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The Role of Digital Twins in the Fulfilment Logistics Chain

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Although Digital Twins has gained great momentum in the last few years, even being developed in the scenario of manufacturing systems, scarce attention has been devoted till now to the Logistics Digital Twin (LDT). In this paper we describe the first efforts to define the requirements and derive from them the architecture and framework for LDT for fulfilment centres. The analysis stems from actual logistics platforms, for internet orders fulfilment and will use them as verification, validation and accreditation (VV&A) testbed.

Keywords: Complex logistic systems, Digital enterprise, Enterprise integration Industry 4.0, Smart Manufacturing, Digital Twin, Fulfilment Centre.

1. INTRODUCTION

Digital Twin (DT) has been defined as long as 15 years ago. According to Grieves (2014) he had proposed such tools already in 2003, in his lectures on Product Lifecycle Management. Only in the last few years the concept was better shaped, leveraging on the exponential increase in the power of the IT tools, sensors, embedded systems, IoT, able to generate and analyse plenty of data. As a possible definition in the manufacturing environment, we can adopt the one coming from (Zhang et al., 2018) "A dynamic model in the virtual world that is fully consistent with its corresponding physical entity in the real world and can simulate its physical counterpart's characteristics, behaviour, life and performance in a time fashion".

In the meanwhile, the structure of proposed DT has evolved from the first three-dimension framework introduced by (Lee and Seshia, 2017), composed of 1) a physical object, 2) a virtual counterpart and 3) a connection, to five parts (Tao et al., 2018) adding 4) data and 5) services.

The great interest coming from several industries is demonstrated by the birth of a workgroup in the TC184/SC4 ISO sub-committee for Industrial Data, which recently approved the four parts standard ISO-23247, for the circulation as a Draft of Industry Standard on "Digital Twin manufacturing framework" opening to the realization of Manufacturing Digital Twins (MDT).

Notwithstanding this developments, few works have been published on DT development and utilization in the scenario of fulfilment logistics plants. For this reason the need to fill this lack; our work will try to define a model for Fulfillment Centers (FLC) able to help the management in taking the decisions, as in the work of (Tao et al. 2017) with their decision making DT; a whole review of logistics systems inside the context of Industry 4.0 can be found in the article of Winkelhaus and Grosse (Winkelhaus and Grosse, 2019). Inside the section regarding the CPS Cyber Physical Systems many works are cited but no one with the specific intent of building a managerial tool for fulfilment centres FLC. The raw materials as well as the finished product warehouses are certainly in the scope of modelling of an MDT, but even recent surveys like (Kritziger et al.,2018) do not report on specific application on inner logistics of materials. Moreover, the highly specific issues of a fulfilment logistic platforms, as far as the Authors can know, have been addressed only in (Korth et al., 2018).

A Fulfilment Logistic Centre (FLC), as it will be considered in this work, is a plant/logistic platform, where the customer orders are fulfilled. This process apparently simple hides many complex sub processes. With the term fulfilment it is intended the submission of a product/service to a single and final user/customer. Our work will be focused on a fulfilment centre that delivers physical products to final customers. Figure 2, later on, describes the basic steps for fulfilling a physical order of a customer, ordered, for example, on a website.

A FLC, following the vision of Industry 4.0 paradigm, can be seen as part of a wider chain, where also suppliers and other players are involved, and the interoperability among all the actors is part of the game. Gartner (Panetta K., 2017) list DT in its yearly analysis for 2018 emerging technologies. Many big players are in the race to get a DT as soon as possible in order to gain achievements for several aspects, we will try to examine later in this paper, and eventually to reach costs reduction and gain competitiveness.

Inside the paradigm of Industry 4.0, aim of this study is to answer the following research question:

RQ(1): what kind of framework would allow the development of a supportive tool for the management using a DT for a Fulfilment centre?

To give an answer to RQ(1) a LDT will be developed and the results given to the management of the testbed facility. During a second stage the effectiveness of the LDT will be proved and tested through a survey given to the management.

In order to give a clear outlook of our work, this paper is the first step of many that has the objective of creating a Digital Twin for fulfilment centres inside the logistic chain of Web stores. With this paper we set the fundaments of our work: starting from the interaction between academicals and industrial environments purpose is a DT able to forecast the behaviour of a fulfilment centre under different conditions; for example when a increase in sales (Black Friday) is there to see the reactions of the system and a proper planning in resources is needed.

The following of the paper is organised as follows: in the second chapter several applications of DTs to diverse sectors are presented together with the different use cases and purposes; chapter 3 lists some implementation of DTs to logistics while chapter 4 discusses similarities and differences in fulfilment logistic centres. Chapter 5 draws out the conclusions and presents the future steps of this research.

2. APPLICATIONS OF DIGITAL TWINS

As a matter of fact, DT can be applied to remarkably diverse scenarios, going from the products to the systems. One of the use is certainly in supporting the different life cycle phases of a production plant, but in general DT can provide better insight on processes, as in traffic, smart cities and many others fields of application. A DT is the natural evolution of a digital model of the product/system, usually a simulation model, enabled and powered by means of new or enhanced technologies and their decreased cost. For instance, Big Data analysis capabilities, IoT and IIoT diffusion, and 5G network deployment, provide now a fertile environment for DTs as in (Zhang et al., 2018): now a simulation model can communicate quicker and in real time with the environment (intelligent sensors) being up-to-date with the representation of the physical counterpart, and the huge amount of data can be smoothly processed with the new IT tools as the one for the implementation of Artificial Intelligence. It needs to be remarked that some of these enabling technologies are not new at all, but have been developed and their implementation cost has dropped dramatically; mainly for these reasons it is now possible to empower a simulation model in order to transform it in an actual DT. The DT in fact is a simulation model that is connected to the real world and thanks to this interconnection it is able to use the real state of the system in order to perform a simulation in a digital environment. The output of a DT could be used in many environments, in order to have better insights, to analyse and to predict a future state of a real or digital system. We mentioned a digital system also because a DT could be used during the different phases of the lifecycle of a system. In Figure 1 below we schematize the application fields of a DT.

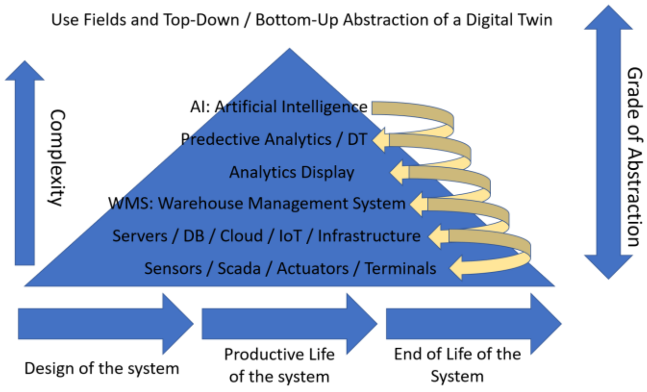

Fig. 1. Abstraction of a DT and its lifecycle.

From Figure 1 it is possible to observe how wide is the application field of a DT; its interoperability allows a DT to be applied to different phases of the lifecycle of a system and also to different types of industries, from health care to heavy machinery, as described in (Dohrmann, 2019) where many application industries have been listed.

For example, manufacturers of gas turbines start selling their products as a service and no longer as a simple self-standing product. The age of servitisation of a product is now there and not only buying a product but renting it, will be even more present. This means that the data is collected from the field usage of the product while the customer is using/experiencing it. The collected field information is then sent to a DT, that for example, processing the information is able to set the optimum for maintenance intervals or the right usage setup, in order to consume less and save costs (Baron, 2018).

Another example of a DT is in the management of a city traffic, by using the traffic lights as traffic doors; this could lead to minimize the traffic queues and reduce the smog and dust impact.

Figure 1 reports 3 Phases during which a DT could be used in order to save costs and reduce the carbon footprint. For example, in the first phase, of system design, a DT could be used to correctly dimension the parts of a process even before the existence of it; this allows the designers to avoid bottlenecks later on in the production phase; this way of dimensioning a system or an asset in its Beginning of Life (BOL), testing it on a DT in design phase, reduces the risk of having greater issues in the productive phases of running a plant. In this use DT can be defined as a Digital Twin Prototype (DTP) as (Grieves, 2019) explains.

During the productive life of a system, the DT helps to find out the optimum of used resources in order to run optimally a production process.

While in the final phase of a system, the DT helps to determine the optimal running costs in order to reduce production costs or revamp the plant with different products. In such use, DT can be defined as Digital Twin Instance (DTI).

Another important role for DT in the Middle of Life (MOL) or End of Life (EOF) of an asset is to enable the collection of use information and performance by an asset vendor or by users of multiple assets of the same kind (like in the case of airplane engines and in general of a company that manages fleets of assets). This allows the single DT to leverage on the knowledge coming from all the other identical DTs in place, and can be defined as a Digital Twin Aggregate (DTA), (Grieves, 2017).

According to our perspective, similar to MDT, (Grieves, 2017) formalises the typical use of a DT for managing the manufacturing operations in a factory. Besides the replication of the physical twin, that makes it more "transparent" and increases the knowledge of the system's state, the MDT can be used for Front Running Simulations (FRS), for instance simulating the future behaviour of the system subject to some perturbation of the endogenous or exogenous variables like machines fault, employees availability, demand increases and so on.

3. DIGITAL TWINS IN LOGISTICS

Coming to the aims of the Authors' research, i.e. the implementation of DT in logistics fulfilment plants, many papers reports about the application of DTs in logistics, but few of them cover the specific case of a fulfilment centre. In the past, many simulation models (also called Digital Models to differentiate them from DT) have been developed but none of them can be defined as an actual DT. We should say that this lack of coverage can be the result both of the recent definition of DT paradigm, and the emersion and empowerment of the technologies on which DTs are based. As a matter of fact, in past scientific and managerial literature many examples of Digital Models for logistics were published, and some of them with core features typical of DTs. As previously cited the work of (Winkelhaus and Grosse, 2019) has reviewed many works inside the context of industry 4.0 and logistics, leaving a gap for a managerial DT in fulfilment centres.

In the white paper of (Dohrmann, 2019) it is possible to find a short chapter about the e-commerce, but applied to shop layout and the prediction of future buying behaviours, and not the application to the logistics environment behind this new huge phenomenon.

More and more papers are being published, as the one of (Tao et al., 2017), concerning the application of a DT in manufacturing environment (Smart Manufacturing).

Our purpose is the transfer of a similar paradigm to a pure logistic system. While in a manufacturing plant it is possible to have different shop-floors that do some operations in order to enrich raw material with some kind of operations on the material itself, and thus the movement and storage of raw materials and finished products is a logistic process, in a logistic plant it is possible to assume that the process of packing the products is the equivalent of the shop-floor process/operation and the picking, moving, of the single items upstream, and the moving, sorting and shipping of the boxed items downstream is the logistic process.

4. A DIGITAL TWIN FOR A FULFILMENT LOGISTIC PLANT

Bringing ahead the parallel of a fulfilment centre with a manufacturing environment we can use the schema about the "Operation mechanism of a DTS" (Tao et al., 2017) which considers 3 phases: before, during and after production. In a fulfilment plant an order coming from an online customer can be considered as a production order to be processed in an Manufacturing to Order (MTO) environment as in (Worthmann, 1983). To fulfil the order different phases are needed. To be considered is also the work of (Zhang et al., 2018) where a framework for a production-logistics system is reported and a case study has been developed assigning also objective functions to the model. In order to fulfil to our aim the model of Tao and Zang (2017) is the one that we will consider as starting point for our work; their model needs to be adapted from a manufacturing to a logistics environment.

A Fulfilment Centre (FLC) can be considered as a storing centre where the orders of customers are produced/fulfilled within a specific time frame. There is a warehouse with a storing capacity that on request has to be ready within a certain time frame to dispatch the order as packed good(s). First the order arrives into the warehouse management system (WMS) of the facility; at this point the WMS creates a picking batch order according to a specific logic; then a picker goes to pick the items according to a specific route assigned (Man to Goods). In some highly automatized plants, some Automated Guided Vehicles (AGV), automated transportation units that have the task of carrying some material from point A to point B, can bring the goods to the operators (Goods to Man). Once the goods are collected by different pickers, these are then consolidated into single orders ready to be packed. After packing, these are sorted to specific vectors according to their delivery time frame chosen by the customer (for example express or standard shipment). To cover all the plants, we should consider also the process of storing the goods arriving from the vendors, which certainly impact on the use of resources. But this process is performed in shadow with respect to the fulfilment process and thus it does not affect the customer perceived performance, and we can keep it out, at least in the first approach of our work.

In Figure 2 is described the typical flow of the Man to Goods process. This is a typical process in a fulfilment centre that uses a not fully automated way of picking the items. The picker receives assigned a picking list of items belonging to a certain area and starts the tour of picking these. In the case that an item is not available then the picker presses a button on the handheld and a back loop as in figure 2 is generated; in this case we have a Pick NOS (Not on Stock) and the item is set back in the picking container for a second trial according to certain rules.

Figure 2 reports also the packing procedure also in this case it is possible to have a back loop if a Pack NOS occurs, the order is set back in the picking container waiting to be released according to certain rules.

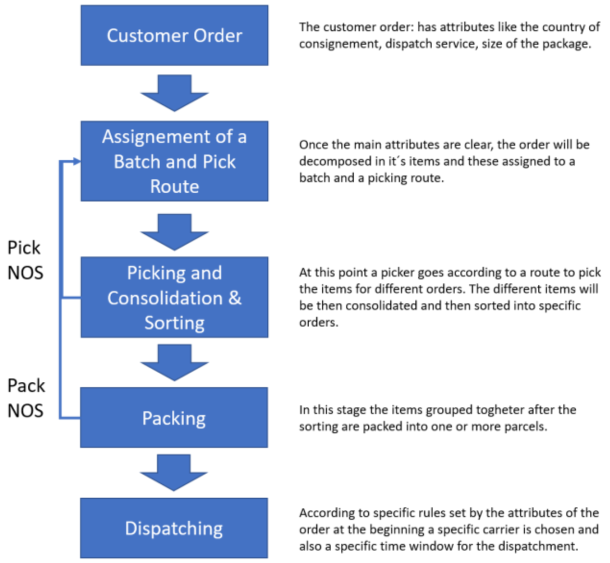

Fig. 2. Basic steps of fulfilling a customer order (Man to Goods).

From the previous description it is possible to see that there are two main phases:

- The first phase gathers the requirement for the production process and is a virtual one; in fact the order is collected together with its attributes and a "production plan" is generated in order to collect the items and consolidate them into a parcel.

- The second phase is a real one, the picker has to collect the real items and sends them to consolidate and then to sort. In this second phase the packing step is foreseen.

With the aims to define the requirements, and derive from them the architecture and framework for LDT for fulfilment centres, we can generalise the two different configuration. We can schematise a FLC with two main parts which could be redundant of each other. The two main parts will include on one side a manual process of fulfilling orders while on the other side a highly automated system able to do the same but with less resources. The downstream part of the process is the automatic handling of the packages assembled, this is common to both configurations.

Such LDT can be developed to be a DTP, to be used in the design phase of the FLC to choose the automation level, to dimension, to forecast the workforce needed and asses the delivery performance of the plant. For this use the data to be used can be given by the historical transactions of other similar plants or the results coming from other similar DTs. In any case, keeping in mind that the core structure of a LDT for FLC, like in the manufacturing applications, can be the same both for the DTP and the DTI, we start from developing the requirements and the related architecture of the latter one.

The LDT will get the data from the WMS and from other sources (like the plant's SCADA, and the MES Manufacturing Execution System if it exists) which allows a long range planning and simulation period stemming from the present situation. The main aim of the LDT is to be used by the management during the lifecycle of the plant as a supportive tool for decision taking in the operations. One of the key issues of the DT is going to be the information flow among the various parts needed. Keeping in mind the parallel with the work of (Tao et al., 2017) is possible then to specialise the latter for a FLC. The LDT will be integrated with the WMS of the plant through an API (Application Programming Interface) interface, this will allow through SQL programming to feed the LDT with the right Data and almost in real time (delay of 10 to 20 Minutes) with respect to the productive environment. Figure 3 reports the schema of the information flows among the different parts of a LDT, distinguishing among the 3 phases of: before, during and after production. This schema is a first tentative stage of representation that could change during the development of the real LDT and its validation in the real and cyber environments, the so called Cyber-Physical System (CBS).

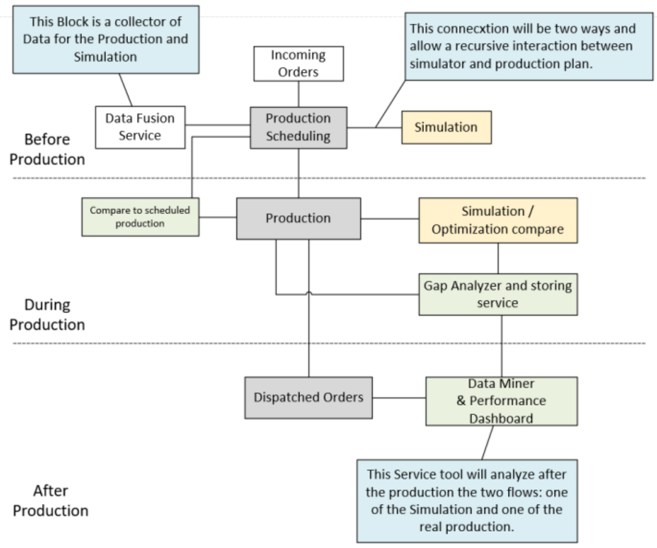

Fig. 3: Information systems, manufacturing activities and services for the DT adapted to fulfilment plants.

From Figure 3 is possible to have an outlook among the different parts of the DT and their interaction flows. In a first stage the real orders arrive to the WMS from a website; then these are processed according to their attributes in order to be assigned a priority and a picking sequence for collection.

Objective of this schema is to give a first framework for the next step of our work of building and programming a DT through data retrieval from different sources and the simulation model itself. Our contribution will be the development of a LDT in a nice segment of DT for Logistics and the aim to shape it as a usable tool for the Management in the testbed environment, the FLC in which will be validated.

The data fusion service similar to that of (Tao et al., 2017) collects all the data needed in order to run the production scheduling and the simulation tool as well.

In the production phase: the real production is compared with the scheduled production and with the LDT virtual production. If any discrepancy is monitored, this will be reported to allow to diagnose it.

In the after production phase: the real dispatched orders and a data miner tool cooperate in order to get the relevant information for the management (KPI Dashboard for example).

As final phase of the work is foreseen a validation of the DT on a real fulfilment plant. The first step of validation will consider historical data from the plant itself; the second stage of validation is going to predict a future state of the plant and validate the data after producing.

5. CONCLUSION AND FUTURE WORK

This paper has the aim of defining the requirements, and deriving from them the architecture and framework for LDT for fulfilment centres in order to build a LDT for a generic fulfilment plant and verify, validate and certify it; the LDT is going to help the management in their critical decisions trying to reduce the risk or at least assessing the risk for each scenario of conduction. In this early stage of this work the literature has been reviewed and a first conceptual model of the LDT stemming from the one of (Tao et al., 2017) has been developed. Next steps will be the formalization and implementation of the Digital Model with a suited simulation software and then the verification and validation with respect to a real plant. Results of this first stage are the identification of a framework starting point, as the one of (Tao et al., 2017) and it´s adaptability to the different field of application.

REFERENCES

Baron, K., (2018). Seeing double: Digital Twins make GE and Baker Huges supply chain innovators. [Online], Available at: www.ge.com/reports [last accessed on 20/10/2019].

Dohrmann, K., B. G. J. W., 2019. Digital Twins in Logistics: a DHL perspective on the impact of digital twins on the logistics industry.

Korth, B., Schwede, C., Zajac, M., (2018). Simulation-ready digital twin for realtime management of logistics systems. IEEE International Conference on Big Data, pp. 4194-4201.

Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W., (2018). Digital Twin in manufacturing: A categorical literature review and classification. IFAC PapersOnLine, 11 (51), pp. 1016-1022.

Grieves, M., (2014). Digital Twin: manufacturing excellence through virtual factory replication. Whitepaper.

Grieves, M., (2017). Driving Digital Continuity in Manufacturing. [Online] Available at: https://ifwe.3ds.com/it/media/driving-digital-continuity-in-manufacturing. [last accessed on 3/10/2019].

Grieves, M., (2019). Virtually Intelligent Product Systems: Digital and Physical Twins, in Complex Systems Engineering: Theory and Practice. American Institute of Aereonautics and Astronautics, pp. 175 - 200.

ISO/CD 23247-1 (2019), Digital Twin manufacturing framework - Part 1: Overview and general principles.

ISO/CD 23247-2 (2019), Digital Twin manufacturing framework — Part 2: Reference architecture.

ISO/CD 23247-3 (2019), Digital Twin manufacturing framework — Part 3: Digital representation of physical manufacturing elements.

ISO/CD 23247-4 (2019), Digital Twin manufacturing framework — Part 4: Information exchange

Lee, E.A., Seshia, S., (2017). A. Introduction to embedded systems: a cyber-physical systems approach, 2nd ed. Cambridge, MIT Press, Massachusetts.

Panetta, K. (2017). Gartner Top 10 Strategic Technology Trends for 2018. [online] https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2018/ [last accessed on 13/09/2019]

Winkelhaus, S. and Grosse, E., 2019. Logistics 4.0: a systematic review towards a new logistics system. International Journal of Production Research, 58(1), pp.18-43.

Worthmann, J.C., (1983). A classification scheme for master production schedule. In: Efficiency of Manufacturing Systems. New York: Plenum Press.

Tao, F., Zang, M., (2017). Digital Twin shop-floor: a new shop-floor paradigm towards smart manufacturing. IEEE Access **5**, 20418-20427.

Tao, F., Zhang, L., Liu, Y., Nee, A.Y.C., (2018). Digital Twin driven prognostics and health management for complex equipments. CIRP Annals, 1(67), pp. 169 - 172.

Zhang, Y., Guo, Z., Lv, J. and Liu, Y., 2018. A Framework for Smart Production-Logistics Systems Based on CPS and Industrial IoT. IEEE Transactions on Industrial Informatics, 14(9), pp.4019-4032.