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A Conceptual Framework for Data-Driven Digital Transformation from the Perspective of Cyber-Physical-Social Systems Thinking

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Abstract

Purpose: The purpose of this study is to answer the main question of what is meant by the concept of data-driven digital transformation from the perspective of cyber-physical-social systems' thinking.

Method: Comparative Evaluation method is used in this study. In this method, after identifying different definitions and interpretations of the digital data-driven transformation and also cyber-physical-social data, these definitions are compared based on this method. Based on this analysis, then a conceptual concept from the perspective of the notion of cyber-physical-social systems for the concept of data-driven digital transformation is proposed.

Findings: Based on this research, the concept of digital transformation has different definitions and interpretations. Some of these definitions focus on "what" and some on "how". But the complex nature of the concept of transformation has not been noted enough. Now we're cyber-physical-social systems as a platform for data creation and data flow. The nature of these systems is based on transformation and the digital data-driven transformation is achieved by data flow management in these systems.

Digital data-driven transformation is a concept based on digital convergence between social, physical, cognitive, and cyber systems. These systems are the context of creating big data, and data flow management requires data-driven notions and analytics, which is essential for the transformation and sustainability of societies.

Conclusion: According to the proposed framework, data-driven digital transformation is a concept based on digital convergence between social, physical, cognitive, and cyber systems. These systems are the context of creating big data, and data flow management requires data thinking and analytics which are necessary for the transformation and sustainability of societies. **©authors**

Keywords: Data-Driven Digital Transformation, Cyber-Physical-Social systems, Sociocybernetics.

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1. Introduction

Recently we've noticed digital hardware and software technology developments, and their growth has made so many changes and innovations in human life and work (Dornberger, 2020). Advances in digital technology have also changed and transformed the world of industry and production (Gadre & Deoskar, 2020) and have raised topics and concepts such as digital transformation and industry 4.0 and taken them into more consideration (Vial, 2019; Eremina, Lace, & Bistrova, 2019). In other words, by developing the Fourth Industrial Revolution, industries and businesses are adapting themselves to the process of global digitalization, which is called business model digital transformation (van Tonder, Schachtebeck, Nieuwenhuizen, & Bossink, 2020; Coskun-Setirek & Tanrikulu, 2021). Industries are provided with new opportunities to develop new business models using digital technologies and innovation management (Matt, Modrák, & Zsifkovits, 2020). On the other hand, with the Coronavirus outbreak in the whole world, the importance of digital business models has become more and more prominent and many businesses have made digital transformation a key part of their strategy (Tripathi, 2021).

Digital transformation is rapidly disrupting the rules and relationships of social, physical, and cyber systems. So far, various definitions of digital transformation have been offered by researchers and industry leaders, but there are still different interpretations. For example, the ambiguity that still exists between the definitions of digitization and digitalization. Therefore, during this rapid process of entropy, it is absolutely important and necessary to ponder deeply on numerous and varied definitions of the digital concept. Given the abstract and intangible nature of the subject of transformation digitally, it is not simple, but it is vital that we do our best about such future determining topics.

The main issue to be considered is the lack of a single definition of the concept of digital transformation in the interdisciplinary era of the Fourth Industrial Revolution, which in addition to preventing the growth of the concept in these spaces, may lead to a deviation to one of the selective and of course impractical definitions in today's complex atmosphere. In this study, we've tried to offer a comprehensive definition of this concept.

Overall, it can be said that the purpose of this article is providing a digital transformation conceptual framework that can explain and cover the expressed issues about this concept in this framework. Here the main question is despite these partial and sometimes contradictory definitions of an important concept called digital transformation in the literature, is it possible to define it in a framework that can fully explain the issues in the definitions of this concept in the literature, cover their shortcomings, and help researchers in an interdisciplinary environment to take a unified look at the concept of digital evolution?

Accordingly, the sections of this article are organized as follows: The second section expresses the theoretical foundations and research background in the field of defining cyber-physical-social systems as a definition framework as well as common definitions of digital transformation. In the third section, the research method and the defined steps to achieve the proposed framework are described. In the fourth section, based on the theoretical background and research method presented in the previous sections, the proposed framework and its components and process are described. Finally, in the fifth and final section, the results, limitations, and suggestions for future research are discussed.

2. Literature Review

According to Umpleby's article (2014), the nature of cyber-physical-social systems is fundamentally transformational (Umpleby, 2014). In other words, these systems' network nature, provides complex ecosystems that admire agility and are rapidly evolving and disrupting the classical laws and paradigms of the Third Industrial Revolution. Like many modern and abstract concepts, many disciplines have tried to define the term digital transformation and each has offered its interpretations. Although the diversity and

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frequency of these definitions enhance our knowledge of digital transformation; on the other hand, this abundance, and variety, as well as the abstract nature of the concept in many cases have confused, and incorrect and sometimes erroneous interpretations of this practical concept in the era of the Fourth Industrial Revolution. Therefore, the need for a comprehensive and comprehensive definition is definite. To ensure the comprehensiveness of the subject, we need a wide lens. Cyber-physical-social systems' transformational nature will guide us well to achieve this target.

Next, we're going to identify cyber-physical-social systems as a syntactic context and then review some common definitions of digital transformation. Due to the key role of data in digital transformation and the emphasis on the flow of data sources in the digital age, definitions of digital data-driven transformation are now the criteria.

2.1. Definition of cyber-physical-social systems

Figure 1 shows the development of the cyber-physical-social systems paradigm. In this figure, the supportive & background concepts and the basic principles and technological areas are illustrated. From the bottom to the top, the level of detail increases (Levels of Abstraction), and the volume of data increases. Thus, cyber-physical-social systems are completely abstract and rich in data.

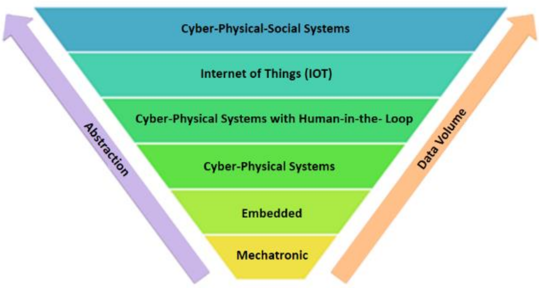

Figure 1. Maturity of Cyber-Physical-Social Systems

Studies on cyber-physical-social systems show that these systems started from mechatronics. Mechatronics combines the science of mechanics, electrical engineering, and control in industrial processes (such as driving trains and vibration analysis of vehicles). From the summary level point of view, design processes are defined at this level and support the interpretation of designed procedures into physical systems. In Embedded System, the focus is on computing systems that are embedded and hidden in the physical system (such as a thermostat).

Cyber-physical frameworks, which are the next generation of hidden systems, combine computing technologies and communication technologies. Cyber-physical systems are often involved in sensing and controlling physical phenomena through interconnected networks of interconnected devices to achieve the intended purpose of these networks. These systems control physical environments using a system including some sensors and actuators (such as cups with sensors or MediaCups that display the temperature of the contents of the cup).

Recent research have referred to the close connection between the concept of the Internet of Things and the concept of cyber-physical systems, noting their differences and similarities. Cyber-physical systems seek to link the physical world with the cyber world, but the Internet of Things seeks uniquely to identify intelligent objects and inhomogeneous devices and connect them to the Internet. Despite the similarities between these two concepts (coordinating devices to achieve goals), the IoT looks at the components of interactive hardware horizontally, but cyber-physical systems look vertically, which consists of networked hardware, computational processes, and control mechanisms. Of course, in some articles, these two concepts are equivalent and used interchangeably.

Unlike classical cyber-physical systems, recent research has examined the importance and feasibility of Human-in-the-loop (HiTL) CPS. This system has controlling loops with humans interacting with the system (humans are intrinsic actors in this system). These systems are highly individual and focus on learning the human state (physical, physiological, and emotional conditions) due to brain-computer systems and through adaptation to human needs. In such systems, humans must be equipped with a system and be an integral part of it, which is considered impossible and undesirable in computational and urban computing scenarios. Human systems are used in areas such as 1. Life support systems, 2. Brain-

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computer systems, and 3. Factory facilities with humans as the controller (Assisted living, Brain-computer systems, and Factory settings with a human in the control center).

Ultimately, cyber-physical-social systems integrate data from different sources such as physical, cyber, and social spaces through data fusion methods to provide comprehensible interpretations and summaries for humans. These systems are implemented in human equipment and facilities in order to react to the physical world and extract knowledge related to it (Suprana, Zhou, Abad, & Iker Larizgoitia, 2017).

X. Shi and H. Zhuge (2010) stated in their paper that the cyber-physical community will become a cyber-physical-social ecosystem so that the natural physical space, social space, mind space, and cyberspace will interact and interact in harmony. CPSE (Cyber-Physical Socio Ecology) notes the relationship between individuals in the cyber-physical-social environment, between individuals and communities, and between humanity and the environment. CPSE will become a multidisciplinary science about the research, planning, development, and transformation of the cyber-physical community (Shi & Zhuge, 2010).

Bernard Scott (2015) in his article “The role of social cybernetics in understanding the future of the world”, provides a definition of social cybernetics, and since the physical concept is also implicit in the definition of cybernetics, we can refer to this definition. Sociocybernetics applies theories and methods of cybernetics and systems science to the social sciences by providing concepts and tools for addressing problems generally and globally (Scott, 2009).

In a different article, X. Shi et al. (2016) stated that the cyber-physical-social system (CPSS) is generally considered as a community environment with an intelligent, stable, viable, and autonomous variable within the CPS; CPSS therefore semantically gathers and organizes resources into semantically rich forms so that both machines and humans can use them easily. Such a system includes globally distributed resources, including devices, information, and knowledge. The main topic in a CPSS is how to describe and integrate the interaction between hardware, social environment, and physical environment in an efficient way.

In their research, X. Shi et al. introduced a model called the cyber-physical-social thinking model for the data management system. Although their research is about geology this model applies to other fields too. This model is shown in Figure 2 below. This model is fully compatible with Figure 1 (the maturity of cyber-physical-social systems), which was presented earlier.

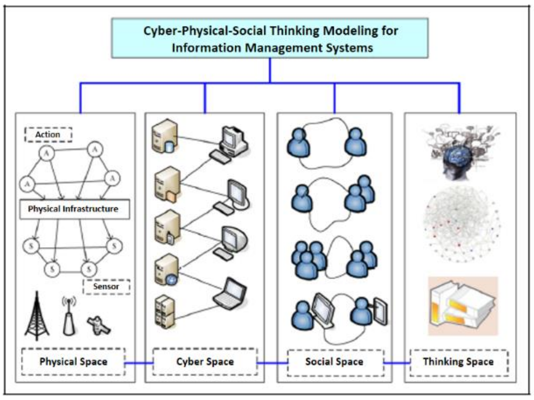

Figure 2. Cyber-Physical-Social Thinking Model for Information Management Systems

2.2. Digital Transformation Definition

Recently there have occurred some developments in the field of digital hardware and software technologies, and their growth has made so many changes and innovations in human life and work (Dornberger, 2020). Advances in digital technology have also changed and transformed the world of industry and production and have raised topics and concepts such as digital transformation (Gadre & Deoskar, 2020) and industry 4.0 and have taken them into more consideration (Vial, 2019; Eremina, Lace, & Bistrova, 2019). In other words, by developing the Fourth Industrial Revolution, industries and businesses are adapting themselves to the process of global digitalization, which is called the digital transformation of the business model (van Tonder, Schachtebeck, Nieuwenhuizen, & Bossink, 2020; Coskun-Setirek & Tanrikulu, 2021). Industries are provided with new opportunities to develop new business models using digital technologies and innovation management (Matt, Modrák, & Zsifkovits, 2020). On the other hand, with the Coronavirus outbreak in the whole world, the importance of digital business models has become more and more

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prominent and many businesses have made digital transformation a key part of their strategy (Tripathi, 2021).

There are several definitions of digital transformation. Matt et al. (2015) have defined digital transformation as major changes in a company's business operations, products, processes, and organizational structure that have implications for the use of digital technologies (Matt, Hess, & Benlian, 2015). Atwell et al. (2015) consider digital transformation as a process in which organizations transform themselves to adapt to and use digital technologies (Attwell, Peffer, Jones, Kerr, & Kämäräinan, 2015). The Gartner Institute also introduces the digital transformation of the business as the process of utilizing digital technologies and their support capabilities to create a new and sustainable digital business model (Gartner IT Glossary, n.d.). In their joint project, MIT and the Capgemini Institute have introduced digital transformation as follows: The use of digital technologies to radically improve an organization's performance or output (Capgemini and MIT, 2011; Westerman, Calméjane, Bonnet, Ferraris, & McAfee., 2011). Confirming this, Schallmo also states that the absence of elements of digital transformation in this definition has reduced its power and comprehensiveness. According to him, digital transformation means digital technologies should be used to establish new interactions and cooperation with customers by reshaping the customer value proposition and transforming business processes (Schallmo & Williams., 2018). Kane et al. (2015) introduce digital transformation as the ability to create a new digital image of a business (Kane, Palmer, Phillip, Kiron, & Buckley, 2015). Capgemini Institute for Digital Transformation uses new digital technologies (such as social networking, analytics technologies, mobile, etc.) to make major and significant improvements in the business (such as creating a new business model, improving the customer experience, etc.) (Fitzgerald, Kruschwitz, Bonnet, & Welch., 2014). Mazzone (2014) has defined digital transformation as the continuous and conscious digital transformation of a company, business model, and its processes, products, communications, and interactions, which have both strategic and technical aspects (Mazzone, 2014; Schallmo, Williams, & Boardman, 2020). Beckkhus (2016) considers digital transformation as the use of digital technologies to improve the performance of companies (Bekkhus, 2016). Attwell (2017) believes that digital transformation is a digitally programmed shock for system functions and the factors that affect them (Andriole, 2017). In summary & according to the definitions provided, it can be said that the goal of digital transformation is to transform the organization and business in a way that in the digital age can achieve and maintain a competitive advantage (Peter M. K., 2018; Peter M. K., 2017).

These are some of the most common and rich definitions of the concept of digital transformation. The less noted point in these definitions is the importance of data as the language of transforming technologies. The entire outcomes of digital transformation are all the result of the coexistence of technologies, which are referred to through data as the most important source of digital economics today. Papas et al. (2018) believe that our decisions, actions, and even our presence in the digital world create data. This data provides pure opportunities to refine business models and organizations. There is an urgent need for theories based on data analytics ecosystems. Accordingly, they have introduced a model called Digital Transformation Sustainability (DTS) and Sustainable Development. To achieve digital transformation and create sustainable societies, the proposed model addresses the issue that any society player should be included and we need to improve our understanding of their interactions and interrelationships that lead to knowledge, innovation, and value creation; then, we need to gain much deeper insight about the capabilities needed to use the potential of big data analytics. (Pappas, Mikalef, Giannakos, Krogstie, & Lekakos, 2018) The model of Papas et al. is shown in the Figure 3.

The mentioned definitions of digital transformation can be discussed from three aspects. First, according to these definitions, some kind of sectional and specialized view has focused on this word and its functions by researchers in the field of business management.

Second, as mentioned earlier, the term digital transformation is widely used today in various

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fields and contexts; but it is observed that like many other abstract concepts, there is no one definition. The definitions are different compared to each other and more they have dealt with the concept of digital transformation from an epistemological point of view.

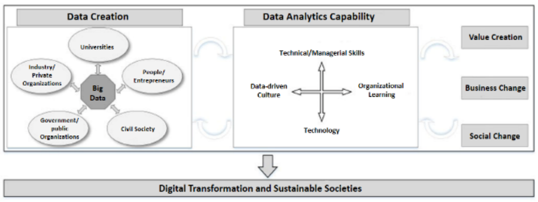

Figure 3. Digital Transformation and Sustainability Model

Third, despite the undeniable importance of data in the concept of digital transformation, most definitions of technology and business are from a technological and business perspective and apart from Papas et al., it seems to be overlooked by other researchers despite the increasing maturity of cyber-physical-social systems and the increasing importance of data as a key and vital resource during the Fourth Industrial Revolution.

Considering the aforementioned aspects, we need a wider redefinition that fits the lens of cyber-physical-social systems. As mentioned in Umpleby's article, the essence of the cyber-physical-social systems approach is fundamentally transformational (Umpleby, 2014).

3. Method

The method used to analyze the definitions provided by the content is the Comparative Evaluation which principles are presented by Vartiainen. In his opinion, the purpose of adaptive assessment is to understand, explain and interpret different phenomena and states that Comparative evaluation is performed to seek evidence to support or refute the accuracy of certain generalities when applied in different cases. He states that to make a comparative Evaluation, it is necessary to identify four important principles (Vartiainen 2002). Now we're going to introduce these principles and explain how to identify them in this study.

Selecting an object for evaluation: This principle refers to the concept that it should be stated what object is selected and how it is selected for comparative evaluation. This principle is recognized as the most important principle in the success of the evaluation process. The object known in this study as the main basis of comparative evaluation defines the conceptual framework of data-driven digital transformation from the perspective of the cyber-physical-social system's notion, which was mentioned in the introduction.

Level of comparison: This principle refers to the definition of the scope of evaluation and the principles on which the evaluation is based. One more thing that needs to be specified at the comparison level is the level of similarity or difference of the units to be compared. In this study, the borders of evaluation are limited to all areas of expertise for which the concept of digital transformation is applicable. Of course, this assessment is limited to the digital transformation in those areas of expertise mentioned in the introduction. About the similarities or differences like the objects being compared, as all the definitions in comparison have considered a single concept called digital transformation, therefore some objects are similar. Vartiainen states that once similar cases are compared, evaluating their differences is more natural and interesting than evaluating their similarities. In his study, he considered this approach to be the right one. Therefore, the present study also focuses on differences.

Conceptual understanding: A clear definition of existing concepts is the third principle that should be considered in a comparative evaluation. This principle should be done to standardize the existing concepts in a comparative evaluation. In the introduction of this research, precise definitions of digital transformation, as the main objects being compared and in the theoretical context, the concept of their components and comparing them with similar concepts and theories and basic models of these concepts are explained.

Analyzing the Findings of an Evaluation: This principle of comparative evaluation refers to the method of analyzing the findings of an evaluation. Vartiainen says the comparative evaluation of information produces more effective comparability once units being evaluated are very similar. In

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general, he introduces two general comparing methods: analytical comparison and Illustrative Comparisons. In an analytical comparison, the evaluation units are directly compared with each other. In Illustrative comparison, the evaluation units are compared indirectly and based on the proposed study model or framework. According to him, one of the main applications of illustrative comparison is standardizing and generalizing the application of the framework used in the evaluation.

In this study, plus presenting a proposed framework based on the existing definitions and theoretical contexts, an Illustrative comparison is also done to compare the existing definitions with the structure and definitions of this framework and express its generalizability. In other words, in this comparison, the key components in the proposed framework and how they work in defining the concept of digital transformation with the components and functions of the concepts in the definitions are evaluated comparatively to show the integrity and efficiency of the proposed framework in defining content. The results of this comparative evaluation show which added value the proposed framework in this study adds to each of the previous definitions of digital transformation (Khedmagozar, Hanafizadeh, & Alipour-Hafezi, 2018).

4. Findings and Discussion

Based on the raised issues and based on a set of logical arguments, here by presenting a conceptual framework, the representation of the digital transformation position and its related relationships should be examined from the perspective of cyber-physical-social systems. This framework can be seen in Figure 4. In this figure, the definitions mentioned in the first section and their adaptation to the proposed framework for defining data-driven digital transformation are also shown.

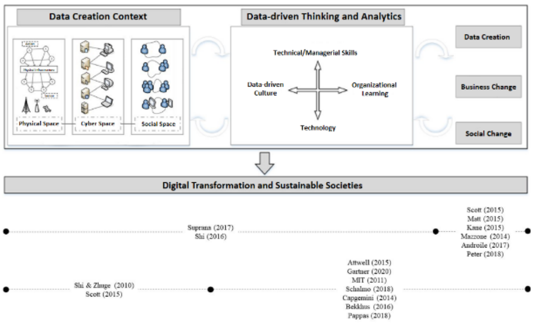

Figure 4. Proposed Framework for Data-driven Digital Transformation

Describing its framework, it is divided into four main elements: data creation platform element, data-driven analytics and notion element, outputs and results element, and finally data-driven digital transformation element and sustainable societies. The data creation element is an element of cyber-physical-social systems based on the definitions of Suprana (2017), Shi (2016), Shi and Zhuge (2010), and Scott (2015) in the background of this research. As shown earlier in Figure 1, as the maturity of cybernetic systems increases, the level of abstraction and data volume increases, and cyber-physical-social systems, as the most mature level, have the highest level of abstraction and volume of data.

Control and management of this level of abstraction require abstract notions. The mass of data resulting from interactions and communications in a cyber-physical-social system requires a data-driven notion, analysis, and approach so, the second element is named data-driven analytics and notion. The abstract nature and a large volume of data require technologies, appropriate technical/managerial skills, organizational learning, and above all, a data-driven culture. These points are taken from the definitions of Suprana (2017), Shi (2016), Othello (2015), Gartner (2020), MIT (2011), Schallmo (2018), Capgemini (2014), Bekkus (2016), and especially Pappas. (2018).

The third element is the element of outputs and results, which are represented by blocks like value creation, business, and social change. Data-driven notion and analytics on cyber-physical-social systems helps us to control and overcome the complexities of these systems to be able to continuously create value and create appropriate

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and innovative businesses as an ambidexterity system, and finally achieve social change and maturity. Results presented by Scott (2015), Matt (2015), Kane (2015), Mazzone (2014), Andriole (2017), Peter (2018), Atwell (2015), Gartner (2020), MIT (2011), Schallmo (2018), Capgemini (2014) and Bekkus (2016) are generally included in the Papas model (2015) the framework presented in this article suffices with the same results.

Finally, the fourth element is called data-driven digital transformation and sustainable societies as a result and the ultimate goal of this proposed framework, which derives from the convergence of digital transformation and achieving balance and stability of cyber-physical-social systems. It cannot be forgotten that this convergence is due to the slow and fast data flow.

5. Conclusion

Today we are facing the most mature level of cybernetic systems, which of course is young. These cyber-physical-social systems, with their extreme abstraction and a large amount of data, make us face some chaotic and complex systems. These systems are inherently transformational, and we need abstract analytics and thinking in the big data world to control them. To manage this complexity, we have to wash our eyes and see data-driven. We need to harness capabilities such as technical/managerial skills and a variety of technologies, and we need to spread organizational learning and data-driven culture to create the purest values through transforming systems and businesses and decent change in societies.

Undoubtedly, such an approach helps us experience the digital transformation of a data-driven and sustainable society.

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