Populating the Dimensions of Industry 4.0 for framework development

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Abstract: The Fourth Industrial Revolution (Industry 4.0) is reshaping the small and medium scale Industry and bringing it into an intelligent manufacturing era. Emerging technologies such as, Internet of Things, big data, cloud computing, and artificial intelligence, Sensors, Bluetooth, Augmented reality, Advanced materials, Hardware specific software,3D printing have penetrated into all stages of the manufacturing life cycle and play a significant role. One of the main characteristics of Industry 4.0 is the impact of technology as an accelerant or catalyst that allows individualized solutions, flexibility and cost savings in Manufacturing processes. Results of various studies indicate that there is lack of methodology or guidance towards identifying the areas that need to be addressed in implementing Industry 4.0. this paper presents dimensions required for development of industry 4.0 framework and the connecting the dimensions for designing the framework of industry 4.0. which will help researchers to design a framework for green field Industry and Brownfield industry.
Keywords: Industry 4.0, Dimensions, green field Industry, Brown field Industry, Learning factory.

I. Introduction

The potential benefits of Industry 4.0 are widespread, from a reduction in production costs to reductions in time to market introductions of new products. Overall, it can be seen that the benefits of Industry 4.0 will have a large impact on certain sectors across world, more specifically the manufacturing sector. promising picture for the future of Industry 4.0, has been seen [1][2]. As previously mentioned, Industry 4.0 will provide benefits in a wide varying number of sectors and in significant amounts, to the companies who wish to pursue it. As such, whether to pursue an Industry 4.0 transformation should not be a debate. A suitable methodology for implementation of Industry 4.0 is however, less clear. In order to accomplish this, a framework or implementation methodology of some sort is required to steer implementation efforts. Research was performed to identify and use such a framework, but it proved fruitless, as most of the frameworks only address implementation of Industry 4.0 on meta levels, which helps organize the implementation efforts from a theoretical standpoint. Other methodologies were even less applicable, such as the reference architecture model for Industry 4.0 (RAMI4.0) which was proposed by Adolphs et al. [3]. The purpose of RAMI4.0 is to present the definitive characteristics mentioned in Chapter 2 of Industry 4.0 in a single model [3]. This, then rules out the use of the model as a framework or methodology for the implementation of Industry 4.0.

The use of simulation software and digital factory models, is useful for testing new alternatives or scenarios before implementing them in the real factory. Their use for implementation scenarios has however, proved less useful in the case of Industry 4.0, where the final state still remains latent. A simulation or digital model also does not provide companies with the necessary change in employee behaviors or [4] skills development, which was noted by companies as one of the top implementation challenges. Since Industry 4.0 also incorporates, to a large extent, new technologies or applications thereof, it is a difficult concept to simulate. A different form of testing scenarios is thus called for, since the trial-and-error costs of implementing such technological changes directly on site, would be, simply put, unaffordable. [5]

CIRP, a production engineering research organization, uses learning factories as research and testing tools for experimental work and showcasing. Such a learning factory is a small-scale factory, in which production of a product takes place, in order to showcase methods taking place in an actual factory, and provides both hands-on training for employees, but also allows for the experimental implementation of new methods without the costs of disrupting actual production lines. Learning factories are, as mentioned by Cachay et al. [6], almost risk-free tools and environments where users, which comprise of industry participants and students, can learn how industry related concepts work as well as try out new ideas. As such, the idea for this thesis was to implement Industry 4.0 concepts within learning factories so that the benefits and possibilities can be showcased to industry partners, as well as to students. This will allow students and/or companies to physically see the effects that Industry 4.0 can have on a production environment, without having to carry the costs themselves. It will allow them to experiment with various scenarios in practice, before determining the more suitable implementation for their specific case.

II. Learning Factory

According to Abele et al. [7], 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.

III. Elements of Learning Factory

Various learning factories were analyzed and studied in order to segment the individual parts that make up a learning factory. Among these learning factories were the ESB Logistics Learning Factory at Reutlingen University and Darmstadt Learning Factory in Germany, the Budapest University Learning Factory in Hungary, the Vienna Learning Factory in Austria, and the Split Learning Factory in Croatia. For the purpose of this project, the following definitions were created for the elements of a learning factory, as identified during the analyses of the various learning factories.

System nodes:

A system node is defined as a user instance which can be altered or changed in some manner to serve a purpose or function within a system process. It is the culmination of smaller objects. System nodes can be seen as a point of convergence of information, processes, materials, and resources. An example could be an assembly station in an assembly line manufacturing children’s toy. The assembly station is a convergence point of information, processes in the form assembly, materials and resources in the form of human labor.

Objects:

An object is the smallest physical element that can be part of, enhance or alter a process function (system node), but cannot be a process function on its own. Objects found in a learning factory are the smallest physical element that can function on their own. An example of an object is a low-cost micro-controller such as the Arduino [9] or any PLC.

Technologies and software:

Technologies and software refer to those required for objects and system nodes to function properly. It is somewhat intrinsic to the previous two groups, since objects can generally not function without software or technologies and in some cases, objects can even be classified as technologies themselves. It has been separated into a different group because many objects and system nodes can possess different types of technologies or software, which in turn can be altered through different programs or methods to create “new” objects.

IV. Dimensions For Industry 4.0

Studying the various Learning helped us to identify the core competencies that are being taught in learning factories through- out the world. Work done by Kreimeier et al. [10] and Abele et al. [7] 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. And further research study, allowed the identification of groups of elements typically found in learning factories and SMEs, since learning factories are representations of SMEs.

During the research the following definitions were created for the elements of a learning factory, as identified during the analyses of the various learning factories for example System nodes, Objects and Technology and software [8]. These groups of elements were used to classify dimensions for the framework.[11]

Dimension for Industry 4.0 framework

1) Competencies: competency is defined as the development of a targeted, industry related ability, which can be taught through various applications.
2) Methods: is defined as comprising of multiple objects and system nodes that, together form a function

3) System nodes: 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.
4) 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.
5) Technologies and software. Technologies and software are defined as the requirements for objects and system nodes to function properly.

Initial Dimension of framework [11]

The dimensions were aligned in such a way, as seen in Figure 1(a) 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. [11]

From the top down, figure 1(b) 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. [11]

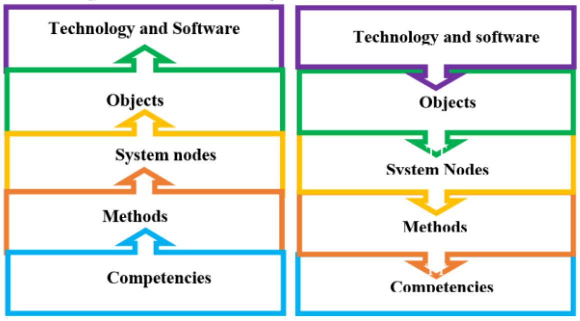

Figure 1 (a) Figure 1 (b)

Figure 1: Initial dimensions for framework.[11]

Final Dimension of framework [11]

The study highlighted some of the numerous benefits that could be obtained from the incorporation of Industry 4.0, and as mentioned in the concluding section, it can be seen as an enhancement tool for operations. Industry 4.0 then 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 2.

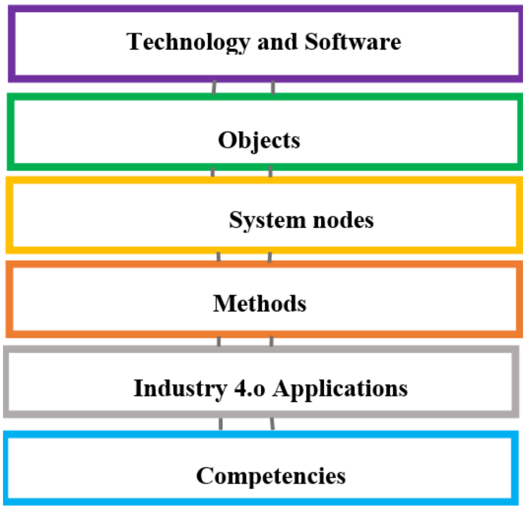

Figure 2: Final dimensions for framework [11]

V. Populating the dimensions

(a) Competencies

The competencies dimension was populated and found all the competencies that are included in this framework. As shown below

Competencies	
design for assembly	low-cost implementation
design for manufacture	visual management
ergonomic design	systems thinking
lean tools	smart logistics

Table 1: Competencies for Industry 4.0

(b) Industry 4.0 applications

A research initiative by the Fraunhofer institute [12][13] regarding classifications of Industry 4.0, in large, provided the elements for the industry 4.0 applications dimension. This dimension's development was further supported by Wan et al. [14] in a paper discussing the enabling technologies of Industry 4.0. In the Fraunhofer research initiative, however, they have labelled the industry 4.0 applications as "Industry 4.0 use cases". The definitions for Industry 4.0 use cases and Industry 4.0 applications are synonymous, although the label of "application" implies that it is a tool. all the identified Industry 4.0 applications are shown below

Industry 4.0 applications	
collaborative work	human movement optimization
digital factory	big data analytics
smart manufacturing	intelligent transport
smart products	real time work visualization

Table 2: Industry 4.0 applications

(c) Methods

The methods dimension is defined as comprising of multiple objects and systems nodes that together form a function in the production environment. It is also the first level that can be used to perform a defined purpose. As mentioned previously, for an SME the method dimension would be the desired implementation to serve a defined purpose or improvement. The methods dimension was populated using the information from the Fraunhofer research initiative, available literature, and learning factory and company visits. All the methods that were deemed applicable to the framework are given below:

Methods	
Efficient resource management	Real time work-data visualization
Additive/reductive manufacture	Product memory
KPI tracking	Synchronized material supply
Real time KPI tracking	Self-execution system (SES) Simulation
Smart work sequencing (SWS)	Standardization
Workplace organisation	Automation

Table 3: Common manufacturing methods in learning factories

(d) System nodes

A system node is defined as a user instance which can be altered or changed in some manner to serve a purpose or function within a system process. A system node is the culmination of smaller objects. The system nodes dimension serves the purpose of tailoring the framework to cater for the specific processes that occur within a learning factory or SME. The list below shows common system nodes that have been included in this framework. It is important to note that these system nodes are general and relevant to modern manufacturing i.e.

post third industrial revolution, otherwise the list of system nodes would be extremely extensive and out of context for this framework.

System nodes	
commissioning	E-kanban
warehouse	kanban
rework	palletisation station
transport system	assembly station
manufacturing machining	product design station

Table 4: System nodes for Industry 4.0

(e) Objects

Objects are the smallest physical element that can be part of, enhance or alter a process function, but cannot be a process function on its own. An example of a process function could be a picking and packing process, at a picking station, where the objects would be the transfer skid where the parts will be placed on, and the transfer trolley or conveyor where the transfer skid is placed on. System nodes are typically made up of objects. the objects identified for this framework are shown below

Objects	
Wi-Fi routers	Barcode scanner
Conveyor(mechanical/automated)	Transfer skid
Smart conveyor	Computer
Supermarket	3D printers
Programmable logic controllers (PLC)	Microcontrollers
Mechanical transfer trolley	Smart transfer trolley
Heavy machinery: CNC, lathe etc.	Robots: Stationary
Robots: light mobile	

Table 5: Objects found in learning factories

(f) Technologies / Software

Technologies and software are required for objects and system nodes to function properly. The technologies/software dimension was populated by considering each of the elements in the objects dimensions and determining what they require to function properly. The technologies and software applicable to Industry 4.0, the identified system nodes and objects are given below:

Technologies/software	
Sensors	3G/4G/LTE
Track and trace	Barcode
Bluetooth	Ethernet
Augmented reality	Wi-Fi
Advanced materials	Near field communication (NFC)
Harware specific software	Smart labels
3D printing	Open-source software (OSS)
Cloud computing	

Table 6: Enabling technologies/software

VI. Connecting the dimensions

The connections between the dimensions were determined in two separate sessions. The first iteration, consisting of five steps, was performed by individually considering each of the competencies in the competency dimension and relating them to the other dimensions.

An illustration of the first step is provided in Figure 3(a) The second step, shown in Figure 3(b), was to take each of the identified Industry 4.0 applications, from step one, and relate them to applicable methods. The third step was linking the identified methods and system nodes, shown in Figure 3(c). The fourth step was identifying which objects are required to fulfil each specific method in each specific, identified system node, as shown in Figure 3(d). The final step was to link the objects to their enabling technologies/software in terms of their other required dimensions, Figure 3€. The linking process, when visualized will give the framework of Industry 4.0.

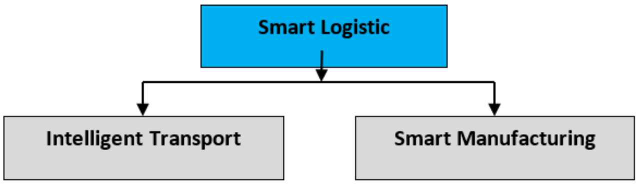

Figure 3(a): Competencies and Industry 4.0 applications

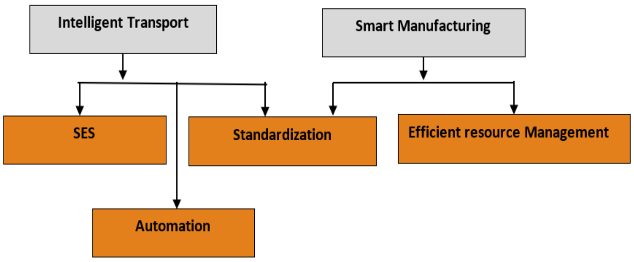

Figure 3 (b) Industry 4.0 applications and methods

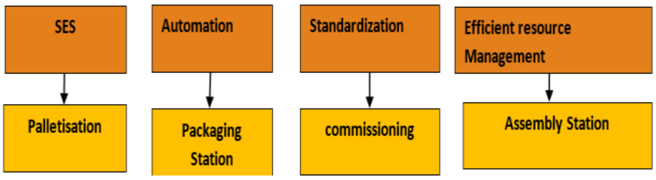

Figure 3 (c) Methods and system nodes

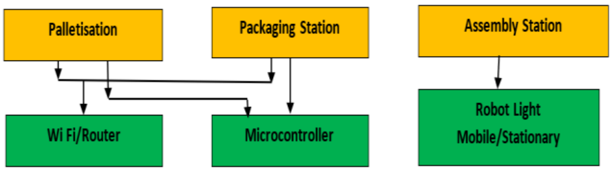

Figure 3 (d) System nodes and Objects

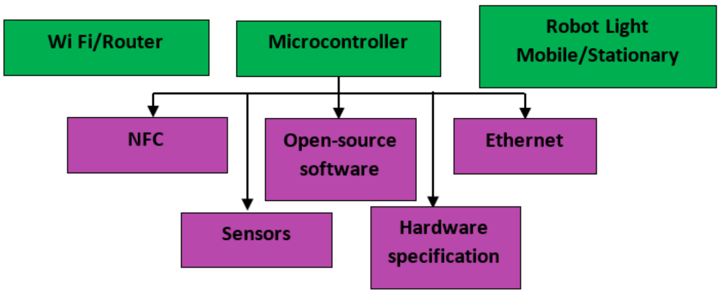

Figure 3 (e) Objects and technologies/software
Figure 3: expansion of connecting the dimensions

Above connected dimensions can be used for designing the framework of industry 4.0. It will provide decision support for complete framework, with a focus on Industry 4.0 (greenfield design), but also for the redesign of existing SMEs or learning factories, who wish to incorporate Industry 4.0 with the elements that they currently have (Industry 4.0 redesign). The third deduced application of the dimensions then, is for already existing learning factories who wish to enhance their current operations with the addition of specific Industry 4.0 applications (Industry 4.0 greenfield design).

VII. Conclusion

The above discussed elements and dimensions can be used for providing decision support for complete framework, with a focus on Industry 4.0 (greenfield design), but also for the redesign of existing SMEs or learning factories, who wish to incorporate Industry 4.0 with the elements that they currently have (Industry 4.0 redesign). And also, dimensions can be used for already existing learning factories who wish to enhance their current operations with the addition of specific Industry 4.0 applications (Industry 4.0 greenfield design).

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