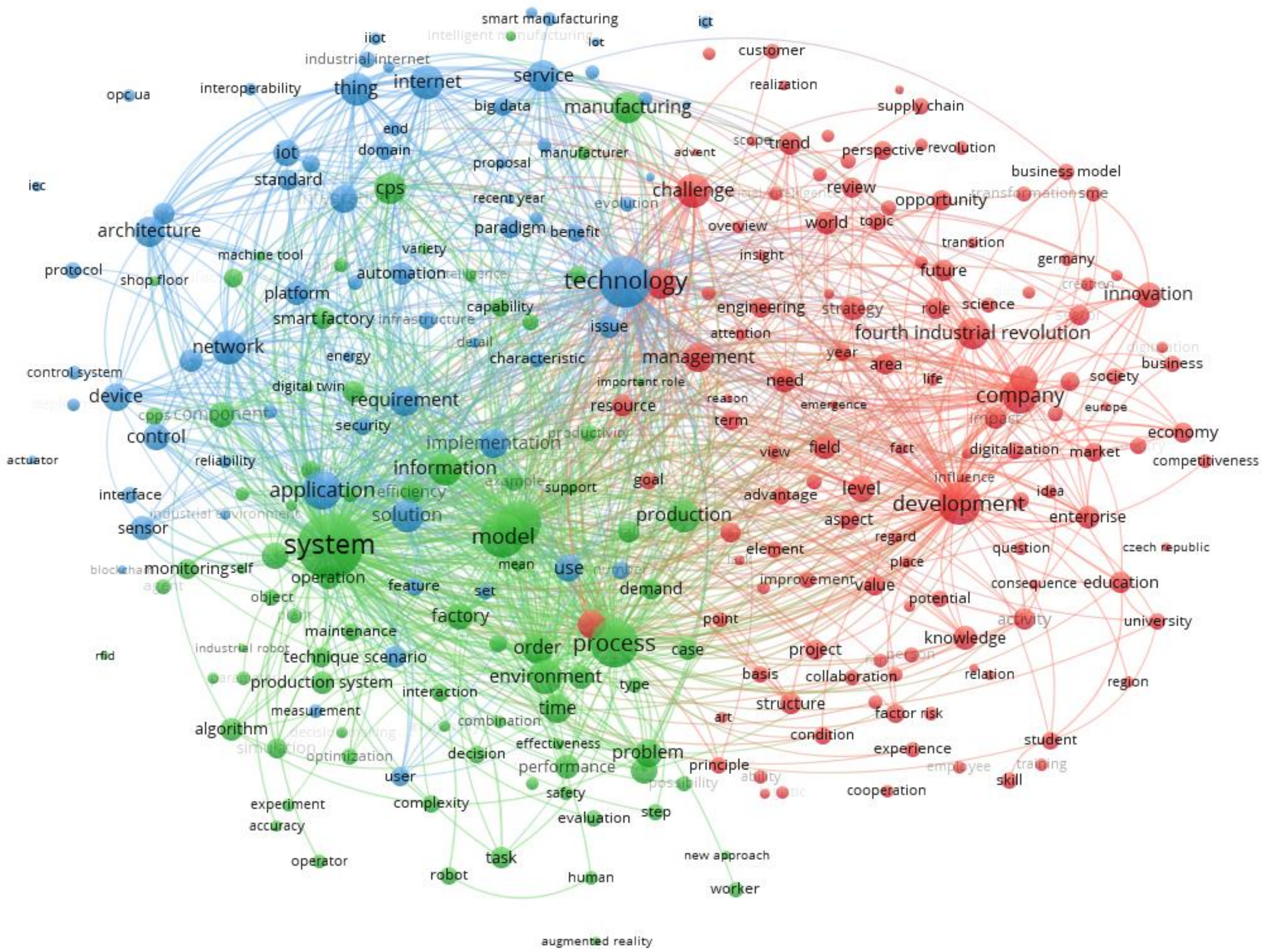

Figure 2. Systems view of Industry 4.0 scholarship

Following the visual representation of the I4 scholarship in Figure 2, we have provided a number of tables to highlight bibliometric and thematic results extracted through the scientometric analysis of the topic. As such, Table 2 demonstrates i) the themes that are prevalent in documents that receive the highest citation counts, ii) the themes that appear in the articles with the most recent publication date, and iii) the indicative disciplinary domains. Table 3 represents top five indicative articles for each of the clusters. Table 4 demonstrates top fifteen journals that have published research on I4 and the 4IR. Table 5 presents top twenty countries by publication volume. And Table 6 reveals the top fifteen authors or groups of authors by a number of citations as of 28/01/2019.

4.1. Blue: Technology requirements and the evolution of the industrial environment

This cluster is associated with the technology used and in the process of development to facilitate the 4IR. As such, the most common topics synthesised from the analysis include *automation, big data, communication, technology, architecture, infrastructure, evolution, smart manufacturing, sensors, cloud computing, additive manufacturing*, and others. The research that investigates big data analytics in smart manufacturing offers solutions on a computational basis (Lee, Kao, & Yang, 2014; Qi & Tao, 2018; Reis & Gins, 2017; Zhang, Ding, Zou, Qin, & Fu, 2019). For example, Lorenzo, Petruzzelli, Panniello, and Garavelli, (2019) identified IIoT, cloud computing, big data analytics and customer profiling, cyber security as the key patented technological trends driving supply chain management in the 4IR.

There has been progress in testing these systems in laboratory settings to offer state-of-the-art solutions (Wan et al., 2017; Wang, Wan, Zhang, Li, & Zhang, 2016; Yan, Meng, Lu, & Li, 2017). Further, there are studies that implemented these state-of-the-art technologies in the real-life environment (Dalenogare, Benitez, Ayala, & Frank, 2018; Santos et al., 2017). As an example, Frank, Dalenogare, and Ayala, (2019) demonstrate that most of the companies that are engaged in I4 integration are utilising the front-end technologies, where smart-manufacturing plays a key role. However, base technologies implementation is still low as most companies lack the big data and analytics capabilities.

Cloud computing, its architectures, and software based on cloud computing remains an area which is predominantly explored through theoretical and conceptual analysis rather than an actual application studies due to the nascent stages of utilisation of such technologies for industrial purposes (Tao et al., 2017; Thames & Schaefer, 2016; Yue, Cai, Yan, Zou, & Zhou, 2015; Zhan et al., 2015). Notably, this cluster also embarks on the discourse of security issues (confidentiality and integrity of data) arising from rapid industrialisation of IoT mainly due to large amounts of critical data on exchanges that may be prone to malicious attacks (He et al., 2016; Nguyen, Ali, & Yue, 2017; Sadeghi, Wachsmann, & Waidner, 2015). Apart from security, issues including transparency, seamless data transfers, self-maintenance, authentication, privacy are some of the features integral to the blockchain technologies which finds a fit with IIoT infrastructures (Fernández-Caramés & Fraga-Lamas, 2018; Khaqqi, Sikorski, Hadinoto, & Kraft, 2018; Sikorski, Haughton, & Kraft, 2017; Viriyasitavat, Da Xu, Bi, & Sapsomboon, 2018). Finally, the cluster discusses energy-efficiency as a theme, where wireless sensor networks and the efficiency offered by these technologies is often considered the future of internet and industrial production (Baccarelli, Naranjo, Scarpiniti, Shojafar, & Abawajy, 2017; Hortelano, Olivares, Ruiz, Garrido-Hidalgo, & López, 2017; Lin, Deng, Chen, & Chen, 2016).

4.2. Red: Opportunities and challenges presented by the 4IR

The largest cluster, is concerned with introducing Industry or Industrie (in German) 4.0 (Drath & Horch, 2014; Lasi & Kemper, 2014; Roblek, Meško, & Krapež, 2016) and the implications of the Fourth Industrial Revolution (4IR) on firms and current systems. The evolution of manufacturing technologies from traditional forms to digitalization and automation through the Internet of Things (IoT) and associated technologies is fascinating and gave rise to few earlier studies into this topic (Kang et al., 2016; Oesterreich & Teuteberg, 2016; Schumacher, Erol, & Sihn, 2016). The themes of sustainability management in manufacturing are also an integral part of organisational development (de Sousa Jabbour, Jabbour, Foropon, & Godinho Filho, 2018; Müller, Kiel, & Voigt, 2018; Stock & Seliger, 2016). While operations management is the domain of the green cluster, logistics and supply-chain management technological processes remain extremely relevant as the pioneers in undergoing changes during the 4IR (Hofmann & Rüsch, 2017; Ivanov, Dolgui, Sokolov, Werner, & Ivanova, 2016; Kovacs & Kot, 2017; Witkowski, 2017). For example, Manavalan and Jayakrishna (2019) demonstrate that future sustainable supply chains are made possible with the technologies and process brought forth by the 4IR, automation, IoT, CPSs, and more.

Another important theme that is explored in this cluster concerns outlooks and experiences for SMEs which either find automation and digitalization a direct threat (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2017; Sommer, 2015) or as opportunities or needs for adjustment for business development (Faller & Feldmúller, 2015; Ganzarain & Errasti, 2016; Müller, Buliga, & Voigt, 2018). Most other studies in this cluster discuss future opportunities and the potential economic value and implications of technology developments underpinning I4 and the 4IR themes (Abele et al., 2017; Bokrantz, Skoogh, Berlin, & Stahre, 2017; Ivanov, Dolgui, & Sokolov, 2019; Liao et al., 2017; Roy, Stark, Tracht, Takata, & Mori, 2016; Sihn, Erol, Ott, Hold, & Jäger, 2016; Vogel-Heuser & Hess, 2016).

4.3. Green: Integration of technologies to the current systems and processes

Similarly to the previous cluster, this cluster orientates itself around possibilities of technologies in organisations, with the difference being in the actual integration of new systems on operational level rather than general discussions of the technological evolution and its implications. As such, operationalization of CPS and/or Cyber Physical Production Systems (CPPS) are the key points of inflection in this cluster (Bagheri, Yang, Kao, & Lee, 2015; Harrison, Vera, & Ahmad, 2016; Monostori, 2014; Monostori et al., 2016; Mosterman & Zander, 2016; Yao et al., 2017; Yue et al., 2015). For example, a study carried out by Xu and Duan (2019) demonstrates that CPS is the driving technology behind I4 thus generating large amounts of data which is then processed through big data systems to help improve system scalability, security, and efficiency.

As such, the research divides into two streams – possibility of integration the new technologies to current systems with some adjustments (Qin, Liu, & Grosvenor, 2016; Schlechtendahl, Keinert, Kretschmer, Lechler, & Verl, 2014; Weyer, Schmitt, Ohmer, & Gorecky, 2015; Yue et al., 2015), or a significant gap between the current systems and proposed standards to ride the wave of the 4IR (Chen & Tsai, 2017; Kannan et al., 2017; Kolberg, Knobloch, & Zühlke, 2017). Expanding on the preparedness, the same argument can be expanded to the human skills and adaptability to the new disruption in operations management. While some believe that the changes brought forth by the 4IR are creating significant issues for employability and human readiness (Hecklau, Galeitzke, Flachs, & Kohl, 2016; Pfeiffer, 2016; Rosen, Von Wichert, Lo, & Bettenhausen, 2015), the others believe that training and personal development is the key to succeed in the competitive environment (Gorecky, Schmitt, Loskyll, & Zühlke, 2014; Longo, Nicoletti, & Padovano, 2017). Finally, general production performance is discussed extensively by the scholars in this cluster – namely the most advanced lean production technologies available due to automation (Kolberg et al., 2017; Mrugalska & Wyrwicka, 2017; Sanders, Elangeswaran, & Wulfsberg, 2016). Having carried out an extensive analysis of European manufacturers, Rossini, Costa, Tortorella, and Portioli-Staudacher (2019) demonstrated that lean production is a direct precursor for integration of the higher levels of I4 adoption.

Table 2. Key themes discussed in the three research areas

	Top article citation impact terms[a]	**Top trending terms[b]**	**Indicative fields**
Blue – Technology requirements and the evolution of	Communication technology; smart manufacturing; cloud; blockchain; integration; mechanism; advance; Big Data; IIoT; industrial internet; scenario; paradigm; cloud computing; software; internet; new concept; service; evolution; deployment;	Blockchain; IIoT; energy; deployment; additive manufacturing; connectivity; reliability; characteristic; cloud computing; IoT; Big Data; communication technology; industrial internet; paradigm;	Computer science, engineering, & information systems

the industrial environment	network; industrial environment; technology; feature; interoperability; ICT; architecture; domain	application; platform; industrial environment; technology; requirement; solution network	
Red – Opportunities and challenges presented by the fourth industrial revolution	Science; China; principle; topic; industrial revolution; manufacturing industry; realization; opportunity; challenge; creation; Germany; attention; stage; initiative; world; question; future; practice; sustainability; strategy; logistic; transformation; IT; engineering	Artificial intelligence; digital transformation; sustainability; reason; SMEs; economy; assessment; supply chain; digitalization; competitiveness; attention; comparison; training; education; market; smart city; China; skill; innovation transition	Business and social sciences
Green – Integration of technologies to the current systems and processes	Self; CPPS; smart factory; intelligent manufacturing; manufacturing; CPS; productivity; factory; object; agent; digital twin; decision-making; industrial robot; real-time; support; shop floor; decision; vision; effectiveness; complexity; production system; information; manufacturing system; machine; flexibility; maintenance; environment; human; new approach; machine tool	Digital twin; effectiveness; experiment; safety; problem; performance; robot; capability; era; quality; decision-making; task; variety; algorithm; interaction; operation; technique; efficiency; augmented reality; possibility; manufacturing process; parameter; intelligent manufacturing; operator; simulation	Engineering & Operations management

[a] Top impact terms are the highest average normalized citation terms arranged in descending order.

[b] Top trending terms are arranged in descending order from the most recent average publication date.

Table 3. Five highly cited representative articles in each cluster*

Blue – Technology requirements and the evolution of the industrial environment
Lee, J., Kao, H.A. and Yang, S. (2014), 'Service innovation and smart analytics for Industry 4.0 and big data environment', *Procedia CIRP*, Elsevier B.V., Vol. 16, pp. 3–8.
Wang, S., Wan, J., Li, D. and Zhang, C. (2016), 'Implementing smart factory of Industrie 4.0: An outlook', *International Journal of Distributed Sensor Networks*, Vol. 12 No. 1, p. 3159805.
Wan, J., Tang, S., Shu, Z., Li, D., Wang, S., Imran, M. and Vasilakos, A. V. (2016), 'Software-defined industrial internet of things in the context of Industry 4.0', *IEEE Sensors Journal*, Vol. 16 No. 20, pp. 7373–7380.
Posada, J., Toro, C., Barandiaran, I., Oyarzun, D., Stricker, D., de Amicis, R., Pinto, E.B., et al. (2015), 'Visual computing as key enabling technology for Industrie 4.0 & industrial internet', *IEEE Computer Graphics and Applications*, Vol. 35 No. 2, pp. 26–40.
Zhan, Z.-H., Liu, X.-F., Gong, Y.-J., Zhang, J., Chung, H.S.-H. and Li, Y. (2015), 'Cloud computing resource scheduling and a survey of its evolutionary approaches', *ACM Computing Surveys*, Vol. 47 No. 4, pp. 1–33.
Red – Opportunities and challenges presented by the fourth industrial revolution
Drath, R. and Horch, A. (2014), 'Industrie 4.0: Hit or hype?', *IEEE Industrial Electronics Magazine*, IEEE, Vol. 8 No. 2, pp. 56–58.
Hermann, M., Pentek, T. and Otto, B. (2016), 'Design principles for Industrie 4.0 scenarios', *Proceedings of the Annual Hawaii International Conference on System Sciences*, IEEE, Vol. 2016–March, pp. 3928–3937.
Stock, T. and Seliger, G. (2016), 'Opportunities of sustainable manufacturing in Industry 4.0', *Procedia CIRP*, Elsevier B.V., Vol. 40 No. Icc, pp. 536–541.
Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H., et al. (2016), 'Smart manufacturing: Past research, present findings, and future directions', *International Journal of Precision Engineering and Manufacturing - Green Technology*, Vol. 3 No. 1, pp. 111–128.
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* The articles identified above met the criteria of containing a minimum of two terms in their title/abstract, with at least 70% of terms belonging to a single cluster (i.e. to help ensure reliable cluster assignment).

Table 4. Top 15 journal outlets for I4 and the 4IR*

Outlet	Cluster	Documents	Avg. cit. per doc.
IEEE Access	Blue and Green	48	4.6
International Journal of Production Research	Red and Green	24	9.7
Technological Forecasting and Social Change	Red	9	5.8
Computers in Industry	Green and Red	20	7.3
Sustainability	Red	22	2.4
Sensors	Blue and Green	22	3.2
IFAC Papersonline	Green	86	3.7
CIRP Annals – Manufacturing Technology	Red and Green	11	21
IEEE Transactions on Industrial Informatics	Blue and Green	18	4
IEEE Internet of Things Journal	Blue	5	6.6
Process Safety and Environmental Protection	Red	9	2.1
Robotics and Computer-Integrated Manufacturing	Green and Blue	5	10.4
International Journal of Precision Engineering and Manufacturing – Green	Red	6	16.5
International Journal of Advanced Manufacturing Technology	Green	14	1.9
Computers & Industrial Engineering	Green and Blue	9	3.8

* Clusters are assigned on the basis of over 50% of the terms in the titles and the abstracts belonging to that cluster, as of 28/01/2019

Table 5. Top 20 countries by publication volume, 28/01/2019

Label	Documents	Citations	Avg. pub. year	Avg. cit. per doc.
Germany	868	2779	2016.507	3.2016
China	252	1163	2016.964	4.6151
Italy	213	424	2017.366	1.9906
Spain	192	480	2017.234	2.5
USA	146	834	2017.418	5.7123
England	138	444	2017.109	3.2174
South Korea	106	158	2017.576	1.4906
Austria	102	328	2016.686	3.2157
Czech Republic	101	112	2017.119	1.1089
Brazil	97	198	2017.278	2.0412
Taiwan	96	211	2017.146	2.1979

Portugal	95	222	2017.179	2.3368
Russia	88	92	2017.511	1.0455
Poland	81	187	2017.309	2.3086
France	77	162	2017.273	2.1039
Sweden	61	354	2017.066	5.8033
Romania	47	47	2017	1
Hungary	45	421	2017.178	9.3556
India	44	67	2017.364	1.5227
Norway	40	74	2016.7	1.85

Table 6. Top 15 authors or groups of authors by a number of citations, 28/01/2019

Label	Cluster*	Documents	Citations	Avg. pub. year	Avg. citations
Wan, Jiafu; Li, Di; Wang, Shiyong; Zhang, Chunhua; Liu, Chengliang	Blue	18	595	2017.222	33.0556
Lee, Jay	Green	5	293	2015.6	58.6
Gorecky, Dominic	Green	6	164	2015.333	27.3333
Toro, Carlos; Sanin, Cesar; Szczerbicki, Edward	Blue	9	153	2015.778	17
Zuehlke, Detlef	Green	5	142	2015.6	28.4
Zhou, Keliang	Red	5	119	2015.4	23.8
Schuh, Guenther	Red	7	109	2014.857	15.5714
Sihn, Wilfried	Red	9	97	2017.222	10.7778
Fernandez-Carames, Tiago M.; Fraga-Lamas, Paula	Green	12	91	2017.75	7.5833
Tao, Fei	Blue	6	91	2017.833	15.1667
Li, Yun	Blue	11	87	2015.909	7.9091
Xu, Xun	Green	11	74	2017.364	6.7273
Erol, Selim	Red	5	74	2016.8	14.8
Vogel-Heuser, Birgit	Green	14	71	2015.714	5.0714
Ivanov, Dmitry; Sokolov, Boris	Green	6	69	2016.833	11.5

* Assignment to a cluster means the author's or the groups' work predominantly appears in the corresponding cluster.

5. Comparison of academic literature and industry insights

It was imperative to combine insights from the leading and influential institutions on this highly relevant topic. We have endeavoured to gain a holistic understanding of the state of industry through algorithmically analysing full-length industry reports on I4. To ensure the views are comprehensive and rigorous, we utilised the reports of Big Four (Spence & Carter, 2014) accounting firms (Deloitte, Ernst & Young (EY), PricewaterhouseCoopers (PwC), and KPMG), Big Three (The Economist, 2013) consulting firms (or MBB are McKinsey & Company, Boston Consulting Group and Bain & Company), and the largest economic supranational institutions – World Bank and International Bank of Reconstruction and Development (IBRD), World Economic Forum (WEF), Organization for Economic Co-operation and Development (OECD), the United Nations Industrial Development Organisation (UNIDO), and the European Commission. A total of 14 industry reports were collected (full details are in the list of references) – Boston Consulting Group (2015); Deloitte (2018); Ernst & Young (2018); European Commission (2017); KPMG (2017; 2018), McKinsey & Company (2015; 2016); OECD (2017); PricewaterhouseCoopers (2016); United Nations Industrial Development Organization (2016); World Bank (2018); World Economic

Forum (2018); World Economic Forum and Bain & Company (2018). The map of institutional reports is presented in Figure 3.

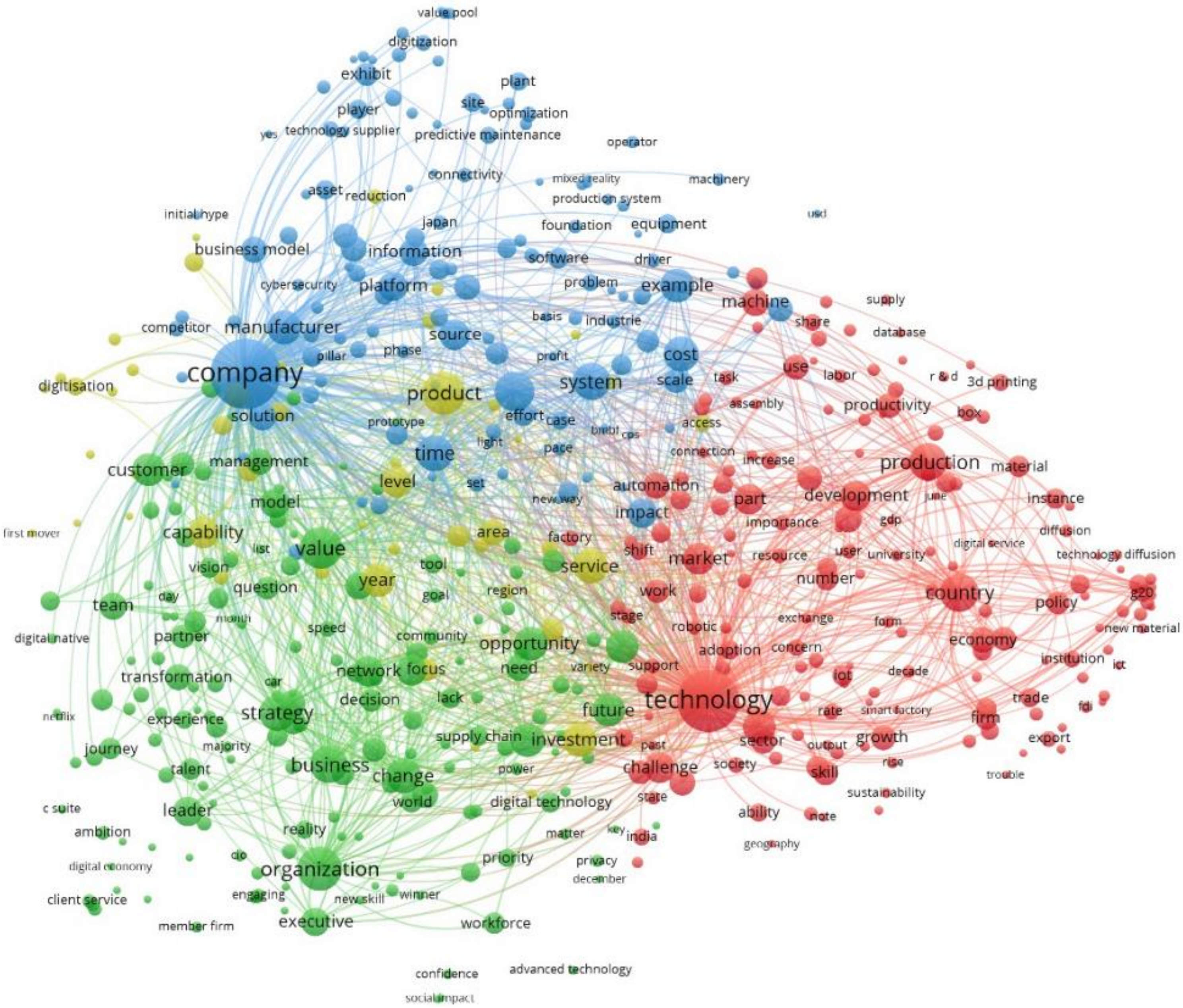

Figure 3. Systems view of Industry 4.0 and the 4IR industry institutional representation

We have utilised 14 industry reports in full rather than titles and abstracts that are utilised in the analysis of academic literature. Thus, it was necessary to average the entire output of industry reports which amounts to 156,466 words into comparable mean of titles and abstracts to gain a meaningful representation of industry output against the entire academic output. Accordingly, we have divided 156,466 words by 250 that happens to be the average amount of words in the 'topic' field in the Social Science literature as indicated by Elsevier, Springer, and a number of articles (see for example, Borja, 2015; HaCohen-Kerner, 2003; Mack, 2012; Plakhotnik, 2017; Springer, 2019) which resulted in approximately 626 comparable documents.

The results of the comparison required a four-step process. First, the total list of top occurring terms was selected from the institutional reports. Terms that had little meaning (e.g., ‘part’ or ‘issue’) were excluded with Cohen’s kappa agreement level between the researchers at 86% which indicates a reliable comparison (McHugh, 2012). If the researchers were to disagree on particular terms, rather than excluding them, these terms were included in the final list for comparison. Second, we calculated proportions of each term occurrence for both–the institutional reports and academic documents. Third, we subtracted the proportion of all occurrences of a term in scholarly articles from the proportion of all institutional output occurrences of the term (full counting of the terms via the VOSviewer options) to gain the discrepancy between the two source streams. Finally, the emphasis ratio demonstrates the proportion of institutional results divided by the proportion of scholarly results to demonstrate the over- or under-emphasis of institutional occurrences over the scholarly mentions (Markoulli, Lee, Byington, & Felps, 2017). Table 7 demonstrates the topic discrepancies between the academic scholarship and industry-oriented institutional outlets.

Table 7. Top 100 terms[a] emphasized in industrial reports compared to academic research

	Institutional occurrences	**Academic occurrences**	**Emphasis discrepancy[b]**	**Emphasis ratio[c]**
1. Internet	54	769	17.13%	0.33
2. Smart Factory	13	331	9.01%	0.19
3. Development	153	976	8.24%	0.75
4. Component	39	427	8.07%	0.44
5. Simulation	20	256	5.38%	0.37
6. Factory	43	358	5.12%	0.57
7. Industrial Internet	11	181	4.30%	0.29
8. IoT	68	448	4.14%	0.72
9. Education	30	233	3.01%	0.61
10. Knowledge	59	369	2.93%	0.76
11. Resource	39	270	2.81%	0.69
12. Condition	31	227	2.65%	0.65
13. Engineering	29	211	2.43%	0.66
14. Possibility	18	132	1.55%	0.65
15. Efficiency	53	290	1.25%	0.87
16. ICT	16	111	1.16%	0.69
17. Cloud Computing	17	102	0.70%	0.79
18. Sustainability	20	111	0.52%	0.86
19. Production Process	44	216	0.21%	0.97
20. SME	32	158	0.18%	0.97
21. Additive Manufacturing	16	60	-0.55%	1.27
22. Consumer	16	53	-0.78%	1.44

23. Acquisition	14	28	-1.30%	2.38
24. Industrial Robot	21	60	-1.35%	1.67
25. Competitiveness	39	145	-1.37%	1.28
26. Exchange	17	38	-1.44%	2.13
27. Supply	18	42	-1.47%	2.04
28. ICTS	13	14	-1.61%	4.43
29. High Level	17	30	-1.71%	2.70
30. Digital Service	**11**	**0**	**-1.76%**	**no result**
31. GVCs	**11**	**0**	**-1.76%**	**no result**
32. GDP	**14**	**11**	**-1.87%**	**6.07**
33. Output	19	34	-1.90%	2.67
34. Policymaker	**12**	**0**	**-1.92%**	**no result**
35. Support	38	123	-1.95%	1.47
36. Manufacturing	125	537	-1.98%	1.11
37. Trouble	**13**	**0**	**-2.08%**	**no result**
38. Training	38	114	-2.25%	1.59
39. Creation	37	106	-2.36%	1.66
40. Chemical	**15**	**0**	**-2.40%**	**no result**
41. R & D	19	17	-2.47%	5.33
42. Income	**16**	**0**	**-2.56%**	**no result**
43. Uncertainty	29	60	-2.62%	2.31
44. Machine	118	484	-2.64%	1.16
45. Capital	**17**	**0**	**-2.72%**	**no result**
46. Introduction	18	0	-2.88%	no result
47. Technological Change	**18**	**0**	**-2.88%**	**no result**
48. Robotic	34	76	-2.89%	2.13
49. Competition	27	42	-2.91%	3.07
50. Policy Maker	**19**	**0**	**-3.04%**	**no result**
51. United States	**22**	**12**	**-3.11%**	**8.74**
52. Bank	**20**	**0**	**-3.19%**	**no result**
53. New Material	**20**	**0**	**-3.19%**	**no result**
54. Technology Diffusion	**20**	**0**	**-3.19%**	**no result**
55. FDI	23	12	-3.27%	9.14
56. Standard	76	263	-3.33%	1.38
57. Future Production	**21**	**0**	**-3.35%**	**no result**

58. New Production Technology	**21**	**0**	**-3.35%**	**no result**
59. Employment	31	45	-3.45%	3.29
60. Manufacturing Sector	29	35	-3.46%	3.95
61. Incentive	**22**	**0**	**-3.51%**	**no result**
62. Bio	**23**	**0**	**-3.67%**	**no result**
63. Stock	**25**	**0**	**-3.99%**	**no result**
64. Revolution	54	131	-4.24%	1.97
65. Labor	31	20	-4.28%	7.39
66. Foresight	**27**	**0**	**-4.31%**	**no result**
67. Regulation	**34**	**31**	**-4.39%**	**5.23**
68. Robot	69	193	-4.56%	1.71
69. Diffusion	**29**	**0**	**-4.63%**	**no result**
70. Price	**29**	**0**	**-4.63%**	**no result**
71. Nanotechnology	**32**	**12**	**-4.71%**	**12.72**
72. NPR	**31**	**0**	**-4.95%**	**no result**
73. Worker	**66**	**165**	**-5.02%**	**1.91**
74. Adoption	63	138	-5.44%	2.18
75. Science	64	131	-5.84%	2.33
76. Job	**56**	**69**	**-6.63%**	**3.87**
77. 3D Printing	51	43	-6.71%	5.66
78. Export	**42**	**0**	**-6.71%**	**no result**
79. Demand	103	269	-7.44%	1.83
80. G20	**47**	**0**	**-7.51%**	**no result**
81. Institution	**47**	**0**	**-7.51%**	**no result**
82. Share	**47**	**0**	**-7.51%**	**no result**
83. China	**72**	**112**	**-7.75%**	**3.07**
84. India	**49**	**0**	**-7.83%**	**no result**
85. Automation	**110**	**283**	**-8.09%**	**1.85**
86. Trade	**59**	**22**	**-8.69%**	**12.79**
87. New Technology	**83**	**118**	**-9.31%**	**3.36**
88. Skill	**100**	**187**	**-9.71%**	**2.55**
89. Risk	**91**	**144**	**-9.71%**	**3.01**
90. Next Production Revolution	**64**	**0**	**-10.22%**	**no result**
91. Productivity	**105**	**181**	**-10.71%**	**2.77**
92. Policy	**88**	**99**	**-10.74%**	**4.24**

93.	**Economy**	**117**	**215**	**-11.49%**	**2.60**
94.	**Firm**	**88**	**62**	**-11.98%**	**6.77**
95.	**Government**	**90**	**63**	**-12.27%**	**6.81**
96.	**Material**	**78**	**0**	**-12.46%**	**no result**
97.	**Growth**	**102**	**90**	**-13.28%**	**5.41**
98.	**Production**	**225**	**602**	**-15.78%**	**1.78**
99.	**Market**	**167**	**195**	**-20.15%**	**4.09**
100.	**Country**	**248**	**194**	**-33.12%**	**6.10**

[a] Institutional output measurement: n = 626; academic article sample: n = 2,986 articles.

[b] The 'emphasis discrepancy' is calculated by subtracting the proportion of all occurrences in institutional output occurrences referencing a term from the proportion of all scholarly publications referencing the term.

[c] The 'emphasis ratio' is the division of the proportion of institutional outputs referencing each term by the proportion of scholarly articles referencing that term.

The first twenty terms demonstrated in Table 7 are overemphasized in academic research compared to industry-oriented outlets. These include the emphasis on *internet, IoT, IIoT, smart factories, production processes, knowledge, ICT,* and others. Terms 21-100 demonstrate the ascending discrepancy of topics emphasized in industry-related outputs vs scholarly outputs. We have highlighted the topics that have a specific divergence between the source streams in bold. As such, there are three themes that particularly stand out when analysing the discrepancies.

First, industry-related literature is highly concerned with policymaking, country competitiveness, and integration of the global value chains. The policymaking-related theme is highlighted by discrepancies in topics including *policymaking, policy makers, government, institution, regulation, policy, foresight,* and *uncertainty*. These mainly stem from the supranational-organisational reports and concerns for the global development and societal well-being (United Nations Industrial Development Organization, 2016; World Bank, 2018; World Economic Forum, 2018). Narrowing down the global development concerns, country and region competitiveness as well as development are high on the discussion within the selected reports (European Commission, 2017; OECD, 2017; WEF & A.T. Kearney, 2018). This is highlighted by divergences in terms including *G20, United States, China, India*, and *Country*. Finally, this theme discusses opportunities and challenges for firms, industries and countries in the 4IR driven by globalisation (United Nations Industrial Development Organization, 2016; World Economic Forum, 2018; World Economic Forum & Bain & Company, 2018). The divergence is highlighted by terms including *global value chains (GVCs), trade, foreign direct investment (FDI), economy,* and *export.*

The second major dissonance between the literature streams is in commercialising and managing competitiveness out of the production revolution. Indeed, the reports, especially the Big 4 accounting firms and the Big 4 consultancies, are very much targeted at organisations and institutions to create value out of the current technological shifts. The discrepant terms include *income, consumer, acquisition, competitiveness, output, R&D, income, capital, competition, bank, incentive, price, share, productivity, market,* and others. Industries that have been quick on the uptake of technologies either report or expect cost reductions in production, increases in quality, increased revenues, and increased customer satisfaction (Ernst & Young, 2018; McKinsey & Company, 2016; PricewaterhouseCoopers, 2016).

Finally, the third theme that is highly prevalent in institutional reports is a generic technological change and its implications for the workforce, firms, and states. While the academic literature is quite specific as to the positioning of the 4IR, the reports tend to generalise and simplify the recent developments into the next production revolution (Boston Consulting Group, 2016; KPMG, 2018b; OECD, 2017; World Bank, 2018). The impact for firms and countries is evident from such terms as *new production technology, technological change, technology diffusion, future production, new production revolution (NPR),* and *new technology*. The impact on the workforce is highlighted by topics such as *training, labor, worker, employment, job, skill,* and other related terms.

There are three themes that industry-related outlets tend to emphasise in greater detail that include policy making implications, the return on investment discussion, and the implications of technological developments on the workforce, firms, and policy-makers. Researchers should pay closer attention to the discrepant topics as well as the two maps provided for both, the academic and industry-related, output streams.

5.1. Proposed definition of I4

Having analysed the three clusters of the academic literature and the divergent themes of the practitioner oriented outlets through the systems perspective we can identify the premises of I4 to propose a unified definition that can drive research further. Our definition of Industry 4.0 is the integration of networking capabilities to machines and devices that allows seamless collaboration between the digital and the physical ecosystems for increased efficiencies in the organisational value chains that transforms industries and the society for an increased level of productivity and efficiency.

It is beyond the scope of this paper to individually analyse each technological advancement that drives the 4IR wave, the references to CPS, (I)IoT, human-controlled robotics, smart …, big data, cloud computing, sensors, autonomous devices, and others are abound in the growing literature. Also, we do note that technologies driven by AI, mass personalization instead of the current mass customisation, synthetic biology, internet of everything (IoE), digital ecosystem, and complex adaptive systems are being tested and even applied by organisations and states, are not part of I4 or the 4IR, these fall in the premises of Industry 5.0 (see for example, Clim, 2019; Haleem, Javaid, & Vaishya, 2019; Javaid & Haleem, 2019; Ozkeser, 2018; Sachsenmeier, 2016; Skobelev & Borovik, 2017).

6. Conclusion and future directions for research

The systems view of the academic literature of I4 and the 4IR reveals the broad division into three large domains. This analysis provided the holistic systems view of the majority of the academic research represented by 2,986 documents on this highly important topic. When viewing I4 through the systems perspective, we can easily identify the emergent properties of I4 in that the system is consistent of sub-systems including CPS, IoT, digital twins, automation, big data, sensors, etc., which by themselves are individual systems (that, again, can be divided into sub-systems) within the holism of I4. I4 by itself is a sub-system of the larger system of industrialisation. As such, these are the multi-layers that constitute the emergent nature of I4. By taking a step back and providing a birds-eye view of the scholarship and industry insights we immerse into systems perspective of holism that looks at the entirety of the system and on ensuring parts communicate and control each other to serve the purposes of the whole (Jackson, 2003, 2006). Finally, we see the interaction of the I4 system with the environment including industries, economies, societies, agents. Without this interaction, which is referred to as the open system, it would not be viable for I4 to exist and evolve. We thus studied I4 from a systems perspective to demonstrate the entirety of the system, the sub-systems within, the interaction between the sub-systems, and the evolution of the industrial development.

Researchers will benefit from a detailed and contextualised view of what the scholarship has to offer. This holistic representation will be helpful in combining the knowledge of researchers in this field and these results to overcome boundaries between disciplines. Together with the offered definition in Section 5.1. and the comprehensive view of the scholarship we aim to help move the research forward.

We believe there are a number of opportunities for further research that become evident when approaching the topic from the systems perspective as we have done in this paper. Although it has to be noted that the depicted institutional reports are aimed at non-technical readers (including shareholders, general management, etc.), there are still a number of take away lessons that can bring the two streams closer together and guide research further.

The first major direction is research into return on investment of firms and may be even countries. As seen from the comparative table, the research into this theme is virtually non-existent with common terms including *income, capital, bank, incentive, stock,* and *price* have not occurred 10 times or more in the entire academic documents results. The second direction is in investigation of wider economic and policy benefits for countries and regions as a result of technological advancements in the context of the 4IR or next industrial revolution. The third direction is in studying the competitive dynamics emerging within the context. Indeed, strategic management has been slow in the uptake of technological advancements studied in this context and applying these to study competitiveness of firms. The fourth direction is in studying particular technologies that have been left out of the discussion in the context of the 4IR. These included, but are not limited to, additive manufacturing and its value, industrial robotics, digital services, and nanotechnology, as highlighted by the comparative table. The fourth direction may include studying the impact of the 4IR on the workforce, as highlighted by the discrepancies in the third theme, above. Finally, the fifth direction for future research is studying regulatory frameworks and the implications. How to converge technological progress within the formal institutional frameworks to ensure security and safety of processes, data and people.

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