IJITCE

ISSN 2347- 3657

International Journal of
Information Technology & Computer Engineering

Email : ijitce.editor@gmail.com or editor@ijitce.com

International Journal of Information Technology & Computer Engineering
ISSN 2347–3657
Volume 6,Issue 1,Mar 2018

An Industrialized Form of Cyber-Physical Systems Based on "Virtual Engineering Objects" and "Virtual Engineering Processes"

C INDHUMATHI11, P.SAFIA2, R.SWATHI3

Abstract

Cyber Physical Systems (CPS) are compared and contrasted with VEOs and VEPs (Virtual Engineering Objects and Processes) in this research (CPS). Virtual Engineering Objects (VEOs) and Virtual Engineering Processes (VEPs) are two ways in which engineering knowledge may be represented. We use the term "cyber-physical systems" to refer to systems that use computer, communication, and control technology in a tightly integrated manner (CPSs). VEO/VEP is a subset of CPS with substantial potential to contribute to the foundation of Industry 4.0, as shown by the study of core principles and techniques of application. As a result of merging the two approaches, we may soon have access to very sophisticated analytics and intelligent robots.

Keywords: Decisional DNA, Set Knowledge Experience Structure (SOEKS), Virtual Engineering Object (VEO), and Virtual Engineering Process (VEP).

1. Introduction

There is a global push to increase industrial manufacturing's output and efficiency by connecting factories to the internet and other digital networks (ICT). The primary motivation for this convergence is the need to take full advantage of the exponential growth of the ICT sector. First, ICT will be used to increase productivity using less energy and materials. ICT qualities including robustness, resilience, information security, and real-time capabilities will also improve the development of industrial applications.

The culmination of these thoughts is the novel Industrie 4.03 notion. Towards a networked and always-available resources management strategy, this potent idea encourages the computerization of conventional industrial facilities and their ecosystems. Ultimately, we want to achieve the "intelligent factory," a production facility that is flexible, efficient with its resources, and user-friendly, and that also involves its customers and business partners in its value creation. Cyber-physical systems (CPS) and the Internet of Things are the technical foundations of the Industrie 4.0 movement, which advocates for the creation of "smart factories" (IoT) 3.

Computer-Placed Systems (CPSs) are the next generation of engineered systems that must tightly integrate computing, communication, and control technologies to achieve stability, performance, reliability, robustness, and efficiency when dealing with physical systems across a wide range of application domains.

4.

Cyber-physical systems rely heavily on knowledge engineering since there is no one way to describe the wide variety of data and application contexts prevalent across the many physical domains.

5. Knowledge representation of engineering objects and processes, based on actual use cases, is what the Virtual Engineering Object (VEO) and Virtual Engineering Process (VEP) concepts are all about. This literature study seeks to answer the question of whether the VEO/VEP idea may be seen as a subset of CPS and so put to use in the Industrie 4.0 design process.

Asst. Professor[1,2,3]
Department of cse
SRINIVASA INSTITUTE OF TECHNOLOGY AND SCIENCE , KADAPA
Chennai- Hyderabad Bypass Road, Ukkayapalli ,kadapa -516002

Following is the outline for this paper: In the second part, we'll go through the fundamentals of Industry 4.0, CPS, IoT, and the difficulties of putting them into practice. In Chapter 3, we explore the meaning of VEO and VEP. In the fourth portion, we will compare CPS to VEO, and in the fifth and final section, we will present our findings and

International Journal of Information Technology & Computer Engineering
ISSN 2347–3657
Volume 6,Issue 1,Mar 2018

draw our conclusions.

2. Industrie 4.0 : New industrial revolution

There have been three major industrial revolutions in human history, and some predict that a fourth is on the horizon (see Figure 1). The first was defined by mechanization and the associated efficiency advantages, the second by the advent of electricity and mass manufacturing, and the third by the widespread use of electronics and IT. The Industrie 4.0 revolution will bring about the Internet-wide interconnection of physical objects..' [6].

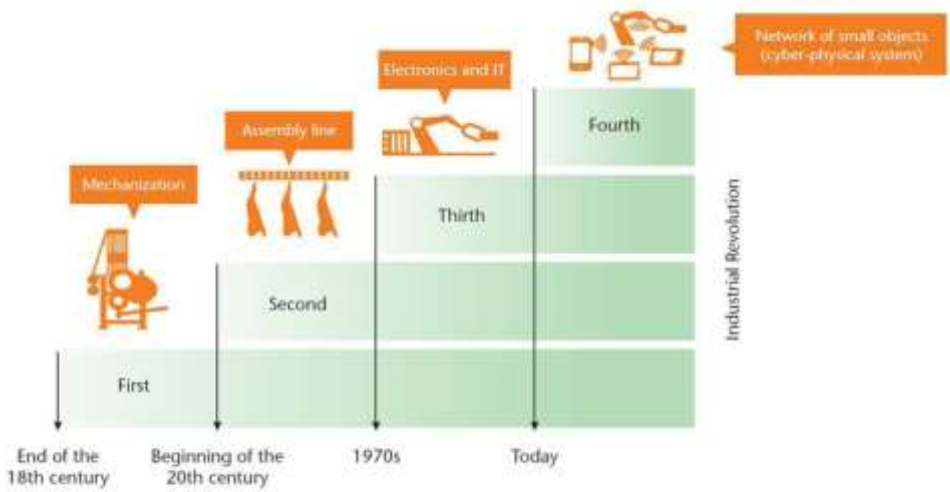

Fig. 1. Emergence of Industrie 4.0[1]

Although the notion of Industrie 4.0 is being studied and researched, there is currently no agreed-upon definition for it. Examples of definitions that may be found in books include the ones below:
To begin, the definition of "Industrie 4.0" is "the integration of complex physical equipment and gadgets with networked sensors and software, employed for prediction, control, and planning to increase corporate and societal outcomes."
7. Alternatively, "Industrie 4.0 is a new level of value chain structure and administration throughout the lifetime of commodities," as stated in the second definition.
The third definition is: The term "Industrie 4.0" refers to an approach to manufacturing that uses a variety of tools and methods to enhance the production process. CPS monitor manufacturing floor activity, mimic reality, and make decisions autonomously inside the Smart Factories of Industrie 4.0's modular architecture. It's possible that CPS will be able to work together in real time with one another and with humans thanks to the Internet of Things. Internet of Services enables the distribution and consumption of cross-organizational services both internally and externally by players throughout the value chain (IoS). Therefore, it is quite evident that Industrie 4.0 is the convergence of high-tech tools, production networks, and workflows. It also emphasizes the idea of digitizing and integrating all production units in an economy consistently, so converting existent virtualization into a colossal data network. As shown in Figure 2, Industrie 4.0 is comprised of a number of interrelated principles that must be understood and used. Cyber-physical systems, the Internet of Things, the Internet of Services, "smart products," etc., etc., etc., etc., etc., etc., etc., etc., etc., etc., etc., etc., etc., etc., etc., etc...

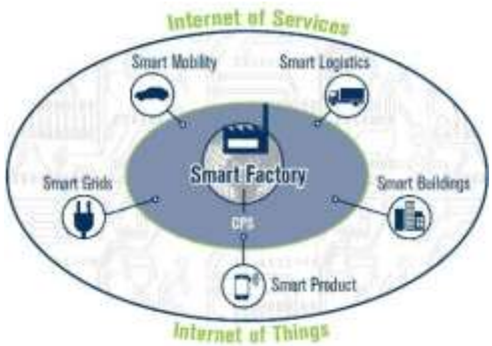

Fig. 2. Framework for Industrie 4.0 and CPS[6]

Objectives of Industrie 4.0

2.1. According to the literature1, Industrie 4.0 is concerned primarily with the following:

2.2. Manufacturing that can automatically and flexibly adapt to small batch sizes or even individual demand thanks to advances in information technology.

Improved human-machine interaction (HMI) paradigms, such as coexistence with robots or radically new ways to interact and operate in factories; production optimization; and radically new types of services and business models contributing to changing ways of interacting in the value chain are all possible thanks to IoT-enabled communication in smart factories.

Methods for Creating and Implementing an Industrie 4.0 Strategy

2.3. Results from the literature review

2.4. The following six design concepts may be inferred from the Industrie 4.0 subsystems:

2.5. Integration of digital and physical systems in manufacturing; What we mean by "virtualization" when we say it's an electronic copy of the "real thing"

2.6. With the IoS, enterprises, CPSs, and individuals may make their services available to other users. Individual parts are given autonomy in making decisions. Definition of Real-Time Capability: The ability to gather and analyze data in near-real time.

2.7. Modularity allows Smart Factories to adapt to changing requirements by swapping out or adding new components.

2.8. To achieve these design objectives, Industrie 4.0 will be implemented in two stages.

2.9. Manufacturing technology requires (1) the modification of existing fundamental technologies and expertise to meet the specific needs of the manufacturing sector, and (2) the development of strategies for extending manufacturing operations into new geographic regions and commercial markets (see also: 6, 9). The three characteristics to remember are:

Horizontal integration may be seen in a variety of systems, including resource management, logistics, marketing, and an inter-business value chain.

The phrase "vertical integration" is used to describe the process by which several IT systems are integrated at various levels of an organization's structural hierarchy throughout the whole production process.

The full digital integration from beginning to end: This method of digital engineering aims to close the gap between product creation and purchase by the end user.

advantages that may arise

Despite its increasing complexity, the Industrie 4.0 system offers tremendous advantages1,6. In order to swiftly adjust to changes in demand and value chains, production procedures have become more streamlined and adaptable. This paves the way for more adaptability, shorter lead times, and higher throughput. Information that is directly relevant to production may be used immediately thanks to the streamlined data collection process. choosing actions regardless of geographical location.

It is feasible to include small-batch customisation and last-minute alterations into the Industrie 4.0 process, as well as individual client needs for design, configuration, ordering, planning, manufacture, and operation.

Businesses may be able to save money through improving value chain management and automating manufacturing. In order to cut down on energy costs, factories should be managed efficiently. High levels of automation in manufacturing reduce production costs by eliminating the need for less qualified workers.*Cyber Physical Systems (CPS)*

Cyber-physical systems (CPS), one of the fundamental technological principles of Industrie 4.0, was discussed in the preceding section and is shown in Figure 2 below. Companies' equipment, storage systems, and production facilities are all part of "CPS," which defines the convergence of the digital and physical worlds as global commercial networks. Cyber Physical Production Systems (CPPS) are CPSs used in manufacturing that comprise of interconnected, autonomously operating, and intelligent machinery, storage systems, and production facilities. These improvements may have far-reaching implications for manufacturing, engineering, material usage, supply chain, and life cycle management. 10, 11.

Because of their network connectedness, an increasing number of machines, plants, and factories will be made available as data objects. This enables searching, browsing, and analysis across the board. This will cause a deluge of information and objects that can be accessed from anywhere12.12..

Table 1. CPS requirements and their corresponding advantages

CPS requirements	Advantages
physical objects	intelligent machines
data models of the physical objects in a network	advanced analytics
services based on the available data	people at work

2.2 To do this, it is necessary to capture, analyze, and interact with the real (physical) and virtual (digital/cyber) production environments with a high degree of precision across all dimensions (spatial and temporal) 1,13.

2.3 At its core, advanced manufacturing is the quick incorporation of new information into production processes and products. As an essential enabling technology, ICT is essential for boosting industrial production. The numerous components, products, and other entities engaged in the production process would each be given a unique digital identity. They might engage in monetary exchange or simulated social interaction. Systems may be virtually integrated, tested, and optimized. The

2.4 The digital production facility and the online installation would be available to everybody. Tables 11, 12, and 14 illustrate that it is feasible to use algorithms to boost autonomous performance.

2.5 Cyber-Physical Production System (CPPS) CPPS is a specialization of CPS that finds widespread use in manufacturing. Both of these frameworks have a lot of common ideas. While CPSs, which exist at the level of sensors and actuators, provide more granular information about a process, CPPSs, which aggregate CPSs, have a higher degree of knowledge. One operates at the object/machine level and the other in manufacturing cells, which are part of the production line. Among the various official definitions of the abbreviation CPPS are:

2.6 First definition: manufacturing that makes use of cyber-physical technologies, which allow for continuous monitoring of goods, machines, and systems throughout the whole design, development, testing, production, and distribution28 process.

2.7 Systems that integrate information technology into conventional manufacturing to ensure compatibility between IoT devices29.*Internet of Things (IoT) and Internet of Services (IoS)* The development of intelligence (smart devices, networks, and decision technologies) and the proliferation of supporting technologies (cloud computing, low-cost Internet solutions, secure and reliable networks, mobile Internet access, etc.) are reshaping the Internet of Things and Services (IoT&S) as we know it.[3, 6].

2.8 Challenges of implementing Industrie 4.0 and CPS

Along with the standard challenges of computing and communication, there are also the more specific challenges of embedding, predictability, adaptation, and resistance to unexpected conditions. There are a number of challenges to overcome, not the least of which is the fact that the physical components of such systems need a new degree of safety and reliability that is incomparable to that of conventional computers. Physical components also vary from their object-oriented software counterparts in both behavior and abstraction level4.

A thorough CPS is built on the backs of many models, systems, and concepts from many other disciplines. Our proposal is to broaden this vision with VEO/VEP, which will enable and provide novel services and approaches.

3. VEO/VEP: Fusion of the physical and virtual world

In this section, concept and architecture of VEO and VEP is discussed first and then parallels are drawn with CPS.

3.1 Virtual engineering object (VEO)

There are three characteristics 23–25 of a VEO, which can be thought of as a knowledge representation of an engineering artifact: I the incorporation of the decisional model expressed by the set of experience; (ii) a geometric representation; and (iii) the means to relate such virtualization with the physical object being represented.

VEOs are living representations of objects that can learn from experience and use that learning in ways that are analogous to a human expert in the item. A Virtual Engineering Object (VEO) may store expert-level information on a physical object's design and operation. You may do this by collecting data on the six characteristics (chromosomes) of an entity, as shown in Fig. 3: its features, functions, requirements, connections, current state, and past experiences.

When an engineering item is considered VEO, all of the information and data pertaining to it are collected and organized in a central database. This data may be used to improve the object's operability, serviceability, and dependability, as well as for making decisions in these areas. In order to build subclasses that are consistent enough for the purposes of the categorization scheme15, the idea of VEO requires interlinking the body of knowledge of related items.

Cradle-to-grave thinking informed the creation of VEO, which stores or links together data and decisions made about an engineering product from the time it is first conceived to the end of its useful life. To address the challenges of expressing both continuous and discrete objects, VEO was developed using the knowledge representation approach of Set of experience knowledge structure (SOEKS)-Decisional DNA (DDNA).

We propose SOEK-DDNA16-19 as a unified framework for collecting, organizing, analyzing, and reusing past judgments. Its very name is a metaphor for the method in which our genetic material is passed along from generation to generation. Literature reviews18, 22, 26 show that SOEKS-DDNA is an innovative method for reusing everyday knowledge and formal judgments. It's a generic and cross-disciplinary method since it can be applied to a wide range of contexts and implemented using a wide range of methods and technologies (e.g., ontology, reflexive ontology, software-based, fuzzy logic, etc.).

International Journal of Information Technology & Computer Engineering
ISSN 2347–3657
Volume 6,Issue 1,Mar 2018

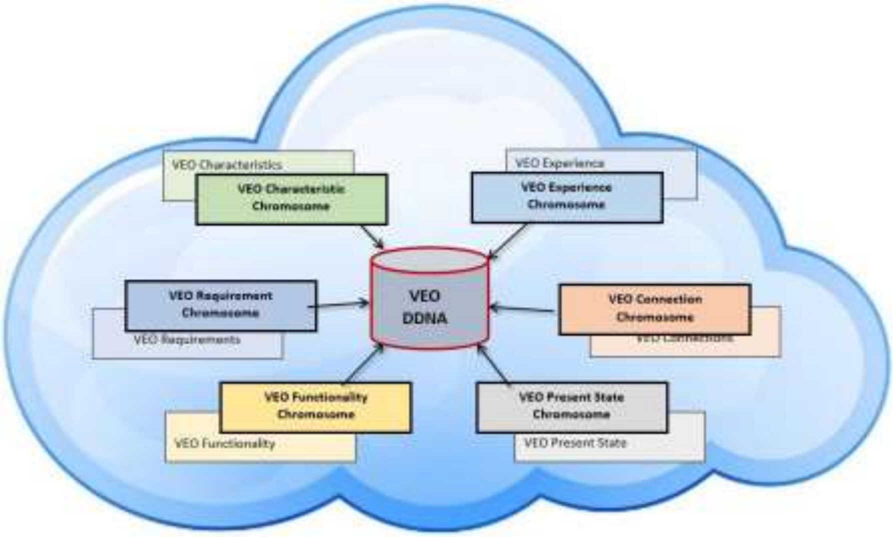

Fig. 3. VEO Structure[21, 22]

Spindle thermal deformation, tool failure, chatter, and work piece deformation brought about by clamping force, cutting force, and material inner stress are only some of the machining circumstances that may have a major effect on machining quality and efficiency. As shown in Figure 4, VEO will provide decision support for issues that may arise during the machining process as a result of complicated machining-level situations.

3.2 Virtual engineering process (VEP)

As shown in Fig. 4, a system in a manufacturing environment consists of a collection of processes, each of which consists of a set of components, tools, or objects. According to this scheme, as stated in Section 3.1, virtual representations of artifacts in the form of VEO have already been accomplished..

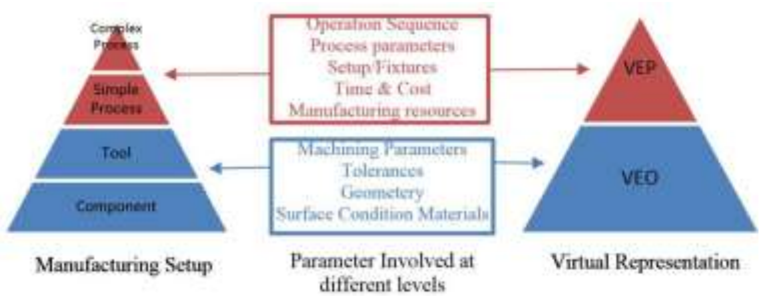

Fig. 4. Correlation between physical and virtual world

- As can be seen in fig. 4, the virtual engineering process (VEP) is a knowledge representation of the manufacturing process/process planning of an artifact that includes all shop floor-level information regarding the operations required, the sequence in which they must occur, and the resources necessary to produce the artifact. A design model must be "transformed" into a physical component in a cost-effective and competitive manner, and VEP addresses the selection of relevant manufacturing processes, determination of their sequences, and selection of manufacturing resources.
- The term "process planning" refers to the process of combining information about the needed operation, production sequence, and machinery required20. More than that, however, you need to know about every VEO that the resource involved in the process has in order to make use of VEP. Therefore, the VEP is built (figure 5) with the following three basic pieces or modules to contain knowledge of the aforementioned areas:
- I Operations: This section of VEP keeps track of all the steps involved in creating an engineering item. Knowledge in the form of SOEKS on operational processes and timetables is included. In addition, operational relationships between

International Journal of Information Technology & Computer Engineering
ISSN 2347–3657
Volume 6,Issue 1,Mar 2018

functions are themselves a component of the operational framework. The following is a list of the many subcategories and the interaction planning functions for each:

-
- Planning your journey with consideration for both the big picture and the details.
- • Capabilities and costs associated with the process.
- Tolerances, surface finishes, sizes, materials, quantities, and timeliness are all examples of process parameters.

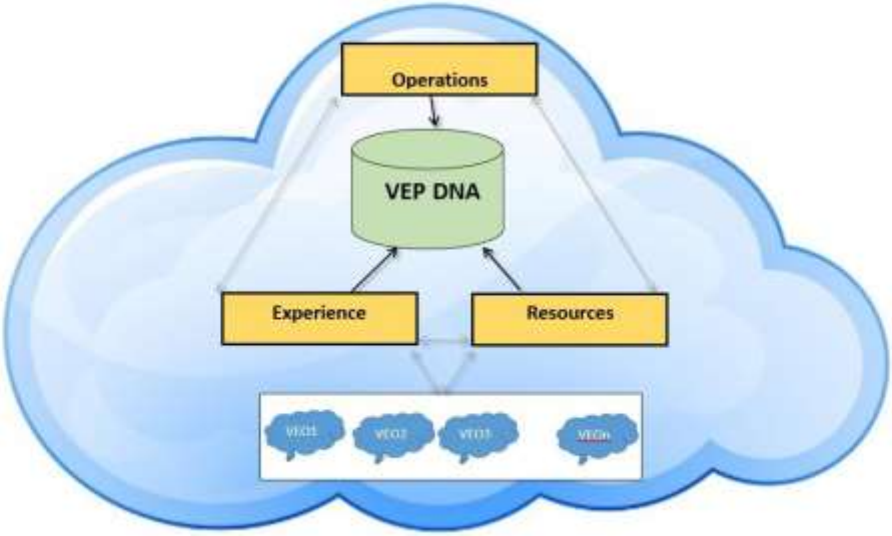

Fig 5. VEP architecture

(ii) **Resources**: Resources utilized in the production of a component described in the VEP operations module are documented here based on historical data. This section contains the following machine-level knowledge:

(iii) • Machine and tool choices, including machine availability, cost, capabilities, size, length, cut length, shank length, holder, material, geometry, roughing, and finishing.

(iv) • Fixture choice -function of fixtures, location, support, gripping surfaces, stability

(v) Section 3.1 contains links to the VEO information addressed therein, broken down into the categories of features, needs, functioning, current condition, connections, and experience..

(vi) **Experience**: The knowledge base contains references to SOEKS from VEOs and explicit decisions made by VEP to produce engineering components in the past. In this context, they stand in for the connections to SOEs that have been established based on the machine's historical knowledge of how to carry out a specified activity, as well as operational and routing parameters.

Salient Features of VEO/VEP

- Previous we saw how VEO/VEP uses the SOEKS and Decisional DNA methods of knowledge representation. Case studies21, 27 conducted in the laboratory show that the following characteristics will be present in a DDNA-based VEO/VEP knowledge system.
- Because of the knowledge structure's adaptability and dynamism, it may be adapted to fit a variety of contexts.
- • It is dynamic because it stores one's explicit daily experience in a single, cohesive form.
-
- Having information that can be taken everywhere, used in any situation, and passed along to others.
- • The ability to make inferences and take actions based on historical data.
- • Being able to make decisions; possessing sufficient and relevant information.

4. VEO/VEP : A tool for building CPS and Industrie 4.0

Comparing the intellectual and practical underpinnings of Industrie 4.0, CPS, and VEO/VEP finds striking commonalities amongst them. CPPS are a kind of CPS specification that operates at the process level in the context of industrial production. Like a VEP is a set of VEOs, a CPPS is a collection of CPSs. Table 2 provides a synopsis of key

VEO/VEP elements that might aid in the design and implementation of CPS/Industrie 4 to support the claim that VEO is a subset of CPS..0.

Table 2: VEO/VEP features can contribute in Industrie 4.0 design and implantation requirements

CPS	Key Aspects	VEO/VEP features
Design requirements	Interoperability	Product self-awareness (history, status, location, delivery strategy and service)
		Throughout linking product virtual model and situational physical status.
		Resource/energy efficiency and sustainable production
	Virtualization	Empowering end users in the final product configuration.
		Generation of production and manufacturing working options.
		Accounting for time and cost.
	Decentralization	Analytics of production and manufacturing data.
		Real-time mixing of production data with engineering design data.
		User interface dynamic adaptation of information to user profile, devices, and context.
	Real-Time Capability	Emergence of new operational models
		Optimized decision making
	Service Orientation	Individualized product tracking and as underlying connection layer between factories and products.
	Modularity	Personalization and flexibility
		Dynamic resource visualization and creation of decisional footprints at the factory and machine levels.
Implantation phases	Vertical integration	Virtual environments. Virtual scenarios for new ways of planning production, especially suitable for dynamic and fast changes. Scenarios for testing different configurations
		Real-time representation of production. Visualizing flows of information, material, and knowledge in the factory, not only physical representation.
		End user interfaces. Editing configurations in demanding work conditions, such as production lines.
	Horizontal integration	Natural flow of a persistent and interactive virtual model throughout entire Product life-cycle.
		Virtual production planning by coupling of production process and product models.
	End-to-end integration	Augmented reality (AR) for process and resources/objects.
		Intelligent streaming/search to improve decision making.
		Preserving critical features for tasks while allowing interaction among VEOs.

VEO offers a framework for manufacturing components to become cyber-physical systems with access to information about themselves and adequate ways of communication. The goal is for this VEO/VEP to be integral to the process as a whole and, in the most extreme circumstances, to have complete command over not just their own production logistics but the whole production process as it relates to them. As a foundation for their involvement, VEO/VEP will provide condensed data adequately drawn from the complicated interrelationships and delivered in a bespoke fashion. This creates a novel kind of collaboration between machines and their constituent pieces. This will strengthen production's capacity to adapt to unforeseen circumstances in the short and medium terms.

Table 2 shows that there is a clear connection between CPS and VEO, with the latter being a subset of CPS designed to enable field devices, machines, plants, and factories (and even individual goods) to maintain digital representations of their physical selves in the cloud. Therefore, VEO/VEP is analogous to a black box in that it is an object/process with a malleable and dynamic structure that has a plug-and-play interface. Connecting these goods together creates a system where machines can communicate with one another.

5. Conclusions

The ideas of CPS, VEO/VEP, and Industrie 4.0 are discussed in this study. One of the most important factors in achieving CPS for Industrie 4.0 has been discovered to be the use of virtual simulation of goods and processes. It has been demonstrated that VEP/VEO is experience-based modeling and simulation of manufacturing processes/objects, and that it encompasses all the crucial knowledge of process planning/artifacts. Furthermore, the information represented above alludes to the reality that the logical and material worlds coexist and are time-locked, which has implications for cyber-physical systems. VEO/VEP covers both the product and process levels for components, machinery, and manufacturing facilities, allowing it to seamlessly overlap with both the actual items and the simulation model. This is a powerful connecting example of product life-cycle management, industrial automation, and semantic technologies, and VEO/VEP has little trouble adapting to self-organizing production and control systems. To sum up, VEO may be thought of as a subset of CPS, while VEP can be seen as a variant of CPPS.

References

1. A systematic review and meta-analysis1. Posada J, Toro C, Barandiaran I, Oyarzun D, Stricker D, de Amicis R, et al. When it comes to Industrie 4.0 and the Industrial Internet, visual computing is a crucial enabling technology. IEEE Transactions on Computers: Visualization and Computer-Aided Design, Volume 35, Issue 2, Pages 26–40, 2015.
2. Kyoung-Dae, K. and Kumar, P. R. Perspectives on Cyber-Physical Systems for the Next 100 Years. 2012, volume 100, issue 100S (Special Centennial Issue):1287-308.
3. Design Principles for Industrie 4.0 Scenarios: A Literature Review, Third Edition, by Michael Hermann, Thomas Pentek, and Bernd Otto. A copy may be found at http://www.snom.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design-Principles-for-Industrie-4 0-Scenarios.pdf.
4. Cyber-Physical Systems: Design Obstacles, by Edward Lee. Technical Report UCB/EECS-2008-8, University of California, Berkeley, 2008. Contract Year 2008. Information retrieved on June 7, 2008.
5. Cyber-Physical System: A New Frontier by Lui Sha, Sathish Gopalakrishnam, Xue Liu, and Wang Q. To be published in PSY Jeffrey J. P. Tsai's edited collection. Using Machine Learning for Cyber Trust, Springer, pp. 3–12.
6. Sixth and seventh: Henning Kagermann WW and Johannes Helbig. Policy suggestions for carrying out the strategy plan Industry 4.0 (2013) (2015-01-04). Available from:
7. This report is available online at http://www.acatech.de/fileadmin/user upload/Baumstruktur nach Website/Acatech/root/de/Material fuer Sonderseiten/Industrie 4.0/Fina l report Industrie 4.0 accessible.pdf.
8. Seven. Consortium II. Fact Sheet, 2013. [retrieved 2015-07-04]. Check it out at http://www.iiconsortium.org/docs/IIC FACT SHEET.pdf.
9. Max Blanchet, Thieulloy GD, Thomas Rinn, Georg Von Thaden. BRIEFING ON INDUSTRY 4.0 This is the beginning of the third industrial revolution. Why Europe will make it. Think Act [Internet]. 2014 01/04/2015. The document may be downloaded here: http://www.rolandberger.com/media/pdf/Roland Berger TAB Industry 4 0 20140403.pdf.
10. The Standardization Plan for Germany 9 VDE ASSOCIATION FOR ELECTRICAL, ELECTRONICAL, AND INFORMATION TECHNOLOGIES; Industrie 4.0, 2013. [06/04/2015]. Get it here: http://www.dke.de/de/std/documents/rm%20industrie%204-0 en.pdf.
11. Cyber-Physical Systems - Lee EA. Are Current Computer Principles Sufficient? Referenced in Position Paper for National Science Foundation Workshop on Cyber-Physical Systems: Research Motivation, Techniques, and Roadmap; Austin, TX. 2006.
12. Cyber-physical systems for controlling manufacturing processes. Wang Y, Vuran MC, Goddard S. 2011. 2008, SIGBED Review, 5, 1, 2
13. R. Drath and A. Horch. Can We Trust Industrie 4.0, or Is It Just Hype? Discussion Board for the Business Community. IEEE's Industrial Electronics Magazine, 2014, volume 8, issue 2, pages 56–8.
14. Cyber Physical Systems. By R. Baheti and H. Gill. In T. Samad and A. M. Annaswamy (Eds.). Control Technology and Its Effects, www.ieeecss.org, 2011. 14. Annunziata PCEaM. The Limits of Human and Machine Cognition in the Age of Industrial Internet 2012 [06/04/2015]. To access this document, go to http://www.ge.com/docs/chapters/Industrial Internet.pdf.
15. Shafiq, S. I., C. Sanin, E. Szczerbicki, and C. Toro. Integrating the Body of Experience Knowledge Structure into Virtual Engineering Objects (VEO) (SOEKS). 2014;35(0):644-52 in Procedia - Computer Science.
16. Set of Experience: A Knowledge Structure for Formal Decision Events. Sanin, C. and Szczerbicki, E., 2016. 2005, Volume 3, Issue 2, Pages 95–113, Foundations of Control and Management Sciences.
17. Decisional DNA and the Smart Knowledge Management System: A method for turning data into understanding. Sanin C, Szczerbicki E. 2017. Editor AG. Enterprise Information System Planning and Development Methods and Techniques. IGI Global, 2008. p. 149–75. New York.
18. Decision-making DNA: A Concept and Its Implementation Platforms. Sann C, Mancilla-Amaya L, Haoxi Z, Szczerbicki E. 2018. 2012, February 01, Cybernetics & Systems, 43(2), pp. 67-80.
19. Applying a Cross-Disciplinary Framework for Knowledge (Decisional DNA) by Sann, C., L. Mancilla-Amaya, E. Szczerbicki, and P. CayfordHowell. published in Nguyen and Szczerbicki (eds.). Knowledge Management using Intelligent Systems. Springer Berlin Heidelberg: 2009, pp. 65-86 in Studies in Computational Intelligence, volume 252.
20. Twenty-fifth, Chen WL, Xie SQ, Zeng FF, Li BM. Parametric flowchart: a novel method for representing process information. Shafiq SI, C. Sanin, C. Toro, and E. Szczerbicki. "Computers in Industry." 2011 1//; 62(1):9-22. Towards Experience-Based Design and Manufacturing in the Age of Industry 4.0 using Virtual Engineering Objects (VEOs). published online February 17, 2015 in Cybernetics and Systems, Volume 46, Issues 1-2: pp. 35–50.
21. Shafiq SI, Sanin C, and Szczerbicki E. Decisional DNA (DDNA) and the Structured Organizing of Experiential Knowledge (SOEKS): A Triadic View of Time. Article 23: Shafiq SI, C. Sanin, E. Szczerbicki, and C. Toro. Cybernetics and Systems. 45(02). 2014. Improve Industrial and Manufacturing Design using Decisional DNA. A Theoretical Study. To be found in the edited collection of works by Jerzy Witek LB, Adam Grzech, and Zofia Wilimowska. Technology and Architecture in Information Systems; Szklarska Pora, Poland; September 22-24, 2013. 24. Shafiq SI, Sanin C, Szczerbicki E, Toro C. Decisional DNA Based Framework for Representing Virtual Engineering Objects. Wrocaw: Wrocaw University of Technology, Wrocaw; 2013. p. Nguyen, N., B. Attachoo, B. Trawiski, and K. Somboonviwat (eds.). Knowledge Management and Database Systems with Intelligence. Page 422–431 in Lecture Notes in Computer Science, volume 8397, published by Springer International Publishing in 2014.
22. Virtual Engineering Objects (VEO): Designing, Developing, and Testing Models. Shafiq SI, Sanin C, Szczerbicki E, Toro C. Edited by A. Grzech LB, J. Swiatek, and Z. Wilimowska. Design, Control, and Decision Support Using a System Analysis Perspective. Published by the Press of the Wroclaw University of Technology, 2014. pp. 183-92.
23. This list includes authors such as: Sanin, Toro, Haoxi, Sanchez, Szczerbicki, Carrasco, E. The Decisional DNA: A Multi-Technology, Shareable Knowledge Structure for Determination Experience. Published: Neurocomputing. 88(0):42-53 (July 1, 2012). . Research by Shafiq SI, C. Sanin, E. Szczerbicki, and C. Toro. Knowledge Representation and Determination Using Virtual Engineering Objects. D. Barbucha, N. T. Nguyen, and J. Batubara. Innovations in Smart Data and Information Systems. Research into Computational Intelligence. 28. 598: Springer International Publishing; 2015. p. 261-270. Manufacturing Infrastructure for the Fourth Industrial Revolution; Cyber-Physical Production Systems (CPPS). [01/04/2015]. The P2P Foundation has a glossary of terms that includes "cyber physical production systems," which may be found at http://www.plattform- i40.de/glossar/cpps. Available at: http://p2pfoundation.net/Cyber-Physical Production Systems

(accessed 01/04/2015).