International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Industry 4.0 Frame Work Dimensions: Study

Sandhya Kumar[1], Shanti Krishnan[2], Dr. Shailesh Kumar[3]

Professor, Electronics and Telecommunication Engineering, Vidyalankar Polytechnic, Mumbai
sandhya.kumar[at]vpt.edu.in

Professor, Electronics and Telecommunication Engineering, Vidyalankar Polytechnic
shanti.krishnan[at]vpt.edu.in

Shri Jagdishprasad Jhabarmal Tibrewala University
shaileshkumar1610[at]gmail.com

Abstract: ***In recent years, there has been dynamic changes in the industrial environment as a result of further innovations called Industry 4.0 (I.4.0), especially in the field of digital technology and manufacturing. Despite numerous examples of the implementation of Industry 4.0 in enterprises, there is no general framework for the implementation of Industry 4.0 with a detailed schedule. Researching the ways of implementing Industry 4.0 is still a current and unexplored area of research. In this paper aims at studying various learning factories around the world and to classify dimensions for the framework which can be further aligned to design the framework of Industry 4.0***

Keywords: Industry 4.0, Dimensions, Learning factory

1. Introduction

In the last few years, the global industrial environment has changed deeply due to successive technological developments and innovations in manufacturing processes. The new concept is called Industry 4.0 (abbreviation: I 4.0) [1]. Industry 4.0 is a strong combination of operational technology (OT) and information technology (IT) in production. The industry 4.0 concept is the result of the technological progress of the Fourth Industrial Revolution [2]. The term "Industry 4.0" was introduced in 2011 by Henning Kagermann, professor of physics and former president of the SAP board, and evolved into a strategy for the development of German industry [3]. Industry 4.0 uses the technical achievements of the Third Industrial Revolution, in the area of the degree of automation and digitization of production already achieved [4]. Industry 4.0 is a technological system with many innovations called Technology 4.0: robotics and automation, 3D printing, collaborative robots (cobots), cloud computing and Internet of Things to be implemented on a large scale in smart factories in the future [5]. Industry 4.0 is based on cyber physical systems with the Internet of Things—IoT and Internet of Services—IoS [6], and Big and Mining Data [7]. The intensive development of CPPS is heading towards the development of artificial intelligence, i. e., self - improving devices and objects, on an increasing scale [8]. Technology 4.0 builds intelligent production processes that are able to independently exchange information, trigger actions and control each other [9]. Industry 4.0 is the path to greater competitive advantage for businesses [10], also SMEs [11].

Globalization and resource scarcity have drastically increased the intensity of competitive manufacturing, forcing companies to deliver on higher expectations with less staff and minimal resource usage. This situation has ushered forth a new industrial revolution, Industry 4.0.

This new revolution, analogous to coined phrases such as smart factories and the internet of things, has given way to exponential advances in technologies. The implementation of these technologies, should in theory, enable firms to reduce the negative impact of their operations on their triple bottom line and improve efficiencies. However, whilst the implementation of these technologies provides seeming and logical improvements; how to implement them, with what, and where is still largely unclear and can lead to total abolishment due to the lack of knowledge. A decision support framework is proposed in this thesis for aiding companies, specifically small and medium enterprises (SMEs), and learning factories in their implementation efforts towards Industry 4.0.

2. Industry 4.0

Industry 4.0 is a term for the current trend of automation and computerization in manufacturing technologies. It is a very popular and extensively discussed topic in social groups, industry as well as in the academic field. Since its first mentioning in 2011 by the German federal government, it has become a top priority for many research centers, universities and companies, especially in Germany [12] [32]. The reason being, is that it has been estimated that the benefits of Industry 4.0 will contribute as much as e78 billion to the German gross domestic product by 2025 [13] [12]. With the popularity of this concept as a research topic, and the fact that for the first time in history an industrial revolution is being predicted a priori, academics and practitioners have obscured the true meaning and definition of Industry 4.0 [14].

3. Industry 4.0 Main Components

A literature analysis performed in 2015 by Hermann et al. [15] [34], in an attempt to define Industry 4.0, provided quantitative evidence for identifying the central aspects of Industry 4.0. The first step was to identify key words associated with the concept of Industry 4.0. For this, Hermann et al. [15] [34] included the English translation, Industry 4.0 in addition to its German counterpart Industry

4.0. The authors searched six distinct databases (CiteSeerX, ACM, AISeL, EBSCOhost, Emerald Insight, and Google Scholar), emerging with the results shown in Table.1.

Table 1: Industry 4.0 keyword associations [27]

Search Term	No. of Publications in which search term occurred
Cyber - physical systems	46
Internet of things	36
Smart factory	24
Internet of Services	19
Smart product	10
Machine - to - machine	8
Big data	7
Cloud	5

Following their identification of key associative words, Hermann et al. [15] identified 51 publications that addressed industry 4.0. Using these 51 publications they performed a backwards and forwards search of each publication and aggregated the results, as shown in Table 2. After further consideration, they narrowed the list to four main components of industry 4.0, by ruling out the remainder of the list. The authors decided that machine - to - machine and smart products are not considered as independent industry 4.0 components. In similar fashion, in line with Bauernhansl et al [13], Hermann et al. [15] regarded big data and cloud computing as data services which utilize the data generated by industry 4.0 instances, and not as independent industry 4.0 components.

Table 2: Industry 4.0 components [27]

Keyword 1	**Keyword 1**
Industry 4.0	**Cyber - physical systems**
	Internet of things
	Smart factory
	Internet of Services
	Smart product
	Machine - to - machine
	Big data
	Cloud
	M2M (machine - to - machine

4. Design Principals

According to Hermann et al. [15], there are six fundamental design principles that are evident in any Industry 4.0 environment. These design principles are not only evident in Industry 4.0 environments, but also assist companies in identifying and implementing Industry 4.0. Kagermann et al.]16] in a paper titled “Recommendations for implementing the strategic initiative Industry 4.0”, do not discuss specific design components for Industry 4.0 as Hermann et al. [15] does, but do list general guidelines for implementing Industry 4.0 by providing use cases examples of what can or should be done to achieve or implement Industry 4.0. These guidelines are on a more companywide strategic level as they provide support and detail to achieving the vertical and horizontal integration of companies and supply chains. . The design principles outlined by Herman et al. [15], are supported by Sundmaeker et al. [17], except for the explicit importance made of standardisation, which has lead to the inclusion of a seventh design principle. Seven design principals are given below

1) Interoperatebility
2) Virtualisation
3) Decentralisation
4) Real - time capability
5) Service orientation
6) Modularity
7) Standardisation

The seven design principles introduced above by various authors are a generalized, yet practical and important part of implementing or designing for Industry 4.0. All seven principles overlap, in the sense that one cannot exist in an Industry 4.0 environment without the other. Each of the principles form a core part of the definitions of the main components of Industry 4.0 and Successful implementation of Industry 4.0, adhering to the design principles will have great effects on a company and its supply chain.

5. Learning Factories

According to Abele et al. [18], a learning factory is a factory environment, where all processes and technologies inside it are based on real industrial sites, more specifically SMEs. Learning factories provide a reality - conform production environment as a learning environment where only minor abstractions are possible, providing participants with a practical learning experience.

Evolving learning factories

According to NIL [19], various projects on innovative learning factories were going on and their goal is to significantly contribute to an internationally recognized standard of the learning factory, so as to support international mobility enabling innovative educational programs that will enhance the quality of existing and future learning factories.

The rapid increase of funding made available and the high success of the learning factories stimulated the academic world and became a topic of general conversation, which lead to its popularity as a research topic. The numerous research efforts have produced a variety of topics, ranging from the validation of the successes of learning factories, to design and implementation methodologies, and improvement and expansion processes. Work done by Cachay et al. [20], for example, was aimed at investigating the learning success of engineering students in learning factories. The results showed increased learning successes of over 20% by control and experiment groups writing pre and post tests. Other works, such as by Matt et al. [22], and Chachay and Abele [21]sought to validate the practicality of the learning factory concept by incorporating it into lectures, as well as providing industry partners from SMEs the opportunity to qualify and further train their personal.

Work done by the above mentioned authors showed that the concept of the learning factory was promising, but there was a lack of literature regarding the setting up of learning factories and defining what is to be taught within the learning factory. Abele et al. [18], then proposed a seven dimension morphology for defining a learning factory.

What is being taught in learning factories

Learning factories implemented around the globe, can be generalised into three forms, cate - gorised in terms of their main teaching objectives. To date, learning factories are focused on teaching lean principles, resource efficiency and management and organisation [23. These three objectives are discussed in further detail in the sections that follow.

Learning factories for lean principles

As previously stated, since the inception of learning factories, their popularity has grown around the world. The Penn State University alone has already conducted over 1800 projects with industry partners [24]. At first, learning factories concentrated mainly on the aspects of lean management and process improvement [38], which can be contributed to the work of the Toyota manufacturing company, evident in Liker [25], as it was the pioneering work of waste removal and manufacturing management shows the strategic learning concepts, that are converted from theory into practice at the Chair of Production Systems (LPS) learning factory at the Ruhr - University of Bochum learning factory. This strategic learning concept is aimed at teaching the lean principles developed by the Toyota manufacturing company

Learning factories for resource efficiency

The rapidly changing industrial environment and the demands created by Industry 4.0, outlined in Chapter 2, has led to the rising significance of resource efficiency [23]. According to Kreimeier et al. [23], this has caused the need to include resource efficiency training into learning factories. The Ruhr - University of Bochum has developed a didactic concept of sensitization for the design of energy - and - resource efficient production processes [23]. This learning factory for resource efficiency (LRE), addresses strategic concepts according to the model shown in Figure 2, for the identification and assessment of process - inherent potentials and how participants can transfer concepts learnt to their own company and processes.

The Institute of Production Management, Technology and Machine Tools (TU Darmstadt) had one of the earliest implementations of a learning factory in Europe [18, 20]. This learning factory started off mainly as a learning factory for teaching lean principles. Since then, it has been developed into a more holistic learning factory, including research efficiency as part of the learning factory package. Kreimeier et al. [23]describe how the LRE operates. In this description, the authors notes that the aim of the exercises performed in this LRE is to understand the information path from the signal to the finished key performance indicator (KPI), so that production processes can be tracked and optimized using the measured data. They further explain that during the data analysis step in the LRE, data is collected and analyzed from the installed measurement sensors. The data collection then makes it possible to directly evaluate the processes, but the valid distribution of sensors and allocation of measuring points is an essential step to create a survey space and to build up KPIs [15, 23]. For this reason, this workshop/LRE teaches the participants how to acquire essential data and how to develop well - based KPI's and optimization measures [23].

Learning factories for management and organisation

The third accepted and taught inclusion under the topics covered in learning factories is management and organization, as described by Wagner et al. [26]and Kreimeier et al. [23]. The aim of this topic, according to Wagner et al. [26], is to show that the education of trainees in the field of management of workers' participation, can reduce the overall operating costs of projects. Hence the underlying concepts taught, is that of the importance and value of social communicative and interdisciplinary skills [26]. The strategic concept developed by Wagner et al. [26] as shown in Figure 2.18 is the management and organizational skills that are mainly focused on in this specific learning factory.

Learning factory for management, organization and workers' participation. After an analysis of the state of the art on Industry 4.0, as well as learning factories, it becomes evident that such learning environments can provide a cost efficient teaching playground for industry partners looking to implement Industry 4.0 (amongst many other things). The idea of showcasing Industry 4.0 in the learning factory, is by no means a method to replace what is currently being taught in learning factories, but rather to provide an enhancement of such environments, analogous to how Industry 4.0 promises to enhance current manufacturing environments and methods in industry.

Whilst literature provided a thorough background and understanding of Industry 4.0 and learning factories, no clear framework exists for combining the two. Although general methodologies for designing and developing learning factories do exist, none provide the necessary implementation steps for incorporating Industry 4.0. It is thus the aim of this thesis to develop such a framework which will provide a clear and practical methodology for implementing Industry 4.0 into the learning factory environment. This framework shall allow for the adaptation of Industry 4.0 to enhance the relevant methods taught in the specific learning factory.

Understanding learning factories

In order to fully understand learning factories, a study was done on various learning factories all around the world. The research

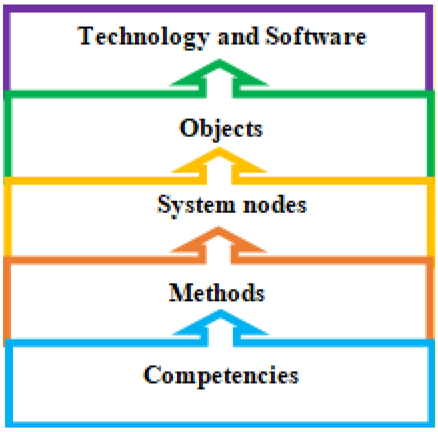

Figure 1: Initial dimensions for framework (from bottom to up)

study helped identify the core competencies that are being taught in learning factories throughout the world. Work done by Kreimeier et al. [23] and Abele et al. [18] list courses that are being taught in learning factories. These courses were translated into competencies taught in learning factories. These competencies form the first level of the framework. Together with the research study, learning factory visits allowed the identification of groups of elements typically found in learning factories and SMEs, since learning factories are representations of SMEs. These groups of elements were used to classify dimensions for the framework.

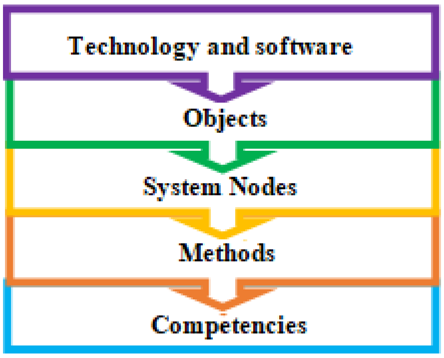

Figure 2: Initial dimensions for framework (from top to bottom)

The first dimension contains those competencies taught in learning factories which are relevant to Industry 4.0. A competency is defined in this project as the development of a targeted, industry related ability, which can be taught through various applications. The second dimension, methods, is defined as comprising of multiple objects and system nodes that, together form a function. This leads to the third dimension, system nodes, which are user instances which can be altered or changed in some manner so as to serve a purpose or function within a system process. System nodes are the culmination of smaller objects. The fourth dimension are these objects, which are the smallest physical elements that can be part of, enhance or alter a process function, but cannot be a process function on their own. The fifth and final dimension is technologies and software. Technologies and software are defined as the requirements for objects and system nodes to function properly.

The dimensions were aligned in such a way, as seen in Figure 1, that it reads from the bottom up as: Certain competencies can be taught through certain methods using certain system nodes, containing specific objects, which are enabled by specific technologies and software. From the top down, (Figure 2) the order would read: Which technologies, software and objects can be applied to certain system nodes to obtain specific methods that allows the teaching of certain competencies in a learning factory. In an SME, it would stop at the methods dimension, as a specific method would be the implementation desired, and no competencies are taught.

Gaining Insight into Industry 4.0

Numerous benefits that could be obtained from the incorporation of Industry 4.0, which consolidates current technologies, software, objects and methods into packages. As such, incorporating a new dimension, industry 4.0 applications, into the framework between the competencies and methods dimensions, enables the framework to capture these packages, and make them attainable. This additional dimension formed a link between the competencies taught dimension and the rest of the dimensions, as can be seen in Figure 3.

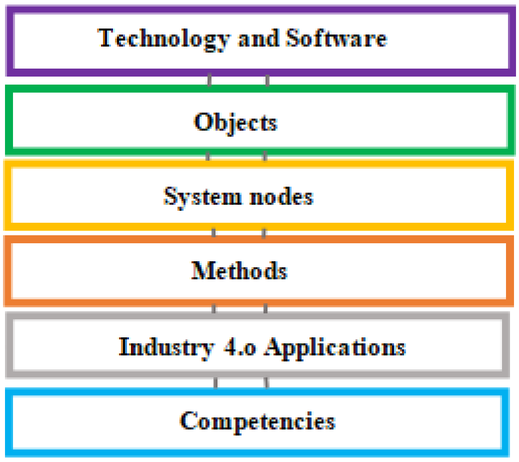

Figure 3: Final dimensions for framework

6. Conclusion

After Studying various learning factories provided us with the insight to identify six dimensions required for implementing Industry 4.0. Each dimension was filled with elements pertaining to Industry 4.0, providing tangible criteria for its implementation.

References

[1] Kagermann, H.; Wahlster, W.; Helbig, J. (Eds.) Recommendations for Implementing the Strategic Initiative Industrie 4.0: Final Report of the Industrie 4.0 Working Group. Industrie 4.0: Mit dem Internet der D

[2] Kagermann, H.; Helbig, J.; Hellinger, A.; Wahlster, W. Recommendations for Implementing the Strategic Initiative Industry 4.0: Securing the Future of German Manufacturing Industry. Final Report of the Industry 4.0 Working Group Forschungsunion.2013. Available online: https: //www.din. de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations - for - implementingindustry - 4 - 0 - data. pdf (accessed on 2 February 2020).

[3] Kagermann, H.; Wahlster, W.; Helbig, J. Final Report of the Industrie 4.0 Working Group; Acatech - National Academy of Science and Engineering: München, Germany, 2013. Available online: https: //en. acatech. de/publication/recommendationsfor - implementing - the - strategic - initiative - industrie - 4 - 0 - final - report - of - the - industrie - 4 - 0 - working - group/ (accessed on10 January 2020).

[4] Kagermann, H. Change through Digitization—Value Creation in the Age of Industry 4.0. In Management of Permanent Change; Springer: Berlin/Heidelberg, Germany, 2015.

[5] Schuh, G.; Potente, T.; Wesch - Potente, C.; Hauptvogel, A. Sustainable Increase of Overhead Productivity due to CyberPhysicalSystems.

Availableonline: https: //www.sciencedirect. com/science/article/pii/S2212827114006453 (accessed on10 February 2021). [CrossRef]
[6] Haller, S.; Karnouskos, S.; Schroth, C. The Internet of Things in an Enterprise Context. In Future Internet Symposium; Springer: Berlin/Heidelberg, Germany, 2008; pp.14–28.
[7] Oks, S. J.; Fritzsche, A.; Möslein, K. M. An Application Map for Industrial Cyber - Physical Systems. Ind. Internet Things 2017, 62, 21–45.
[8] Bauernhansl, T.; Hompel, M.; Vogel - Henser, B. Industrie 4.0 in Produkten, Automatisierung und Logistik; Springer Fachmedien: Wiesbaden, Germany, 2014.
[9] Brettel, M.; Friedrichsen, N.; Keller, M.; Rosenberg, M. How virtualization, decentralization and networkbuilding change themanufacturing landscape. An Industry 4.0 Perspective. Periodical 2014, 8, 37.
[10] Vrchota, J.; Volek, T.; Novotná, M. Factors Introducing Industry 4.0 to SMES. Soc. Sci.2019, 8, 130. [CrossRef]
[11] Moeuf, A.; Lamouri, S.; Pellerin, R.; Tamayo - Giraldo, S.; Tobon - Valencia, E.; Eburdy, R. Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. Int. J. Prod. Res.2020, 58, 1384–1400. [CrossRef]inge auf dem Weg zur 4. Industriellen Revolution; VDI - Nachrichten: Frankfurt, Germany, 2011.]
[12] Gregor, M., Matuszek, J., Medvecky, S. & Stefanik, A. (2009). Digital factory. Automation, Mobile Robotics and Intelligent Systems, 3, 123–132.
[13] Gregor, M., Matuszek, J., Medvecky, S. & Stefanik, A. (2009). Digital factory. Automation, Mobile Robotics and Intelligent Systems, 3, 123–132.
[14] Bauer, W., Schlund, S., Marrenbach, D. & Ganschar, O. (2014). Indus - try 4.0: Volkswirtschaftliches potenzial fu¨r Deutschland. Tech. Rep. TR 2014 - 1, Fraunhofer Institute of Technology, Hansastrassse 27c, Munich (MU).
[15] Hermann, M., Pentek, T. & Otto, B. (2015). Design principles for Industrie 4.0 scenarios: A literature review. Tech. Rep. TR 2015 - 01, Technical university of Dortmund, Emil - Figge - Strasse 72, Dortmund (DTM).
[16] Kagermann, H., Wahlster, W. & Helbig, J. (2013). Recommendations for implementing the strategic initiative Industry 4.0. Tech. rep., Acatech National Academy of Science and Engineering, Lyoner Strasse 9, Frankfurt/main (FRA).
[17] Sundmaeker, H., Guillemin, P., Friess, P. & Woelffle´, S. (2010). Vision and challenges for realising the Internet of Things, vol.20. EUR - OP.
[18] Abele, E., Mettermich, J., Tisch, M., Chryssolouris, G., Sihn, W., El - Maraghy, H., Hummel, V. & Ranz, F. (2015). Learning factories for research, education, and training. CIRP, 32, 1–6.
[19] ESB BUSINESS SCHOOL REUTLINGEN UNIVERSITY (2014). NIL Network Inno - Vative Learning Factories. Http: //Www.Esbbusinessschool. De/En/Research/Research - Activities/Nilnetworkinnovativelearningfactories/, [Accessed: 9 March 2016].
[20] Cachay, J., WENNEMER, J., ABELE, E. & Tenberg, R. (2012). Study on action - orientated learning with a learning factory approach. In International Con - ference on New Horizons in Education, 5, 1144–1153, Elsevier Ltd.
[21] Cachay, J. & ABELE, E. (2012). Developing competencies for continuous im - provement processes on the shop floor through learning factories–conceptual design and empirical validation. Procedia CIRP, 3, 638–643.
[22] Matt, D. T., RAuch, E. & DALLASEGA, P. (2014). Mini - factory a learning factory concept for students and small and medium sized enterprises. Procedia CIRP, 17, 178 – 183, variety Management in ManufacturingProceedings of the 47th CIRP Conference on Manufacturing Systems.
[23] PENN STATE UNIVERSITY (2012). The learning factory. http: //www.lf. psu. edu/, [Accessed: 10 March 2016].
[24] Kreimeier, D., Morlock, F., Prinz, C., Kru¨Ckhans, B., Bakir, D. C. & Meier, H. (2014). Holistic learning factories: A concept to train lean management, resource efficiency as well as management and organization improvement skills. CIRP, 17, 184–188.
[25] Liker, J. K. (2004). The Toyota way. McGraw - Hill, Two Penn Plaza, New York (NY).
[26] Wagner, P., Prinz, C., Wanno¨Ffel, M. & Kreimeier, D. (2015).
[27] http: //www.engineeringnews. c. za/printversion/industry40requiresfactories -