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Digital Twin for Services (DT4S): Conceptual Strategy

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Abstract: While the Digital Twin is now well discussed in manufacturing, the research considering the Digital Twin of services engineering is still in its early stage. The Digital Twin is very focused on the manufacturing operations with gathering data from physical means and information technology. Yet, services are now features and core concerns of complex systems development. However, it is not much focused on services and above all workflow orchestration to deliver these services to user whether it is an internal operator, or a customer. The engineering of Digital Twin services is a complicated phase because of the complexity of interactions and heterogeneous nature of services. The simultaneous use of models and data (e.g., Model Based System Engineering (MBSE)) should be considered for service-oriented engineering projects of complex system (large system, heterogeneous components, autonomous, etc.). Based on this postulate, the contribution of this paper is about Digital Twin and MBSE for Servitization industry. In detail, the paper proposes a recall of information systems for enterprises, workflow and servitization. Then it draws some perspectives about the interest of Digital Twin approach based on models for product service systems. It discusses the relation between service twin and ground data and the link to decision level.

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Keywords: Digital Twin, workflow, PSS, servitization, Model Based System Engineering (MBSE)

1. INTRODUCTION

The Digital Twin is one of the main concepts associated with the Industry 4.0 wave (Uhlemann et al. 2017). This term is increasingly used as a new trend in industry and research. Since its appearance, it gets a particular impact on the literature. Since 2016, it gained its place on the podium of the top 10 technologies according to Gartner. From 2020, it still marks its place as a pillar of orchestration technologies of Hyperautomation which is today of top trend on the Gartner Top Strategic Technology Trends for 2022. However, most research focuses on developing a virtual system equivalent to a physical system while focusing on the maintenance of transformation resources in relation to manufacturing level which disregarded the important role of services and product service system (PSS) in creating value throughout the system life cycle (Zang et al. 2019).

The potential of Digital Twin here is called for to improve the execution of workflows between a wide variety of resources, so that when conducted properly, it can bring significant results in terms of performance. However, of side of business services and support process it is still at the beginning of the expression and formalization of this concept. Based on this premise, the contribution of this paper is about drafting a method to develop Digital Twin for the servitization industry. The method may be supported by the MBSE that will support the system requirements, design, analysis, verification, and validation activities beginning in the design phase and continuing throughout the development and later phases of the life cycle (Chapurlat, et al. 2020). Then, among the challenges,

even if it is already digitized, a service still faces the escalation of information from the physical level to different users. Overcoming this barrier with a clear model-based approach and Digital Twin support will add value to further formalize service orchestration and execution. Indeed, it is obvious that the relationship between the Digital Twin and the different levels of the enterprise information system as described by (Le Moigne 1990) is still a subject of discussion to be addressed. In particular, the data handled at decision level (fig.1) must be specified with respect to the use of the information processed by the Digital Twin.

In detail, the article proposes a reminder of enterprise information systems, workflow, Digital Twin and servitization. It then outlines some perspectives on the interest of the Digital Twin approach to support systems producing products and/or service. Systems engineering (and therefore MBSE) is interested in both products (ISO15288, 2015) and associated services such as, essentially, services that ensure the maintenance in operational conditions of the future product (maintenance, piloting, logistics, etc.), which then find their full meaning in terms of the need for Digital Twin. The proposition then presents why service industry needs Digital Twin to provide more connection with customers and users, help, alert, monitoring, failure prediction, etc., and more specifically in the case of product service systems where a lot a personalization is required at each step of the design and production. Yet, this Digital Twin for service-oriented production is a position concept that will still need further refinements discussed at the end of the paper.

2. STATE OF THE ART

Information in enterprise can be considered as a system that provides services and support to decision. It handles more and more large volumes of data, to provide for a large and potentially complex system. This services system is used by all parts and levels of an enterprise to transport, store and orchestrate information. The information system has been considered as critical since the beginning of the new industrial era in the 60's with the vision of general system theory described just after. But in 2020's, it is still a crucial challenge to correctly handle information by defining proper workflows in the digital world.

1.1 System Theory concerns

The major contribution of computer to industry has been made since the 1970's by several steps where at the end it has been obtained the workflow management systems and more recently, service and Digital Twin. In the 1970s, several works intended to study the impact of efficient data management and organization methods over the industry performance. For instance, Le Moigne (1990) introduced systems theory and the works on the GRAI-GIM methodology started (Zacharewicz 2020). The objectives at that time were to model a production management system to specify needs then to choose a software package for a Computer Aided Production Management system. These methods were supported by the development of database management systems (DBMS) making easier the data extraction from applications. At that time, the "information" model has given rise to the notion of "information system". The information system consists of everything that stores, memorizes, and makes information available (Le Moigne 1990) (Fig. 1). The information system is thus the transmission belt of raw data and information, but also of knowledge (business rules, constraints, objectives, reports, etc.) between the decision-making system, the company's operating system and the outside world (via Internet, for instance relations with key suppliers and customers, etc.).

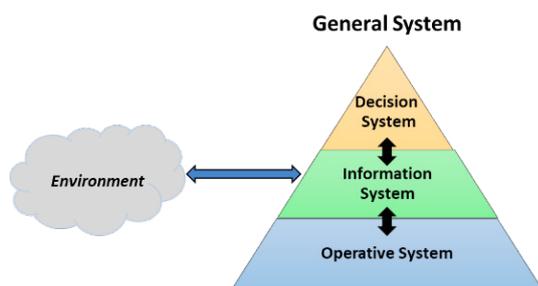


Figure 1 System Theory Information Model (Le Moigne 1990)

Then, according to (Van Der Aalst 1998), in the 1980s, the emergence of User Interface Management Systems (UIMS) allowed application developers to extract user interaction from applications. Then, the appearance of workflow management systems was the next step in extracting generic and orchestrating functionality from applications. The 1990's were marked by the rise of workflow software, allowing application developers to extract work procedures from applications. Nevertheless, application contents from diverse sources and targets lead to interoperability barriers. This issue has been

overpassed by system engineering and in particular MBSE approaches. *How MBSE is contributing to workflow design?*

1.2 Model Driven or Model Based

According to NASA (NASA, 2020), INCOSE defines MBSE as "Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases." In the frame of System engineering, it will be a good challenge to develop the features that can be enhanced by Digital Twin at decisional level.

In addition, the principles of Model Driven Engineering emerged to face up the problem of growing complexity, multiplicity of platforms, need of interoperability and evolution (MDE) (Zacharewicz et al. 2020). It is a good support to navigate from the models of information system to the operative and decisional level.

1.3 Workflows

According to (Zacharewicz et al. 2008), it is difficult to find in the literature a single, and unanimous classification of workflow systems. This is mainly due to the criteria on which it is possible to classify them. These criteria vary according to the different points of view that specialists adopt regarding Workflow and the perception that they have of the services to be rendered or the characteristics presented by these systems. Nevertheless, it is admitted that workflows orchestrate data and tasks to be done human, digital things, and physical means in enterprises. A classification widely used in the literature was proposed by (Mc Cready 1992) and since has been taken up by several authors (Van Der Aalst 1998). It proposes to distinguish three categories of Workflow Systems:

- **Production workflow** systems are very structured since they are linked directly to the enterprise's operational activities. This workflow corresponds to "mission critical" business services. The tasks interrogate devices at operative level, so they are likely to be adjusted less often than pure information processes, due to their link to physical system.
- **Administrative workflow** systems manage data processes. It is about supporting office tasks. The administrative workflow systems route the documents and information necessary for the execution of tasks by an actor (e.g., human, IT). The process and rules are clearly defined and therefore easily automated and scalable.
- **Ad-hoc (adaptive) Workflows** are comparable to production workflows but can handle changes due to uncertainty. These changes can range from local changes (exception handling) to processes redesign (due to alterations or evolution), both having impact in workflow structure. Adaptive Workflows classify the possible changes and attempt to anticipate them. Changes can be considered from several sides: resource, control, process, task, and system.

We believe that the need for greater flexibility and reactivity in Digital Twin leads to a significant perspective about the use of ad-hoc workflow including dynamic changes. Then, with these workflows, information will be gathered from the operational level, whereas ERP deals mostly with information from the information system. Collection of human actions performed and information from IoT will allow to sequentially execute the next steps or the reconfigure the workflow in case the event collected does not correspond to what was expected. To anticipate reconfiguration, simulation may be an option. But it has not been clearly identified in the workflow system or in most ERPs. Thus, forecasting is one of the futures that is another value sought in the digital twin compared to traditional information systems. Thus, the generalization of the ERP concept including resources like human or physical means and digital things could be interesting.

In conclusion, the ERPs and Workflows of the 2000s have made the orchestration of data and resources more efficient but have not yet achieved the integration and reactivity of what is now called the Digital Twin.

1.4 Digital Twin

The design of a virtual digital equivalent to a physical product or a Digital Twin was introduced in 2002 by M. Grieves from the University of Michigan in connection with product lifecycle management (PLM) (Grieves et al. 2017). The Digital Twin originated from aerospace field and has quickly been adopted in industry few years later. Since several works have been published to provide various and diverse definitions of this concept. Several fundamental issues of Digital Twin concept definition are still addressed in the current bibliography. The review of (Negri et al. 2017) has led this flow. In effect, it introduces a review of the Digital Twin concept in a systematic approach. It presents 16 definitions of Digital Twin in the literature, aiming to establish a common and meaningful definition for this concept in the manufacturing context. Subsequently, there was a wave of positioning work, which participated to enhance the maturity of Digital Twin concept and remove several conceptual locks about definition and integration level (Cimino et al. 2019), other identifies new research questions (Sharma et al. 2020), introducing new consideration vision of the Digital Twin, this confirm that it still a long way to go to reach the required maturity level. Until now, developing a full Digital Twin still a complex and challenging task in industry because of the huge amount of data and models involved and implementation cost.

The common feature of all the before mentioned studies is that they introduce the Digital Twin from operative management view. Indeed, although various definitions exist, the core of Digital Twin is the same. It is always presented as a credible and plausible virtual replica of a physical system with real-time bidirectional communication for simulation purposes and decision-making features for manufacturing improvement as presented by (Lim et al. 2020). As defined, a 3-dimensional Digital Twin architecture covers the physical system, the virtual system and the interaction element (Rabah et al. 2018) in manufacturing level.

In this respect, the standard (ISO 23247 2021) was introduced, it defines a framework of use of Digital Twin in manufacturing industry as a virtual representation of a real manufacturing. This guideline provides a formal definition of Digital Twin, its resources, and its environment. As next step, the ISO 23247–2 series will introduce a structure of this field and a Digital Twin reference architecture for manufacturing (Aheleroff 2021).

The recent work of (Semeraro 2021) discusses classifications of Digital Twin definitions according to application contexts, life cycle phases, functions, architecture and components and research issues to identify the scientific and conceptual constraints and explore possible technical challenges in the design and construction of Digital Twin. It is henceforth necessary to develop a systemic approach, which will make it possible to associate the real system with its Digital Twin over the whole process life cycle (Lim et al. 2020) to bring this concept to consider new information level as introduced in (Le Moigne 1990) even though this work still based on a standard 3-layer Digital Twin concept.

Therefore, in order to give a whole Digital Twin Concept definition, our reflection must be oriented towards a global vision of the concept by considering the information and the decision level of Le Moigne. Newly, in a major step to forward Digital Twin global vision, authors (Qi et al. 2018), (Zhang et al. 2021) and (Wu et al. 2021) extended 3 dimensions to 5 in showing the combination of smart manufacturing services and Digital Twin would radically change product design, manufacturing. As defined by the authors (Qi et al. 2018), a five-dimensional Digital Twin architecture is composed of:

1. Physical entities are the set of objective entities, which have specific functions to perform manufacturing tasks based on inputs and outputs.
2. Virtual models are the digital images of physical entities, which can completely and truly reflect the life cycle of physical entities.
3. Services integrate various functions such as management, control, and optimization, to provide application services according to requirements.
4. Data Fusion and interoperability is a core engine of the Digital Twin, including data from physical entities, virtual models, and the service, and their fusion data.
5. The connections between them link the above four parts in pairs, ensuring real-time interaction and iterative optimization. Based on this five-dimensional structure, the Digital Twin offers a new practice of smart manufacturing.

This last definition introduced a new vision of the Digital Twin by highlighting the major contribution of this concept in the context of Smart manufacturing, (Qi et al. 2018) valorises and justifies the importance of the service offer proposed by the Digital Twin, this work was followed by an analytical review presented by (Zhang et al. 2019) in order to justify the importance of this concept. On the one hand, it presents a

systematic review study that explore the Digital Twin in services and PSS. As a result, it concludes that most research to-date focusses on the monitoring of production manufacturing system justified by the small number of works that consider the Digital Twin in services. This study shows that despite a new vision of service-oriented production, most of the literature remains focused on the use of the digital twin for a service in a production of physical goods and maintenance context. On the other hand, this paper gives the arguments to stress the importance of use of Digital Twin in the context of PSS and outlines possible applications for all stages of product life cycle. It had to wait (Ahleroff et al. 2021) that introduce a Digital Twin Reference Model in order to give a general Digital Twin as a services (DTaaS) paradigm.

Referring to those definitions, and while considering the System Theory Information Model of Le Moigne, a new conceptual definition should be presented to give a clear explanation of this position. The state of art proves that all previous work about Digital Twin still mostly related to manufacturing level without consideration of the higher information levels. However, these levels are directly affected by this digitisation of the system since the Digital Twin will be interacting with these levels for the purpose of decision support, and therefore all interacting services must be digitised and so must have Digital Twins, which leads to the big question, *what is a Digital Twin for services (DT4S)? and how can it be represented?*

3. DIGITAL TWIN FOR SERVICIZATION & PRODUCT SERVICE SYSTEM

Servitization is when customers pay for a service - such as a subscription to use a car - rather than purchasing the vehicle itself. According to (Zhou et al. 2020), the product service system (PSS) approach is one of the main avenues for the development of servitization industry. It has been studied by many researchers, who mainly focus on system integration, types of services, stakeholders, and interaction, etc.

Nevertheless, (Zhou et al. 2020) pointed that only a few studies have dealt with co-creation of value. (Goedkoop et al. 1999) defines PSS as an innovative business model which composed of products, services, infrastructure, and stakeholders to better enhance the overall competitiveness of the enterprise, meet customer needs, and avoid harm to the environment. He points out three key elements of PSS: products (tangible goods manufactured for sale), services (economically valuable activities for others), and systems (a collection of elements that include relationships among them). We believe that Digital Twin is an important asset to enhance the system side of PSS better involving user and customer in the co-design and production loop either of products and/or services. The perceived value of being used by customers when using products and/or services in PSS can be augmented by Digital Twin, and with it, customers play a key role by better communicating in achieving this value. Customers are better re-involved as co-producer during the process of value-creation, so PSS needs to include customers through Digital Twins in a suitable way.

Supporting PSS concepts towards the development of services with software and physical means is not an easy task. PSS are often complex, as they might include mechanical, electronic and software components. To achieve optimal results, it is essential that all these components and resources work together. The interdependence between the resources and components of a service requires a perfect understanding of the requirements. MBSE promotes a better understanding of the processes between the different teams, and thus allows them to be more efficient in their tasks. On the other hand, thanks to the simulations that MBSE allows, engineers can ensure that each component of the system is well modeled, detect possible errors and correct them as soon as possible.

As key contribution, this paper presents an alignment of information system and Digital Twin with regard to information levels in Fig. 2. Referring to Le Moigne, it suggests on a symmetric but inversed pyramidal structure in Digital Twin since it generates more feature and skills at information and decision level. They share a common point, both including the 3 major information layers, and both being influenced by exchanged data at different layers with frontiers of the Digital Twin (i.e., blue V in Fig. 2).

Typically, the Digital Twin is connected at operative management level to gather different source of data coming from connected objects including IoT. Standard and current research (state of art) is focusing with the objective to bring information from the operative level to information level to feed models and run simulation at information level.

It can be used as well to build and provide services to customers. In this regard, we distinguish human interaction by users that can be considered as part of the system interacting at operative level and customers that are interacting from outside at information level.

In addition, even not frequently presented, we believe that one core and central component of a Digital Twin is a workflow management system (WfMS) such as the concept proposed by the WfMC and recalled by (Deelman et al. 2015) and Zacharewicz et al. 2008). It enables automated and seamless execution of digital functions and field workflows. According to literature, it allows users to define and model workflows, set their business process deadline, simulate scenario, and monitor Key Performance Indicators (KPI) of interest and anticipate their limitations, and regarding the environments in which digital wish to execute. The WfMS then evaluates these inputs and executes them within the defined constraints. It is the backbone of a Digital Twin.

The Digital Twin is not frequently presented in the literature at tactical, decision or driving level. So, we believe that a next step for is to develop the features of decision level that can gain from inputs provided but the Digital Twin. Regarding this aspect, we present in the fig. 2 some feature that can, be used at decision level including virtual reality / augmented reality environment to help taking decision in in immersed or augmented environment. Then business intelligence needs data warehouse with huge volume of data. Digital Twin can help to generate these data. Then it can help to obtain more data about key performance indicators.

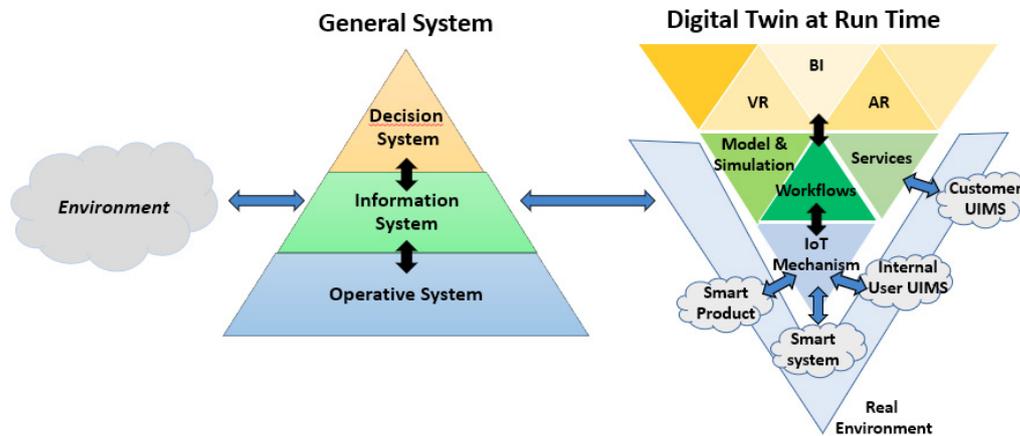


Figure 2 Digital Twin for Services (DT4S)

We propose to stress the difference between different kind of process in the Digital Twin workflow. Business process and support process need to be considered. Business process can be described by BPMN models, they represent the business activity steps of the enterprise while support process is seen as administrative workflow it interacts frequently with internal users and customers, the benefits, and risks of customer participation in PSS development need to be rethink, aiming to identify the factors affecting the benefits and risks from the perspective of the characteristics of PSS and its customer participation. As a result, the concept of Digital Twin for Services (DT4S) is proposed in this paper to enhance the service aspect in Digital Twin in the frame of administrative or service workflows that require to be “digitally twined”.

In service-oriented approaches, Wang et al. (2015) proposed the concept of value co-creation product service system network and analyzed the value co-creation in combination of product and service based on the value network. The Digital Twin can be the corner stone about how enterprises, customers and the environment will create value together through value interaction in the Digital Twin service ecosystem under the internet environment and constructs a value co-creation product service system model of enterprise-customer-environment, linking the enterprise, the customer, and the environment through value creation.

Focusing on the problem of enterprises and customers cooperating to achieve value added in PSS, (Hu 2019) puts forward a value co-creation product service system, which considers the efforts of both parties based on the value co-creation theory of service-oriented logic. Hereby, the current research of value co-creation is mainly related to customers, not all the stakeholders of PSS, and does not involve service process and value flow. In this situation the digital will be the common interface between different stakeholders providing them an appropriate vision of the information they need and asking them to contribute in their turn to the co-creation.

4. DISCUSSION

In future work, since Digital Twin refers to is an interdisciplinary field. We believe that systems engineering (Blanchard 2004) will support confident and appropriate engineering management since it focuses on how to design,

integrate, and manage complex systems over their life cycles. Among System engineering contributions, MBSE (Lemazurier et al. 2017) will be investigated to navigate in a more controlled manner from the different models that can represent the different parts of the Digital Twin at build time and to anticipate future and run time. Digital Twin mostly takes place in the literature at implementation level, but we believe that it can be used at the different steps of system engineering including the Requirements Capture and Analysis, the Architectural Design, SoI Functional, Logical, Organic and Physical architectures design, the Implementation, and then the Analysis support processes.

As perspective, the use of intelligent agents in simulation models of the Digital Twin at build time will be based on the idea that it is possible to represent the behavior of the different active entities in the peripheral world of the Digital Twin in terms of interactions of a set of agents (e.g., Smart, products, Users, customers) having their own operational autonomy. The work of Tuncer Oren (Yilmaz et al. 2009) provides an interesting insight to do this.

5. CONCLUSIONS

These works at the crossroads of workflow, Digital Twin, and service industry. The Digital Twin was mainly focused on the relationship between the operative level and the informational level by dealing with the problem of data collection and formatting in the information system. This system was also very much focused on the manufacturing and user relationship whether it is an internal operator, or a customer was only slightly detailed. Then the information feedback to the decision-making level is also an aspect that has not been addressed much until now. So, this paper initiated a big picture and a discussion to allow to identify new perspectives for the industry 4.0 indeed this industry join more and more closely products, services and systems that allow to connect them.

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