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Literature Review of Integrated Use of Digital Twin and MES in Manufacturing

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***Résumé* – Ces dernières années, l'échange d'informations et de données est devenu une ressource essentielle pour permettre le développement de l'industrie du futur. A cet égard, le concept de jumeau numérique (DTw) a pris une importance croissante permettant à un modèle virtuel d'interagir avec son homologue physique et d'analyser ainsi de nombreux scénarii. De même, dans le domaine manufacturier des logiciels tels que le Manufacturing Execution System (MES) ont permis d'assurer la continuité numérique et l'interopérabilité entre les deux contreparties, permettant un flux d'informations en temps réel. Avec cet article, notre objectif est d'étendre l'analyse existante de la fabrication DTw et également de montrer comment l'utilisation combinée de DTw et MES peut apporter de nombreux avantages. Un domaine d'application possible a été identifié dans l'ordonnancement, pour lequel des études de cas ont été rapportées. Les résultats trouvés sont proposés comme un moteur pour des futurs travaux de recherche dans le domaine l'ordonnancement et la planification de production, aspirant à utiliser largement entre DTw et MES.**

***Abstract* – In recent years, information and data exchange have become an essential resource to enable the development of Industry 4.0 and the emergence of Smart Manufacturing. The Digital Twin (DTw) has become increasingly important in this respect, allowing a virtual copy to interact with its physical counterpart and thus analyse numerous scenarios. Similarly, tools such as the Manufacturing Execution System (MES) have made it possible to ensure continuity between the two counterparts, enabling a real-time flow of information. With this paper, our aim is to extend the existing analysis of DTw manufacturing and also to show how the combined use of DTw and MES can bring numerous benefits. One possible area of application has been identified in the scheduling, of which case study evidence has been reported. The results found are proposed as a driver for future research in a field of uncertainty such as the production planning and scheduling, aspiring to a complete integration between DTw and MES.**

***Mots clés* – Jumeau Numérique, Supervision Manufacturière, Technologies de l'Information, Méthodologie Intégrée, Système de Production.**
***Keywords* – Digital Twin, Manufacturing Execution System, Information Technology, Integrated Methodology, Production System.**

1 INTRODUCTION

Nowadays, in an increasingly dynamic and fast changing environment, manufacturing systems must ensure flexibility to enhance their productivity and survive the global competition.
In this regard, a general process of digital transformation and optimisation of production plants has taken place, referred to as "Industrie 4.0" (I4.0) in Germany, "Industrie du Futur" in France, and "Manufacturing Innovation 3.0" in South Korea (Negri et al., 2020; Wang et al., 2021).
This paradigm has paved the way for the concept of "smart factory", a flexible environment that creates the conditions for a highly modular and digitalised production facility (Negri et al., 2020), where integration and interaction between physical and virtual spaces is becoming increasingly important with the developments of new information technologies (Semeraro et al., 2021).
The natural development of a smart factory leads to the use of Cyber Physical System (CPS), defined as a device equipped

with intelligence and connectivity that enables the link between the virtual and the physical worlds (Martinez et al., 2021). In such a factory, information is one of the main factors to be considered. The continuous sharing of data allows full visibility and greater control of the shopfloor, thus enabling enhanced decision-making capabilities. Vertical integration which is about linking the IT systems from business to shopfloor can solve the problem of seamless production data flow right from the order generation to production execution. To achieve such information transparency, the middle layer of ISA 95, provided by the Manufacturing Execution System (MES), is crucial as it acts as a bridge between the enterprise layer and the shop floor layer (Mantravadi et al., 2022). MES main purpose is to track, monitor and document the process of transforming raw materials into finished goods, providing on-line information about the current situation to help managers and practitioners in the decision-making process on process control and optimization at the shop floor (Sellitto & Vargas, 2019). The presence of large amounts of data and the demand for greater computational efforts that MES provides, are enabler for I4.0 deployment.

At the centre of I4.0 technologies, we find the so-called Digital Twin (DTw), that is the key technology to realize CPS and the core to achieve smart manufacturing (Zhuang et al., 2018). DTw has been introduced in the aerospace fields, and then evolved in the manufacturing one. It is defined as the digital copy of a physical asset and conceived as a system that can replicate, plan, control and directly interact with its physical side (Negri et al., 2020). In the last few years, the concept of Digital Twin has been widely discussed, which provides a new solution for the optimization of production line system (Guo et al., 2021). However, despite DTw is attracting more and more attention, a univocal definition has yet to be found, and no common understanding concerning this term can be found since it is used differently over disparate disciplines (Negri et al., 2020).

Although the literature demonstrates the benefits obtained from tools such as MES and DTw, it seems that even today these systems are at a lower level of maturity than the rest of IT systems in manufacturing. Consequently, DTw are not exploited to their full capacity, thus leading to a misunderstanding of their functionality.

Indeed, after an initial review of the papers found in literature to understand and discuss the concepts of MES and DTw, our intention is to carry out a literature review that brings to light the gaps and limitations of the industrial applications of these tools. Recognising the MES as an important tool to complete the digital thread of the factory, we also want to pay attention to the degree of integration between these technologies, showing how the combined use of DTw with MES can lead to benefits in a field of uncertainty, such as scheduling.

2 STATE OF THE ART

2.1 Literature review on MES

Manufacturing Execution System (MES) is one of the key industrial software for a Smart Manufacturing. Its advent has made it possible to automate operations and data exchanges that were once carried out manually. However, inputs by human operators are still required today (e.g., HMI for production instructions, etc.) and, despite the push of I4.0, the reality of the situation shows that complete vertical integration is still lacking in the manufacturing industry. As demonstrated by (Bibby & Dehe, 2018) in a I4.0 maturity assessment, despite the MES is currently regarded as the most deployed technology, although it's not exploited to its full capacity. A strong contribution of humans is still needed to bridge the gaps between systems. However, the relatively high evaluation score for the MES concept also suggests that there are opportunities for improvement; among them the transition of paper-based processes to the MES itself.

The place of the MES in the plant hierarchy as well as its functions and interfaces are defined and standardized in ISA-95, the industry standard developed by the International Society of Automation (Jaskó et al., 2020; C. Li et al., 2020).

Relying on the ISA 95 model (Martinez et al., 2021), each industrial automated process is commonly based on the Automation Pyramid, a centralized structure composed of five layers (Cimino et al., 2019) (figure 1). In this structure, an MES is the main production management tool that provides a bidirectional link between the enterprise planning layer and the shop floor control/automation layer (Shojaeinasab et al., 2022). From a bottom-top view, the MES receives data on the status of the shop floor through actuators and sensors residing in the supervisory control and data acquisition (SCADA) system such as distributed control systems (DCSs), programmable logical controllers (PLCs), and other smart devices. The information is then abstracted to the level required by the ERP system for decision-making. In a top-down view of the management hierarchy, the ERP system provides data on the planned orders for the MES. Thereafter, the MES translates the production goals into a detailed schedule for execution at the shop floor (Shojaeinasab et al., 2022). Originally, the Manufacturing Enterprise Solutions Association (MESA) has identified eleven MES functions, starting in 1996 with the first published model (Saenz de Ugarte et al., 2009). These functions include (1) Resource allocation and status; (2) Operations scheduling; (3) Dispatching product units (4) Document control; (5) Data collection and acquisition; (6) Labour management; (7) Quality management; (8) Process management; (9) Maintenance management; (10) Product tracking; (11) Performance analysis.

The fundamental features of MES serve as the foundation for implementing I4.0 concepts (Shojaeinasab et al., 2022). Over the decades, this model has introduced features able to handle rapidly flowing streams of data and information brought by the new vision of I4.0. This, will influence the functionalities of MES, bringing it into a new generation. MES should interconnect all components of cyber-physical systems in a seamless, secure, and trustworthy manner to enable high-level automated smart solutions and that semantic metadata can provide contextual information to support interoperability and modular development (Jaskó et al., 2020) (figure 1).

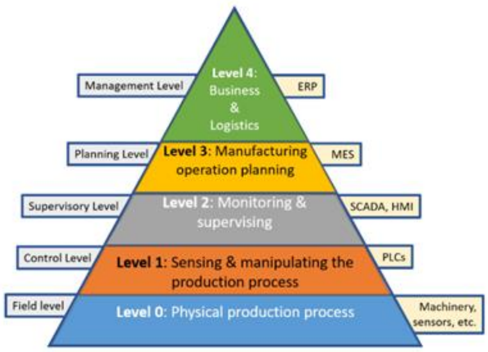

Figure 1. Automation Pyramid according to ISA95 model (Martinez et al., 2021)

According to (Mantravadi et al., 2022), MES needs to be able to interconnect and communicate with the factory's field devices, including legacy devices, through an IIoT platform. When enriched by sensor data from production machines, MES can serve as a candidate for implementing process digital twins. Furthermore, the MES should be able to connect to the ERP system to support vertical, horizontal, and product data integration (Lacroix et al., 2022). In this sense, Digital Twin (DTw) is one of the current research frontiers in MES (Shojaeinasab et al., 2022). Integrating DTw models with MES may improve many of those functionalities, such as the execution of real-time monitoring, resources scheduling, management, maintenance, and performance analysis on the shop floor (Villalonga et al., 2020). Therefore, with this paper we aim to explore how integration of MES with an innovative technology such as the Digital Twin can increase the gains of MES implementation.

2.2 Literature review on Digital Twin

The transition to smart manufacturing makes companies to continuously understand, learn and extract knowledge from the generated data which is of importance to promote production processes (Ouahabi et al., 2021). Digital Twins (DTw) are one of the key enabling technologies that are leading the digital transformation (Villalonga et al., 2020) and are considered the core components of Cyber-Physical System (CPS), meant as the virtual and computerized counterpart of a physical system that can be used to simulate it for various purposes, exploiting a real-time synchronization of the sensed data coming from the field (Negri et al., 2017) and permitting analysis and state control of a part or process (Urbina Coronado et al., 2018).

The concept of DTw was first born in the aerospace field in 2003(Grieves & Vickers, 2017). Only recently it has been adopted in manufacturing contexts. However, scientific literature that describes the contextualisation of the concept in the manufacturing domain is still only emerging. Indeed, most of the papers found in the literature do not seem to refer to a specific and common DTw definition, leading to a lack of knowledge in this emerging technology. A main cause is the variety of focused areas within different disciplines. In order to encourage further contribution in this field of study, the establishment of a common definition is necessary (Kritzinger et al., 2018).

Some authors, such as (Tao et al., 2018) try to give their contribution to this problem, defining DTw as "a set of virtual models. These mirror images and mapping of the physical products in the virtual space. They could reflect the whole life cycle process, as well as simulate, monitor, diagnose, predict, and control the state and behaviours of the corresponding physical entities. The virtual models include not only the geometric models, but also all rules and behaviours, such as material properties, mechanical analysis, health monitoring". They insist on the importance of digital twin data and put forward a new paradigm for product manufacturing, the Digital Twin Shop Floor (DTS). Composed of Physical Shop Floor (PS), Virtual Shop Floor (VS), Shop Floor Service System (SSS), and Shop Floor Digital Twin Data (SDTD) has the capacity to realize the iterative optimization for resource management, production plan, and process control.

Most of the analysed papers concur with the vision of (Kritzinger et al., 2018), which proposes a classification of Digital Twins into three subcategories, according to their level of data integration between the Physical and Digital object. According to this, when data flows between an existing physical object and a digital object are fully integrated in both directions, one might refer to it as Digital Twin (figure 2). A change in state of the physical object directly leads to a change in state of the digital object and vice versa. In this sense, although the majority of papers used the term Digital Twin, only few of them are really describing a Digital Twin with a bidirectional data transfer. Regarding this distinction, (Cimino et al., 2019), (Rocca et al., 2020) and (Negri et al., 2020) propose a Digital Shadow bidirectionally connected to the main controller of the real system (MES) for decision making. Hence, the overall system becomes a proper DTw.

All these various tentative of definition lead to the (Semeraro et al., 2021) contribution. The authors give a definition that summarize over 30 DTw related definition found in literature, previous classified in different clusters according to their application. Hence, what it is a digital twin has been generalised as follow: "A set of adaptive models that emulate the behaviour of a physical system in a virtual system getting real time data to update itself along its life cycle. The digital twin replicates the physical system to predict failures and opportunities for changing, to prescribe real time actions for optimizing and/or mitigating unexpected events observing and evaluating the operating profile system". (Xin et al., 2022) extend the DTw concept to a Digital twin-based process planning where the DTw consists of a series of virtual models (design model of the product, the processes models and machine tools models) that are consistent with related physical objects and can simulate the behaviour and performance of real product manufacturing processes.

In our work, we will take (Semeraro et al., 2021) definition as a reference, considering it to be quite general enough to cover our intent. However, we will base our research primarily on the distinction proposed by (Kritzinger et al., 2018) and its interpretation put forward by (Negri et al., 2020), (Cimino et al., 2019) and (Rocca et al., 2020). Searching for evidence of DTw applications in manufacturing, we will pay particular attention to the presence of an integration between the DS and the MES that can guarantee bi-directionality and control of the physical system, creating true DTw.

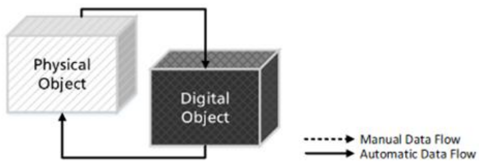

Figure 2. Data flow in a Digital Twin (Kritzinger et al., 2018)

3 DIGITAL TWIN USE CASES REVIEW

In this section, our aim is to analyse papers found in the literature concerning practical applications of DTw, with the aim of highlighting the gaps and limitations in the use of this technology in the manufacturing field. Particular attention has been given to the degree of integration of the DTw with the MES tool, focusing on their technology characteristics and implemented functions. Among them, attention was paid to the possible use of these tools in an area of uncertainty such as scheduling, with the aim of proving that a combined application of DTw with MES can lead to benefits in this field, by completing the MES scheduling function.

Taking (Cimino et al., 2019) literature review approach as a reference for our analysis, we extended its main analysed features to propose an updated review table. New papers and important elements for our purposes have been added.

Table 1. Digital Twin use cases

Authors	Application purposes					Line features		Data acquisition		Simulation features		DT features					Digital twin services								Technology used							
																									MES							
	Support to the management of the production system	Monitor and improve production process	Handle flexibility	Maintenance	Improve production	Production/Assembly line	Laboratory/Industrial application	Dataset	Protocol	Software	Model	Cloud usage	Control of the real system from the DT	Framework proposal	MES integrated module	Intelligent layer/algorithm	Real time state monitoring	Failure analysis and prediction/ maintenance	Behaviour analysis for user operation guide	Analysis for optimization	Layout optimization	Energy consumption monitoring	Scheduling	Reactive Scheduling	Custom	Industrial	Theoretical	Software	ERP	ioT	RTLS	CPS
Coronado et al., 2018		✓				P	L	XML	MTConnect	Android	Acquired data	✓	✓				✓	✓		✓					✓			Android				✓
Zhuang et al., 2018	✓	✓				A	I							✓	✓		✓	✓								✓			✓	✓		
Cimino et al., 2019		✓				A	L		OPC UA	Matlab/Simulink							✓					✓			✓		✓	Matlab/Simulink		✓		
Negri et al., 2020	✓	✓				A	L	XML	OPC UA	Simulink			✓	✓	✓	✓	✓	✓					✓			✓	✓	MES4 by Festo				✓
Villalonga et al., 2020	✓	✓		✓		A	L		OPC UA	MatLab/Simulink				✓			✓			✓			✓			✓				✓		
Ruppert et al., 2020		✓				A/P	I			Plant Simulation	DES model						✓									✓			✓		✓	
Rocca et al., 2020	✓	✓				A	L		OPC UA	Simulink			✓				✓					✓		✓		✓		CIROS				✓
Ward et al., 2021		✓					L		OPC-UA	Plant Simulation	DES model						✓													✓		✓
Martinez et al., 2021		✓				P	L	SQL server	OPC					✓		✓	✓	✓									✓		✓	✓		✓
Barbieri et al., 2021		✓					L	UML		Simulink	DES model		✓	✓		✓	✓	✓		✓			✓	✓	✓			Excel				
Negri et al., 2021	✓					A	L		OPC UA (M2M)	Matlab/Simulink	DES model			✓		✓	✓	✓		✓			✓									
Ragazzini et al., 2021		✓				P	L			Simulink (SimEvents)	DES model		✓	✓		✓	✓			✓			✓	✓								
Villalonga et al., 2021	✓	✓				A	L	MongoDB (online database)	OPC UA		DES model	✓	✓	✓		✓	✓			✓			✓	✓			✓			✓		✓
Bárkányi et al., 2021		✓				P	I			Plant Simulation	DES model	✓		✓			✓			✓											✓	
Wang et al., 2021		✓				P	I		OPC UA/MQTT		3D model CAD/CAM			✓	✓		✓	✓		✓			✓	✓		✓		Saas	✓			
Guo et al., 2021	✓	✓				P	I			Plant Simulation	DES model			✓			✓			✓	✓		✓				✓			✓		
Choi et al., 2022		✓				P	I	XML	OPC-UA and MTConnect		3D model (CAD, ..)	✓	✓				✓			✓						✓				✓		✓
Xin et al., 2022	✓			✓		P	I		OPC UA		DES model	✓		✓		✓	✓	✓		✓						✓						✓
Novák et al., 2022	✓	✓				A	L		OPC UA				✓	✓		✓	✓			✓			✓			✓		Opcenter	✓			
Yang et al., 2022	✓	✓	✓			P/A	I	XML		Plant Simulation	DES model			✓			✓			✓	✓					✓			✓			
Eyring et al., 2022	✓	✓				P	L	external PostgreSQL	Ethernet IP	FlexSim	DES model		✓				✓	✓	✓													
Eunike et al., 2022	✓	✓				A	L		TCP/IP and Modbus			✓		✓		✓	✓			✓			✓	✓								
Magalhães et al., 2022		✓				P	I		TCP	CIMSoft V 88-113D Amatrol tool		✓	✓	✓			✓								✓				✓			✓
Li et al., 2023		✓				P	I		TCP	3DMAX; Unity			✓	✓		✓	✓	✓		✓			✓	✓								

The literature research was executed on Scopus with the keywords: "MES" AND "integrated" AND "Digital Twin" AND "framework". From the totality of 233 papers, only 24 were considered suitable for our analysis. The table 1 reports the results of the analysis of the papers.
Each paper is identified by the name, year of publication and the type of publication. All the papers turned out to be Journal publications.

3.1 Application purposes and line features

Following (Cimino et al., 2019) distinction, the papers are analysed according to their "Application purpose", showing how DTw have been developed and implemented for different scopes. In contrast to its work, we did not want to cluster the various papers by their application. Indeed, it was noted that in many of the presented cases, the technology was designed for various purposes which we wanted to highlight. These, include application purposes regarding DTw to "Support the production system management" by providing a support for decision-making operations and the management in general. The DTw can help to "Monitor and improve the production process" monitoring the various parameters during production, integrating in some cases accurate algorithms or modules for optimizing it. Then, the technology can be used to "Handle the flexibility" of the production systems and for "Maintenance" purposes. As we can see from the table 2, most of the DTw were built or used to monitor and improve the production process (22 cases), with the possible combination of a production system management purpose (10 cases) and or a maintenance goal (2 cases). Only in one case the DTw has been used to also handle flexibility issues. Single evidence has reported a DTw use for the only purpose of monitor and improve the production process. In another case it was combined with a maintenance goal. Then, the "Line features" columns report the environment of the use case, showing whether it is a production line (P) or assembly line (A) and if the applications were developed in an industry (I) or laboratory (L).

Table 2. Application purposes

Application purposes	Support to the management of the production system	Monitor and improve production process	Handle flexibility	Maintenance
Support to the management of the production system	12	10	1	2
Monitor and improve production process	10	22	1	1
Handle flexibility	1	1	1	0
Maintenance	2	1	0	2

3.2 Data acquisition and simulation features

According to (Cimino et al., 2019), some technical characteristics were analysed. The columns under "Data acquisition" and "Simulation features" report the architectures used to support the DTw. The "Data acquisition" section shows details about the "Dataset" and "Protocol" to acquire data from the production system. The dataset description has been clearly mentioned in only 8 papers, showing a majority of XML data format. In the rest of the cases, different datasets are used, or
the description is less detailed or focused only on the protocols. Evidence for protocols were found in 17 papers. The Open Platform Communications Unified Architecture (OPC UA) seems to be the most used (12 cases). Then, the "Simulation features" columns report the "software" used to create the simulation environment and what type of simulation "model" was developed. In most of the papers, the representation of the production system is done with a Discrete Event Simulation (DES) model (11 cases). The rest of the cases present the use of 3D models (2 cases) or no explicit information regarding the model specification is given.

3.3 Digital Twin features

In the "DTw features" columns, the focus is on specific characteristics of the DTw. For the first aspect, "cloud usage", we highlighted those papers that use a cloud or build a cloud-based DTw application. The "control of the real system from the DTw" feature, as suggested by (Cimino et al., 2019), points out those applications in which the real system is effectively controlled by the digital counterpart or attempt to achieve such a configuration. We can see that only 11 papers report evidence of this feature. Among them, (Negri et al., 2020) presents a DTw that is bidirectionally connected to the main controller of the real system for decision making through the MES. In (Ragazzini et al., 2021) the DTw is developed to drive the production control system by setting the production target and by monitoring production. The feedback signal going from the virtual to the real space is provided by a control action setting the allowed Work In Process (WIP) level. The agent in charge of doing this lies in the intelligence layer of the proposed DTw. Anyway, the limited number of cases points out that DTw has rarely been used to its full capacity, resulting in a lack of bidirectional link between the physical and cyber world.
In the column "framework proposal", a search in the literature was made for the presence of a DTw framework or architecture proposal, highlighting in these the presence or absence of MES as an integrated module through the "MES integrated module" column. The variety given by the presence of numerous different architectures shows how the concept of DTw is a rather controversial subject, where a common conception and definition has not yet been universally accepted. In the various frameworks, only in 3 cases is there the proposal of an integrated MES as a module within the DTw architecture itself. (Negri et al., 2020) gives its contribution by defining two DTw-MES bilateral communication frameworks (for error states management and for a reactive disassembly. In the (Zhuang et al., 2018) framework of DTw, MES is directly stated as one of the enabling systems that support the service/application platform and compete to create the DTw itself. Similarly, (Wang et al., 2021) refers to the MES as the service system that complete their five-dimension DTw model. Still, the lack of evidence shows that the concept of integrating DTw and MES is only emerging. These two tools appear to be conceived as separate entities, whereas our aim would be to support a fully integrated system in which the MES would be the module that allow to build a bidirectional communication.
In the next column, the "intelligent layer/algorithm" designated column concerns the presence of an intelligent layer or algorithm which effectively allows to execute dedicated DTw services, such as the presence of optimisation or scheduling algorithms. 10 case studies present such a configuration. This, shows how this technology is still

conceived as an abstract model, in a continuous search for additional features to realise a fully exploited DTw. The evidence in the literature have shown that DTw appears as a mutable concept, changing in relation to the specific case study or application. In this sense, the DTw research is usually linked to other research areas in which they can obtain a functioning and useful DTw, demonstrating that this technology demands for synergies with fields and systems outside the DTw definition.

3.4 Digital Twin services

Taking as reference the services defined by (Tao et al., 2018), resumed by (Cimino et al., 2019), the "Digital Twin services" analysis permits to have an overview about the DTw services that are implemented or considered while developing the simulation purposes. No DTw applications in literature give all the services highlighted, but at most 3 or 4 of them. No papers refer to the use of just a single DTw service, referring to a more exploited technology and step forward compared to (Cimino et al., 2019) results. Having more services offered on the same environment can be useful in case of complex decision making, that needs different aspects analysed at the same time (Cimino et al., 2019).

The services "Real time state monitoring", "Failure analysis and prediction /maintenance", "Behaviour analysis for user operation guide", "Analysis for optimization" and "Energy consumption monitoring" refer to (Tao et al., 2018) distinction. More features were added to meet the objectives of the analysis. With the "Layout optimization" feature, cases are given where the DTw was used as a simulation environment to improve the layout configuration of a production line (Guo et al., 2021); (Yang et al., 2021).

The "Scheduling" and "Reactive scheduling" columns aim to show the use of the DTw to fulfil a function that is inside the MES scope, with a focus on the degree of dynamism of this function, highlighted by the reactive scheduling feature. The results show that 12 cases refer to the use of DTw for the simple Scheduling function, of which 7 are reactive. The widespread use of DTw in this field of application shows that there is an interest in this research area that can be useful in the manufacturing industry.

Indeed, Digital Twin is considered a key approach to enhance the system reactivity to uncertain events and providing a new solution for the optimization of production line system (Barbieri et al., 2021; Guo et al., 2021). DTw integrates actual processing data and simulated data, while considering more comprehensive information to support the precise scheduling decisions. Additionally, DTw reaches iterative optimization of production plan and process control through the integration and fusion of all elements and data (Y. Li et al., 2023). The DTw enables the dynamic scheduling and the reconfiguration of the manufacturing resources in response to the occurrence of uncertain events (Barbieri et al., 2021).

In this sense, MES and DTw should work together to ensure real time scheduling. The DTw should be used as an environment to simulate new scheduling scenarios based on the current state of the shop floor detected by the MES, once a machine breakdown or anomaly alarm has been received.

According to this, (Barbieri et al., 2021) propose a framework in which an intelligent layer receives the information of a breakdown from the PLC, and the remaining jobs to be produced from the MES. Once the DTw has updated the plant status, and the intelligence layer has generated different production sequences, the DTw will test and calculate the time difference between the start and finish of a sequence of jobs or tasks for each one of them and the new optimal sequence will be sent to the MES.

In (Villalonga et al., 2020) the scheduling and the global optimisation modules are responsible to carry out actions of reconfiguration and optimization based on the information collected from the global DTw, the MES, the performance indices and other parameters and variables defined by the operators. Through the DTw simulations at local level and the signals acquired from the process, the decision-making module either directly sends commands to the MES to automatically solve the issues or sends to the operator screens assists the information for an early-stage fault detection resulting in a better maintenance scheduling and increasing the asset useful life.

As suggested by (Barbieri et al., 2021; Parente et al., 2020), future research should include further exploration regarding machine proactiveness, in the sense that machines should be capable of suggesting changes or supplements to schedules, such as the presence of intelligence layer in which we can find special algorithm for the optimization.

Papers such as (Villalonga et al., 2020) and (Negri et al., 2021), show how the use of a tool such as DTw makes it possible to react to unforeseen events by helping decision-making operations and not affecting the actual system, resulting in a better maintenance scheduling and increasing the asset useful life.

In our research, we aim to contribute to the definition of DTw as an I4.0 tool that complete and extend the scheduling function of MES. DTw becomes the platform that use the MES as a continuous income of information. With the use of developed intelligent algorithm will be then possible to extend the functionalities of this system and create a reactive system, able to monitor and control the real system as well. The use of DTw permits to bring the MES function on another level and elevate the system to a dynamic and reactive environment.

3.5 Technology used

The last important feature that has been highlighted in the table concerns the "Technology used" in the DTw application. Among them, a particular attention is given to the MES characteristics, searching for evidence regarding its development and use, trying to find a combined use of DTw and MES in literature. In the "MES" feature, we have divided the papers according to their use of an "Industrial" or "Custom" MES solution, specifying the type of "Software" where this is mentioned. Just 7 papers quote the software used for the MES, demonstrating the absence of attention to the MES in the literature and the fact that is still not fully integrated. In the majority of these, we can assume that the MES was only conceived or was not considered as an important feature in the application of DTw. The "Theoretical" column instead shows only MES considered theoretically, without implementing it in the case study. In the table, in 2 cases the system was developed in a custom or industrial manner, but also recognised as theoretical. This was recognised in those cases where the authors tried to implement the MES without never actually succeed in all the way through.

In the remaining columns, attention was paid to case studies in which the use of DTw was combined with other technologies or systems such as the Enterprise Resource planning "ERP", the Internet of Things "IoT", Real Time Locating System "RTLS" and used within an environment that had reached a Cyber Physical System "CPS" configuration.

3.6 *Findings of the review*

To summarise the results obtained from the review table, we can see that DTw can be applied for various purposes within a manufacturing organization.

Analysing the table revealed 2 interesting gaps regarding the degree of integration of the DTw: limitations in the integration of the DTw with the shopfloor and limitations in the integration of the DTw with the MES.

Regarding the first assumption, as also evidenced by (Cimino et al., 2019), the majority of the proposed DTw applications do not mention the connection of the DTw environment to the control system of the physical equipment.

The results we obtained in this new study report that DTw is mainly used as a monitoring and simulation environment. In all the reported cases, DTw was used as a tool to monitor the status of the equipment in real time, without guaranteeing a bidirectional action to control the real system, resulting in a lack of bidirectional link between the physical and cyber world. The table highlights an important gap in the manufacturing applications. The DTw and shopfloor are considered as 2 separated entities, not exploiting the technology at its full capacity.

This result leads us to confirm another limitation identified in the literature. This evidence, in fact, shows us that (Kritzinger et al., 2018) classification that rests on bidirectional exchanges is not yet fully comprehensive. Indeed, despite its definition appears to be the most frequently cited reference in the cases analysed, according to its distinction, most applications do not reflect a proper DTw. This shows the need for a definition more consistent with the current state of research in the field.

The second interesting gap found in the literature shows how MES and DTw are not fully integrated with each other. The DTw is not used as the tool to extend and complete the MES functions and capabilities or vice versa. From the table we can see that most of the papers recognises the importance of a control instrument such as the MES. Almost all papers mention the MES as a technology present in a smart manufacturing configuration and DTw application. Among these, some attempt to implement this technology in a customised manner or by resorting to industrial solutions. However, conclusions point to a lack of effective implementation that shows how this technology is not fully explored and utilised to its highest potential. In most of the case, we can assume that the MES was not considered as an important feature in the application of DTw. In addition, as pointed out in the previous paragraph, only few papers propose a complete integration between MES and DTw, recognising MES as an enabling part of DTw itself. This few evidence shows a shift towards a greater awareness of the importance of integrating these two technologies. Some papers have directly highlighted this by proposing architectures in which these two technologies match (Negri et al., 2020), (Zhuang et al., 2018); (Wang et al., 2021). Despite these attempts, an integration between these two technologies is still far from being shared and implemented.

4 CONCLUSIONS AND FUTURE WORKS

Recently, DTw has been recognised as an important tool in the manufacturing field. The literature review that we conducted has shown how this technology has been used for a wide variety of applications. Either combined with other systems or used as a stand-alone element, the DTw has permitted to implement numerous services that have enabled it to achieve the intended objectives.

Our analysis results show how DTw is not yet fully explored and how some important features should be better analysed and defined:

- DTw and shopfloor are rarely bidirectionally linked.
- DTw and MES are conceived as two distinct entities.
- Scheduling is a promising area for DTw and MES integration efforts.

The first limitation has demonstrated that the DTw is not completely exploited, leading to another important misalignment between the DTw application and its definition in literature. Indeed, following (Kritzinger et al., 2018) definition, we must note that the majority of the technologies analysed are not proper DTw. This confirm that the area of DTw is still disputed, and that the proposal of a common and unambiguous definition is still yet to be found.

However, these DTw's limitations can be overcome through combined use with other systems that can allow to reach the synergy sought by DTw. In this sense, MES presents itself as an excellent tool for ensuring bidirectionality and to exploit the DTw to its full capacity. Such a perspective has been identified in some case studies, especially in the scheduling area. Despite that, the concept of MES remains undervalued and poorly integrated with DTw.

Further research should thus focus on proposing clear definition and architecture of DTw in manufacturing, overcoming the general definitions that could apply to any field. We insist that any proposal in that sense should include MES, as it is an essential element of the digital thread, both to channel shopfloor data and send manufacturing order to machines.

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