Smart Manufacturing and Industry 4.0: A preliminary approach in structuring a conceptual framework

ELENI DIDASKALOU, PETROS MANESIOTIS, DIMITRIOS GEORGAKELLOS
Department of Business Administration
University of Piraeus
80, M. Karaoli & A. Dimitriou St., 18534 Piraeus
GREECE

Abstract: - Engineering concepts usually, are complex concepts, thus many times are difficult for infusing into curriculums or to be comprehensive for practitioners. A concept that still now is not fully understandable is that of Industry 4.0, an approach that increases the complexity of production systems. Nowadays production systems are facing new challenges, as physical productions systems and internet technologies are directly linked, hence increasing the complexity but also the productivity of the systems. The paper introduces an approach of visualizing the concept of smart manufacturing in the context of Industry 4.0, as the term is not clearly specified, although has attracted attention both academicians and businesses. Concept mapping is a method of capturing and visualizing complex ideas. Concept maps are graphical tools for organizing, representing and communicating complex ideas by breaking them into more key concepts. As Industry 4.0 is a factor that can boost innovation and competitiveness of business, all parties involved in shaping the strategy of an organization, should perceive the issues to be covered. Furthermore, learners must be prepared to meet these challenges and knowledge-building activities may enhance their process of learning. The paper makes an interesting and valuable contribution, by identifying key concepts within the subject of smart manufacturing and Industry 4.0, using the method of concept mapping. Taking into consideration these concepts a conceptual framework will be introduced, by using the software tool CmapTools. The map can be used as a basis for future research in constructing a more comprehensive framework and identifying the concepts that describe smart manufacturing in the context of Industry 4.0, in a more thorough manner.

Key-Words: - Industry 4.0, smart manufacturing, concept maps, CmapTools

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1 Introduction

Nowadays the digital transformation of manufacturing industry is considered vital for the competiveness of industrial and manufacturing companies. Over the last years a lot of discussion is going on, regarding technological transformation which happens at an extraordinary rate. Digitization, automation, and various information and communication technologies, are transforming not only industry, but also any sector of the economy, offering new opportunities to production processes. Advanced digital technologies are already have been used in manufacturing, but new internet and digital technologies, augmented intelligence, exponential technologies, changes the way businesses operate, transform production and manufacturing industry and define a new business environment. A term that often is used to describe these trends is Industry 4.0 [1]. The term Industry 4.0 comes from Germany ("Industrie 4.0") and was first presented at the Hannover Fair in 2011, turning on a vision of a new Industrial Revolution [2], [3]. Plattform Industrie 4.0, which is steered and led by German government, is an institution which aims to contribute to overall understanding of Industrie 4.0, as it is a complex concept and affects many and often overlapping fields of activity [4]. Innovative production processes play critical role for facilitating the full potential of industry 4.0 [5].

In United States the concept is coined as Industrial Internet and has been brought up by General Electric in late 2012, predicting many benefits on global economy [6]. In 2014 National Network for Manufacturing Innovation was established [7]. Another similar initiative was introduced in 2015 by the China Ministry of Industry and Information Technology, called 'Made in China 2025'. China's

strategic plan for developing manufacturing sector, forces investments in hi-tech manufacturing. In all these national initiatives, Integrated and Intelligent Manufacturing is prioritized and advanced manufacturing systems pushes economic development [8].

New technologies have led to automation of manufacturing, and consequently to increasing complexity of the systems. The evolution of manufacturing is focused on integration of the physical world with cyberspace to shape cyber-physical systems [9] [10]. Digital technologies and transition to a new "digital" reality change the rules of production, businesses as a whole, the workforce, and even society itself. In this context, smart manufacturing, which is the fourth industrial revolution in the manufacturing industry, increases flexibility and the ability to take preventive action (eg predicting an event before it occurs) using various IT technologies [11], also making production more intelligent and sustainable. It has to be pointed out many researchers tries to capture and define the concept of smart manufacturing, but till now there are issues to be solved10].

As mentioned, Industry 4.0 has major impact on industry and markets [12] but no a general accepted definition of smart manufacturing systems for Industry 4.0 has been introduced [13]. This study, proposes a preliminary approach in structuring a conceptual framework for smart manufacturing in the context of Industry 4.0, using concept maps methodology. Concept maps are visualization tools for organizing, representing and communicating complex ideas by breaking them into more key concepts. The framework focuses mainly to those involving in learning and teaching processes. This, in turn, may have an impact on the offered curriculum from educational bodies in the engineering field. Learning enhancement and training of future engineers has to be accelerated through new approaches and strategies for teaching and learning [14].

2 Framework

2.1 The vision of Industry 4.0

In today's world of Industry 4.0, physical objects of manufacturing systems are integrated with information systems, creating a so-called "digital twin" (or "cyber twin") of the physical world, and these advanced technologies based systems can make intelligent decisions through real-time collaboration with humans, machines, sensors, conveyers and so forth [15] [16]. The emerging cyber-physical systems (CPS) link up physical world and the virtual world (cyberspace) and in what regards manufacturing, this technological evolution can be described as the fourth stage of industrialization [17] enhancing productivity and efficiency, product quality and customer satisfaction [18].

Industry 4.0 is often compared with changes in production such as those brought about from previous industrial revolution(s) initiated by steam, electricity, oil, electronics etc [19]. According to EEF/ORACLE report the manufacturing sector is on the cusp of the 4th industrial revolution [20]. As Industry 4.0 affects business models and business processes [21], [22] companies in order to adapt in a world of rapid technological change must have a clear vision of what Industry 4.0 is.

The term "industrial revolution" is used to describe periods that complex of technological innovations turn up in a radical and important way, having high impact on society [23]. The three industrial revolutions of the past were all triggered by technical innovations: mechanization and water/steam power, electric power, automation and use of PLC and IT [24] (Fig. 1) [25]. Today industrial production is facing fundamental changes due to digital transformation, the combination of web technologies and future-oriented technologies in the field of "smart" objects (machines and products) [26]. Industry 4.0 will enable manufacturing systems to achieve high level in efficiency and productivity encompassing a big number of diverse techologies like Internet of Things (IoT), Cyber Physical System (CPS), information and communications technology (ICT) [27], [28], [29], [30]. It has to be mentioned that despite the popularity of the term, a systematic approach cannot be identified, explaining what makes Industry 4.0 a revolution. Schwab [31] points out that there are three reasons why today's transformations represent the arrival of a Fourth and distinct one: velocity, scope, and systems impact. As before, the rapid changes in technology, economy and society induced the three previous industrial revolution, the so called 4th industrial revolution, brings in changes of entire systems of production, management, and governance.

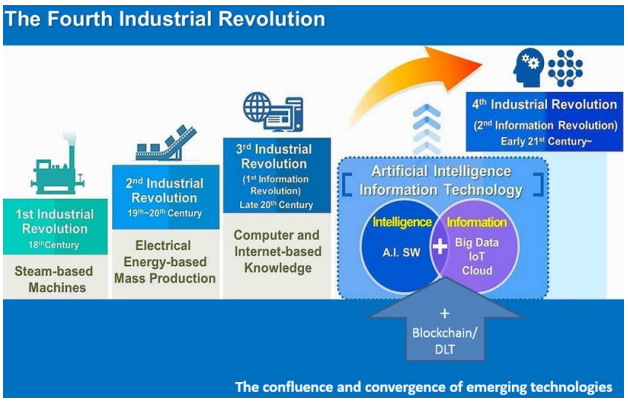


Fig. 1, A history of industrial revolutions [19] (*25*)

Industry 4.0 is a term that stands for rapid transformations in the design, manufacture, operation and service of manufacturing systems and products [32] and is getting an increasingly growing attention as, such technologies will help countries and businesses achieve sustainable growth [33]. Four main characteristics of Industry 4.0 are [34]:

- Vertical networking: use of cyber-physical production systems (CPPSs) to react rapidly to changes
- Horizontal integration: real-time optimized networks via CPPSs,
- Through engineering: synergies between product development and production systems
- Acceleration through exponential technologies: use of exponential technologies to increase autonomy

Industry 4.0 and emerging technologies have high impact on products, supply chain, customers as new business models are differentiated from traditional [35] [36]. The production in the context of Industry 4.0, involves interconnection of systems, machines and production units in order to create intelligent networks along the value chain that can operate separately and control each other in an autonomous but coherent way, in response to changes of the environment [37], [38], [39]. The nodes of such a network, are connected to a larger value-chain network that fulfils a certain customer. These nodes are known as smart factories [40], [41].

Moreover, Cyber-Physical Systems (CPS) are central to the vision of Industry 4.0, realizing a digital and intelligent factory. They are part of smart machines, storage systems and production facilities, able to exchange information autonomously [42]. Distinctive features of CPS systems are the monitoring of physical processes in industrial production, the creation of a virtual copy of the physical world and the decentralized decision making. CPSs combine computing and physical processes into a single integrated production environment, adopt cross-domain sensor sources, activate actions and control each other. At each stage of production, store and evaluate data for modeling and analysis purposes, and cover the entire production cycle [43]:

Although, there are different opinions of the specific requirements of Industry 4.0, it is a necessity to come into sight a procedure which will guide people to fulfil Industry 4.0. [44]. In Fig. 2 the nine pillars that transform industrial production and change relationships among suppliers, producers, and customers, as well as between human and machine, providing satisfying products and services are given [45], [46]:

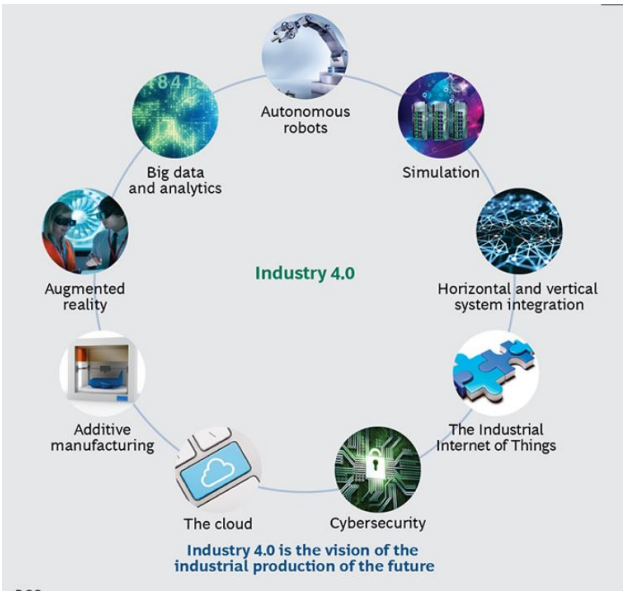


Fig. 2 The nine pillars of Industry 4.0

2.2. Smart Factoring

Industry 4.0 is bringing on forefront smart manufacturing, based on Cyber-Physical Systems (CPS) which merge physical and the virtual worlds, the Internet of Things and the Internet of Services, and will result to fusion of technical and business processes having impacts on every aspect of manufacturing companies [45], [46]. The networking of smart factories, smart products, and other intelligent production systems allow factories and production units, via CPS systems, to respond quickly and flexibly to any parameters such as demand levels, stock levels, machine errors and unforeseen delays, so as manufacturing systems are updated to an intelligent level [16]. Cyber-Physical Production Systems (CPPS) is the adoption of CPS in a smart factory and may be grouped in three layers [47]:

- Data acquisition and data processing
- Machine to machine communication (M2M)

- Human-machine interaction (HMI)

In Fig. 3. the Toyota Production System that integrates various principles and is supported by Industry 4.0 technologies is given,

	Data Acquisition and Data Processing				Machine to Machine Communication (M2M)		Human-Machine Interaction (HMI)	
	Sensors and Actuators	Cloud Computing	Big Data	Analytics	Vertical integration	Horizontal integration	Virtual Reality	Augmented Reality
5S	+	+	+	+	+	+	++	+++
Kaizen	+	++	+++	+++	+++	+++	+++	+++
Just-in-Time	++	++	+++	+++	+++	++	+	++
Jidoka	+	+++	+++	+++	++	++	+	+
Heijunka	++	++	+++	+++	+++	++	++	+
Standardisation	++	+++	+++	+++	++	++	+++	+++
Takt time	+	+	+++	+++	+++	+++	+	+
Pull flow	++	+	+	+	+++	+++	+	+
Man-machine separation	+	+	+	+	+	+	+++	+++
People and teamwork	+	+	+	+	+	+	+++	+++
Waste reduction	+	+	++	+++	+++	+++	+	+

Fig. 3. Industry 4.0 impact matrix on Toyota's production systems [47]

The "smart" factory is a flexible system that can optimize its performance, within the network of a company's digital supply chain, to adapt to new conditions in real time and to execute autonomous decisions and entire production processes and can be characterized as connected, optimized, agile, transparent, proactive. A Smart Factory adopts smart production processes and promises significant improvements in terms of efficiency and productivity indicators. Key digital technologies that enable smart factoring are connectivity, intelligent automation cloud-scale data management and analytics. "Smart" operations that may be digital transformed are [48]:

- Plant control tower.
- Intelligent automation
- Real time information management
- Energy management
- Enhanced operator
- Quality analytics and Adaptive testing
- Predictive maintenance
- Flow simulation

The main aspects

2.3. Concept maps

Concept maps are graphical tools that depict relationships between ideas, concepts, or problems [49]. Are tools for organizing ideas. A concept map has a hierarchical ''tree'' structure with super-ordinate (main topic or concept) and subordinate (key concepts) parts. Concepts, usually enclosed in circles or boxes (nodes), and the relationships between concepts indicated by a connecting line connecting the two concepts and usually having some verb description. The most inclusive, most general concepts are positioned at the top of the map with the more specific, less general concepts are arranged hierarchically below. The concept is defined as the perceived regularity in events or objects, or records of events or objects, which is determined by the label of the nodes. The map normally begins with a word or concept or phrase, which is called focus question, and represents the issue that will be solved with the use of the concept map [50]. Circles or boxes are used to define the main ideas and arrows to connect concepts. Words or phrases, such as ''leads to'', ''results from'', ''is part of'', etc., above the arrows are the linking words or phrases and explain how the concepts related to one another. Linking words/phrases and linked concepts represent the prepositional phrases [51]. The main characteristics of a concept map are given in Fig. 4

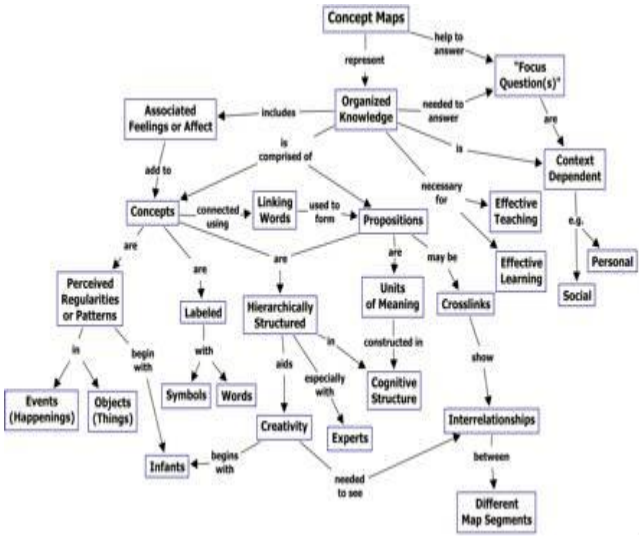


Fig. 4. Concept map that explains the basic features of concept maps [50]

Concept maps can be used to condense and simplify information in an understandable form. A researcher in a particular field may use concept maps to organize and represent knowledge of a subject. This is achievable by following two steps, described by Novak [52]: a) Identification and grouping of concepts related to the subject under consideration, and classification of these concepts in descending order of importance b) construction of the map, positioning the more general and more comprehensive concept at the top of the map, going to the most specific concept, located them at the bottom of the map, by establishing, progressively, all relationships that may appear between the relevant concepts. At the end a concept map will be created as shown in Fig. 2

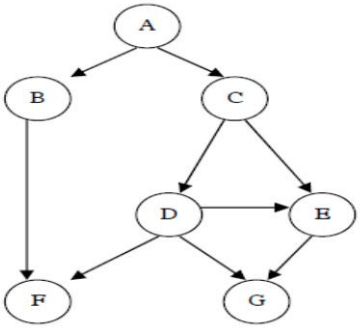


Fig. 5, An initial concept map in a specific field [52]

3 Concept map of Smart Manufacturing

The paper introduces, through literature review, a conceptual framework of Smart Manufacturing in the context of Industry 4.0, as it is a complex one and has not been fully elucidated. The authors believe that the tool of concept mapping should be used in a more extensive and systematic way in order to make "visible" the aforementioned concepts. It should be noted that this research is at an early stage, and is not structuring the scientific landscape for Smart Manufacturing and Industry 4.0. The aim of the project is to point out that conceptual mapping is a method that can be used to make engineering concepts and ideas more “transparent”.

For the construction of the concept map the following basic steps will be followed:

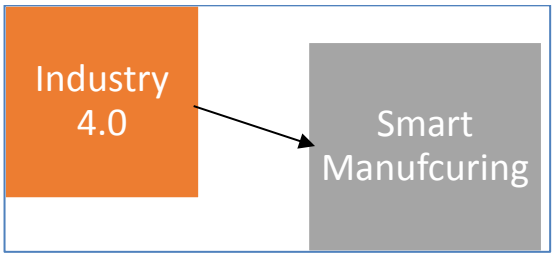
Identification of the most important concepts that will be included in the map:

Identification of the important terms or concepts of a field of knowledge or more generally with the subject to be examined.

Grouping of concepts

The concepts of the previous stage should be classified into more general, intermediate and more specific. For each concept / keyword should be identified those concepts that explain it, make it more specific and analyze it.

Drawing of the concept map: Initially the concepts should be placed at the nodes. The most general concepts appear at the top. The intermediate concepts below general concepts and at the bottom the more specific concepts. At this stage, the relationships between the concepts should be defined. A feature of the concept maps is their scalability. For the development of the concept maps of this study the scalability feature was used, based on which the connection process continues at all or most nodes of the map. As the connections progress, new nodes or concepts are added to the map to explain some of the existing concepts. The possibility of magnification continues until the user feels that the subject he wants to describe is satisfactorily explained by the map and take into account to some extent the natural acquisition of knowledge. Thus, 2 sub-maps were gradually developed,



The following two concept maps (Fig.6, Fig. 7), which were developed using the software CmapTools (https://cmap.ihmc.us/), notify main concepts regarding Industry 4.0 and Smart Manufacturing. From these maps the following propositions were createdIt has to be mentioned that new technologies offer great potential in improving the educational process [53].

4 Conclusion and Future Work

The concepts of Smart Manufacturing and Industry 4.0 are a complex ones and are used in a variety of different contexts. Industry 4.0 has extensive impacts on production systems. Smart, connected technologies are transforming how parts and thus organizations need to overlap a range of barriers and to adopt technological innovations of Industry 4.0. Industry is at a really exciting turning point, where cyber-physical systems and “Internet of Things”, give to managers the opportunity to make real time, decentralized decisions about the production ability of the manufacturing facility, hence creating a connected and digitized “smart plant”.

A tool to communicate complex concepts with many dimensions, is concept maps. Concept maps are easily created using “friendly” softwares. Concept mapping is a special technique of visualizing the relationships between different concepts. It is a common way of representing knowledge, of which it is an imaginary conceptual structure. It is also used for the emergence of these representations of those who learn by using graphs in the form of a network. Concept maps were originally used in primary and secondary education, but today their applications are constantly expanding at all levels of educational stages as well at business-level.

In this study we describe smart manufacturing in the context of Industry 4.0, using concept maps. Overall, concept mapping, should be exploited to

shed some light on the confusing subject of Smart Manufacturing in the context of Industry 4.0.

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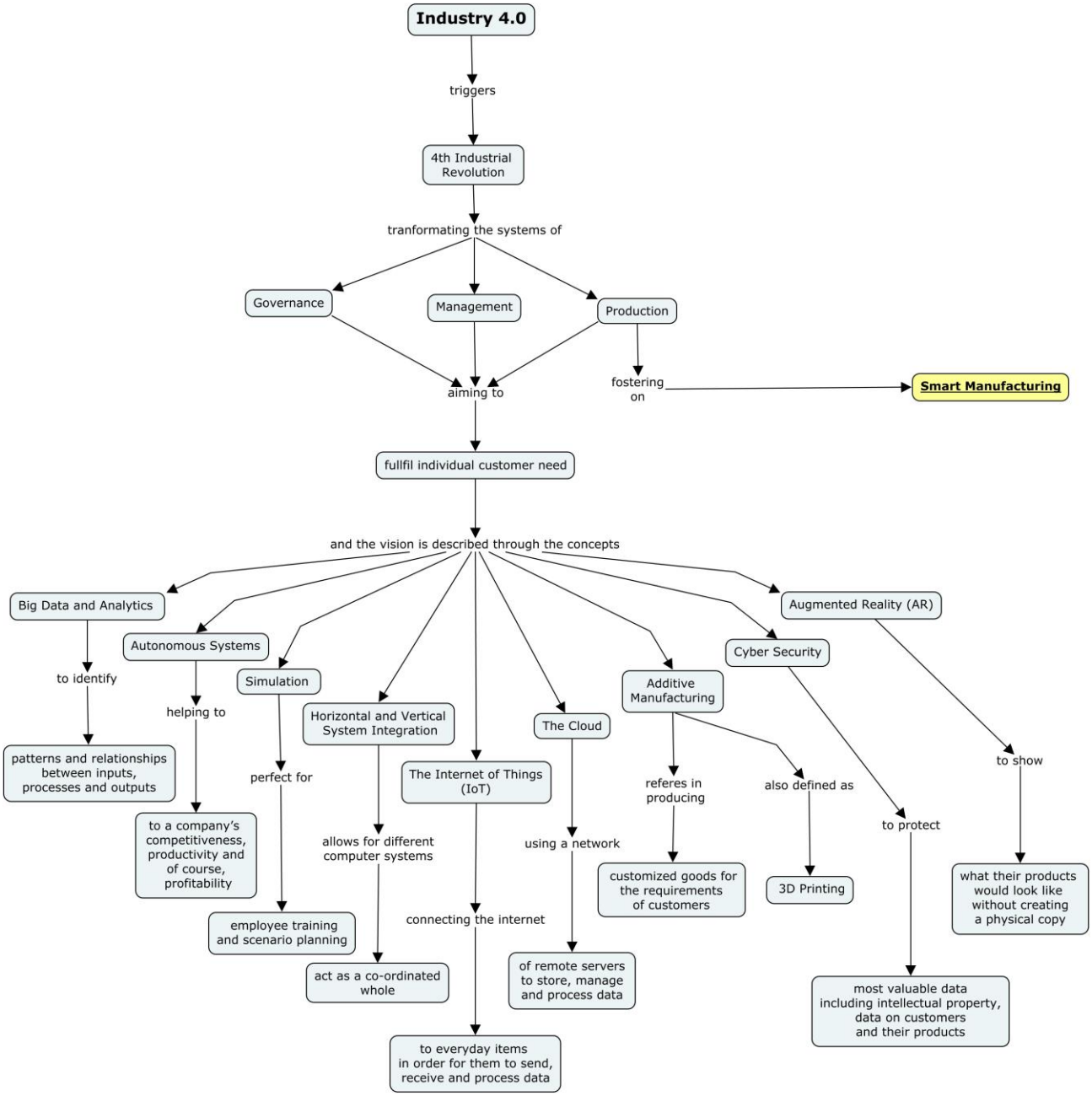

Fig. 6, Concepts regarding Industry 4.0

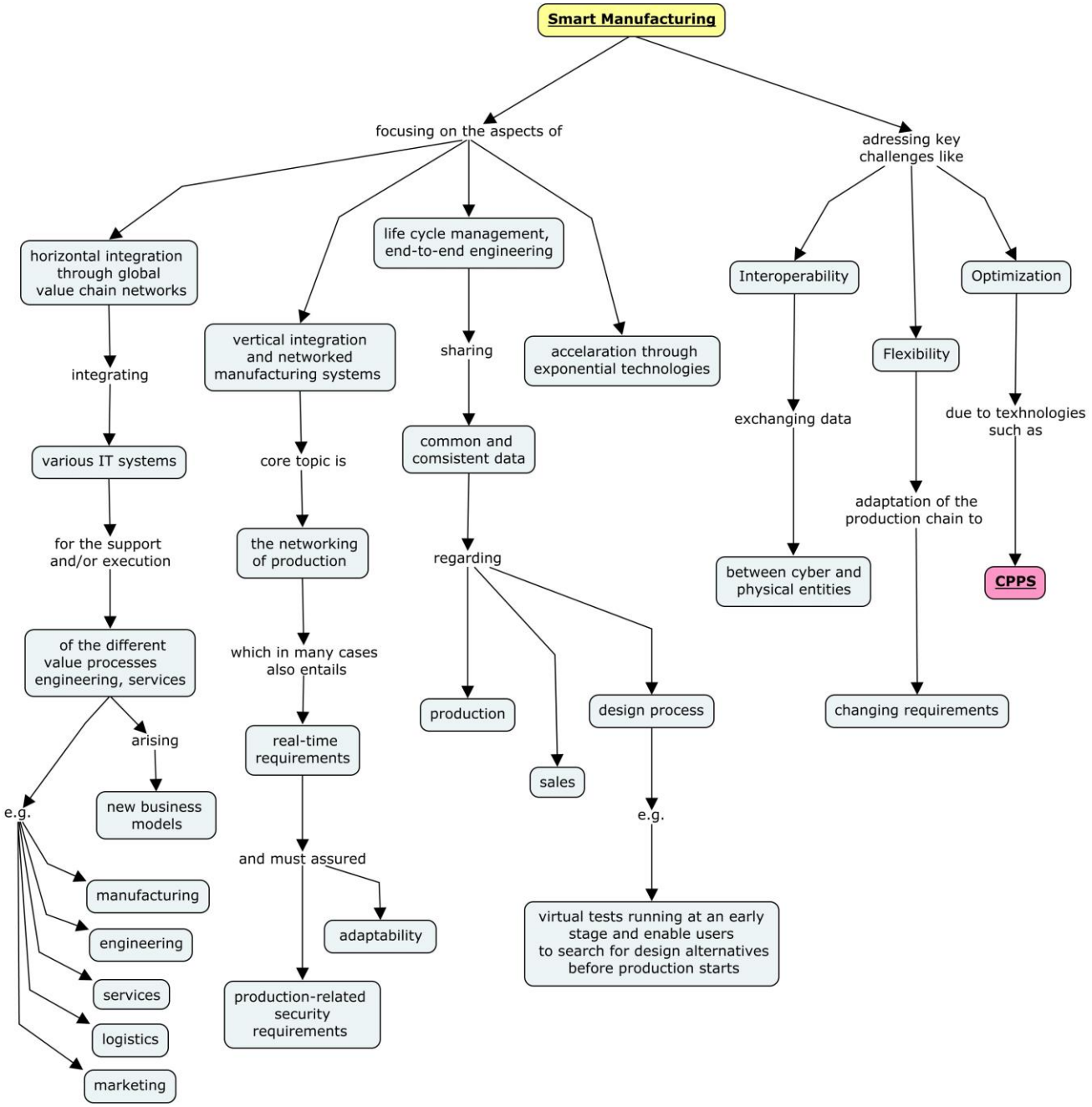

Fig. 7, Concepts regarding Smart Manufacturing

Fig. 5, Concepts regarding CPS