Value Assessment of Digital Twins

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ABSTRACT

Making business processes smart is a topic of great interest in recent times and with it came the newest iteration of business process simulation: the Digital Twin. This study explores the concept of Digital Twins and their relationship with value creation and reviews a model proposed by Barth et al. [4] by applying it to a use case. The model underwent changes and extensions in order to take a first step to quantification of value. In conclusion, the model with certain changes and extensions is applicable to a logistical use case. Furthermore, there is an apparent knowledge gap in terms of quantitative analysis of Digital Twin implementations.

KEYWORDS

Digital twin, value assessment, automation, container logistics, business case.

1 INTRODUCTION

With the 1960s came the introduction of computer aided management tools for businesses [37]. Throughout the decades, the computational power increased substantially, and with it the support computers could give for management decisions. Since the early 2010s, there is a push for smart management tools that can not only support in management decisions, but even make them themselves. Digital Twins (after this referred to as DTs) are part of this latest push into smart management tools. In 2021 the global DT market was estimated to be USD 6.9 billion with an estimated increase to 73.5 billion in 2027 [19].

1.1 Origin

Although the term DT seems to be of the last years, with Gartner discussing it for the first time in their hype cycle of 2017 [9], the concept of a virtual environment working together with a physical environment has been suggested as early as 2002 [12]. Even prior to this, NASA was already using a physical twin of the space craft they were launching into space in the 60s as a way to prepare astronauts before their trip into space [4, 12, 29, 37]. Grieves is the first one to use the term Digital Twin for digitally simulating business processes [3, 4, 11, 13, 29].

These developments fell together with several programmes all over the world that are calling to utilise the potential of DTs, as discussed by several authors found in the literature search [17, 22, 24, 31, 37]. For example, the German "Industry 4.0" or the Chinese "Made in China 2025". This call for smart management resulted in a significant increase of research papers discussing DTs to scientific databases in recent years [8, 29].

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1.2 Problem domain

Due to this rapid expansion of papers discussing DTs, there are several areas in which there are knowledge gaps surrounding DTs. For example, Sharma et al. [26] states that without a universal DT framework, development of DT in practice is significantly hindered. Agrawal et al. [1] argue that a clear model to visualise benefits is of utmost importance to create consensus on the concept of DTs in practice. Something that is ascribed to by Wright and Davidson [36] in their paper as well as they warn that no clear distinctions between DTs and models will lead to a probable early abandonment of potential benefits when the hype dies down for DTs. Meierhofer and West [21] insist that, especially for value creation, there is a need for a differentiated perspective on DTs. Rasheed et al [23] call for standardisation in their conclusion by arguing that just as physical assets that have to interact with other physical assets, it is likely this is going to happen with virtual assets as well. Thus, DTs have to be able to communicate with each other. On a slightly smaller scale, Lind et al. [18] also make a call for standardisation between all the stakeholders, although it is just for the maritime sector as they have to interact with each other to increase efficiency. Nevertheless, this could also be the case for a lot of other industries. Tao et al [29] identify in their future work that currently research focuses on model construction whilst neglecting to assess already proposed models by their peers leading to model integrity going unchecked. Even stating that it is a pressing matter.

In conclusion, there is a clear call for standardisation, and one for testing existing models. As well as creating nuanced perspectives on the concept of DTs. This study steers towards standardisation by testing a model proposed by Barth et al. [4] for the use case of Port of Twente.

1.3 Research questions

The research is split up into two perspectives: a knowledge component for which a literature review will be used. The literature study follows the method of Webster and Watson [35]. Secondly, the literature search resulted in a model that is tested using the use case of Port of Twente. The research questions are as follows:

1. How to assess and measure the business value of digital twinning?
2. How can these assessment and measurements be visualised clearly?

1.4 Structure

In Section 2 the methodologies for the literature research and the model testing will be described. Followed by the findings of the literature study in Section 3. Section 4 explains the model used and the changes and extensions made to it. Section 5 examines the use case of Port of Twente and the application of the model to said use case. Section 6 discusses the limitations of this research. Lastly, Section 7 is the conclusion of this study and proposes future work based on the limitations and findings of this research.

2 METHODOLOGIES

This section explains the methodologies used for the literature search as well as the model testing. In Section 2.1, the literature study methodology is discussed. Section 2.2 briefly explains method used for model testing and the scientific contribution of this methodology.

2.1 Literature review

The literature review will be done based on the method proposed by Webster and Watson [35]. The method uses three steps to identify relevant literature. First, start in major journals as the major contributions will be in those. Second, go backwards in these articles by looking at the references used and determine which studies might apply to the topic. Third, go forwards by using online databases to search for research that cite the identified key studies in the last two steps. Thereafter, this method uses a concept matrix which Webster and Watson adapted from Salipante et al. [25] to show which groups sources by their concepts they discuss which can be found in Section 3.1. All these sources have been found by using the following databases:

- Scopus - Elsevier
- Web of science
- LISA (University of Twente library tool)

And with the following queries, shown in Table 1.

Table 1. Queries used for literature search per concept.

Concept	Query	Number of 'hits'
Digital Twin	(Digital OR digital) AND (Twin OR Twins OR twin OR twins)	Scopus: 16,113 Web of science: 11,378 LISA: ~51,600
Value	Value OR value; (Value OR value) AND (Digital OR digital) AND (Twin OR Twins OR twin OR twins)	Scopus: 7,909,950; 1,614 Web of science: 5,392,584; 1,218 LISA: ~5,200,000; ~10,100
Value modelling	(Value OR value) AND (Modelling OR modelling)	Scopus: 415,652 Web of science: 1,488,088 LISA: ~1,400,000

Regarding inclusion and exclusion criteria, all papers found with the queries had to be from at least 2019. Other exclusion criteria were relevancy to the scope of the study and the focus on research papers, as opposed to technical reports, thesis, and other similar papers.

With the first iteration of papers discovered by query search, the papers were assessed for the relevancy by reading through abstracts, introductions, and conclusions. After this process was done, a snowball search was done by looking at the sources used in the papers founds and assessing them in the same way.

2.2 The model

As for the model, the methodology was based on cooperative work of the author and Port of Twente, as the use case of this study is currently being worked on and there was a need to model this DT in order to communicate to stakeholders effectively. The model this study tests is the model proposed by Barth et al. [4]. In order to make a first step to quantifying the value creation of a DT a table has been added. Also, the model has been modified to better fit to the use case of Port of Twente. The model is a result of iterative design in cooperation with Port of Twente.

3 LITERATURE REVIEW

This section discusses the prior knowledge already gathered and discussed regarding DTs, value, and value assessment and modelling. Section 3.1 gives an overview of the results of the literature search. Section 3.2 discusses the definitions found in the literature and concludes with a definition that will be used for this study. Section 3.3 examines what value is and provides a definition for this study. Section 3.4 gives and overview of the literature about valuing and modelling DTs.

3.1 Results of the literature search

As discussed in Section 2.1, a table was created to group papers together based on the concept(s) they discuss. Important to note is that the set-up of the table has been flipped in order to facilitate the lay out of this paper. The main concepts are written in bold to make them stand out more for easier comprehension. This paper focuses on three main concepts: the concept of DT, the concept of value and value modelling of DTs. These concepts are split up in smaller sub concepts which are shown in Table 2.

Table 2. Concept matrix as proposed Salipante et al. [25]

Concept	Sources
Digital Twin	9, 18
Origin	4, 11, 12, 16, 21, 23, 28, 30, 36
Definition	2, 8, 12, 13, 27, 29, 31, 33, 35
Value	32
The concept	6, 15
Value of DTs	22
Value modelling of DTs	
Challenges	1, 3, 5, 14, 17, 22, 25, 26, 35
Value modelling	7, 10, 19
Value modelling of DTs	3, 4, 20, 28

3.2 Definition of a Digital Twin

Throughout research done on the concept of DTs, several different definitions have been created to capture the essence of DTs. Van der Valk et al. [32] studied 233 papers of DTs and Barricelli et al. [2] did another study on definitions of DTs. Wright and Davidson also examine several definitions in their paper [36]. Firstly, the Defense Acquisition University has defined the DT as follows:

"[A DT is] an integrated Multiphysics, multiscale, probabilistic simulation of an as-built system, enabled by Digital Threat, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin." [34]

Whilst Rod Dreisbach, a NAFEMS council member defined it:

"[A DT is] a physics-based dynamic computer representation of a physical object that exploits distributed information management and virtual-to-augmented reality technologies to monitor the object, and to share and update discrete data dynamically between the virtual and real products." [28]

These two definitions seem to hint to the same important factors a DT should have, which Wright and Davidson summarise that a DT has to have *"a model of the object, an evolving set of data relating to the object, and a means of dynamically updating or adjusting the model in accordance with the data."* [14]

Though, they also note that not all people working with DTs use this definition as they also quote the definition given by LMS research: *"A DT is an executable virtual model of a physical thing or system."* Which Wright and Davidson argue that this has been already a thing for decades [36]. A similar definition is given by

Unal et al. [30]: *"A DT is a digital replica of a physical system that captures the attributes and behaviour of that system."*
Grieves and Vickers also discusses how they define DTs in their book "DT: mitigating Unpredictable, Undesirable Emergent Behaviour in Complex Systems" [12]. They argue that a DT are a collection of virtual information constructs which are used to accurately portray a conceptual or existing physical system. And that at its maximisation of use, a DT should be able to provide the same completeness of information as one were to inspect the physical environment. In the same book they also argue that there are two distinct types of DTs: A prototype and an instance version, with a prototype showing a concept for a physical system and an instance actually being the virtual twin of an existing physical environment.

These definitions all try to summarise a complex system in just a couple of sentences, which leaves the implementation of a DT out of consideration due to this constraint. Consequently, this study uses Dos Santos et al. [8] their approach of defining the concept DT. As opposed to the definitions discussed previously, Dos Santos et al. propose that a DT consists of four main components:

- A virtual system,
- a physical system,
- systems data,
- and a communication interface.

The virtual system is, as the name suggests, the digital representation of the physical environment, which is the physical system in this definition. These two environments can interact with each other through the communication interface(s) using the systems data which is generated by the physical system(s). This physical system would be using several communication interfaces to communicate data to the systems data. Think of sensors and other smart devices gathering data which in turn is sent to databases for storage. This data is the systems data which periodically updates the virtual system through another communication interface. This virtual system in turn can use the systems data and other tools to simulate and predict situations that might happen in the physical system in order to see the consequences when, for example, a road is closed so the terminal tractors have to be rerouted. With this new information, the virtual system can give feedback to the physical system through yet another communication interface making the circle complete.

3.3 Value

Discussion about what the concept of value entails have been ongoing since the days of the great Greek philosophers [33]. As posited in the prior two paragraphs, businesses do need to know what value they are actually bringing to the market. But to assess said value, one needs to know what value is first. Lepak et al. [16] propose to use the proposition of Bowman and Ambrosini [6] splitting up value into two components: use value and exchange value. Use value, as Lepak et al. [16] define, is *"… the specific quality of a new job, task, product, or service as perceived by the users in relation to their needs"*. Exchange value is defined as: *"… either the monetary amount realised at a certain point in time, when the exchange of the new task, good, service, or product takes place, or the amount paid by the user to the seller for the use value of the focal task, job, product, or service."* The combination of use- and exchange value will be the basis for the literature review of value modelling as it defines clearly how value is created and can be applied to DT value creation.

Combining this with the findings of Rasheed et al. [23], although it has to be noted that the study is limited by the lack of quantification of value, an overview based on their categorisation of the value DTs might create is given below:

I. *Real-time remote monitoring and control:* This is a use-value of DTs, as it provides the owners of the DT to possibility to access an in-depth view of large and/or complex systems in real-time and wherever they are. It also gives the opportunity to remote control the performance of the system when feedback mechanics are implemented.
II. *Greater efficiency and safety:* As will become apparent for most of these potential values, this is another use-value. DTs will make it possible for humans to forego the more dangerous, dull, and dirty jobs due to automation in the form of robots cooperating with DTs such as the use case of Port of Twente.
III. *Predictive maintenance and scheduling:* Another use-value, this will be realised by sensors monitoring the physical system in combination with machine learning on the side of the DT to detect problems in the systems earlier than was possible until now.
IV. *Scenario and risk assessment:* Due to the Big Data aspect of DTs, the possibility to use this data in order to simulate scenarios and risks will greatly improve the assessment of the two. Making it yet another use-value.
V. *Better intra- and inter-team synergy and collaborations:* This is yet another use value of DTs. It will help with planning of tasks within a team or multiple teams resulting in improvement of collaboration.
VI. *More efficient and informed decision support system:* A use value, which, such as points III and IV, can with the use of data and advanced analytical tools assist in decision-making.
VII. *Personalisation of products and services:* This is an exchange value due to the use of historical data in order to offer products and services that are closely catered to the wants of the customers.
VIII. *Better documentation and communication:* Unlike the last value, this is again a use-value. The main benefit of this is that the combination of real-time information with automated reporting of said information will improve transparency towards stakeholders.

3.4 Value models

With this definition of value in Section 2.2 alone it is hard to quantify value in such a way it can be communicated to other parties involved. Meertens et al. [20] state in their introduction of their paper that numerous IT projects fail due to never realising proposed solutions and techniques, and that this is often caused by pushing the technology to its limits without proper analysis of the situation that is supposed to be solved by this technology. This has been an issue for quite a while, as it has been discussed in other contexts such as the dot.com boom of the early 2000s. The book "dot.con" by Cassidy [7] discusses the many companies jumped on the chance to earn money in the brand-new online space without proper value propositions. Cassidy even states that these practices had roughly the same effect as the Tulip crash on the Amsterdam market. This is ascribed to by Gordijn [10], who briefly discusses Cassidy's book as an argument for why he proposes a value ontology, the e^3-value, in their paper as a way to put value propositions on paper in an understandable way.

For DTs specifically, this sentiment of inadequate preparation before actually building a DT is supported by multiple scholars [26, 36]. Most of the times, DTs are used for complex situations, and they have already been applied to an incredibly diverse set of conditions in several different industries [5, 23]. Tao et al. [29] show that just in the last couple of years papers have been written about DTs in manufacturing, aerospace, energy, and other industries. Due to this, it is difficult to establish how, what, and why a DT will offer in a specific context in order to realise the added value it might have in said situation [1, 15]. These challenges have to be overcome to secure value creation for a potential implementer of a DT [3, 27]. Rasheed et al. [23] discusses common challenges of DTs more in depth in their paper.

To conclude, the idea behind DTs has been in the works since the early 2000s. Nevertheless, the concept of a DT itself is more recent as it is integral to the Industry 4.0 and similar programmes world-wide. Due to this novelty of DTs most of the research has not been done in order to generalise the concept of DTs. Van der Valk et al. [32] did make a taxonomy of DTs in which they sort the most common definitions and concepts regarding DTs. Although, it has been identified by multiple scholars that there is a definite need for it as discussed prior. Besides, there is a focus on creating new ways to visualise value of DTs on paper resulting in a neglection of testing the integrity of the proposed models. Therefore, the rest of the paper will study the model proposed by Barth et al. [4] more closely, followed by applying it to the use case of Port of Twente. Lastly, discussions and conclusions will sum up the findings. The choice for this model was mainly based on the fact that in the literature search there were four papers that explicitly examined modelling value for DTs, and this specific model is the most detailed, as it is already based on previous research by the same authors.

4 THE MODEL

In this section the original model and the changes and extensions to the model are explained. Section 4.1 explains the structure of the model of Barth et al [4], which this study assesses. Section 4.2 discusses the value creation dimensions used. Section 4.3 focuses on the changes and extensions made to the model.

4.1 Structure of the model

This model in itself is already an iterative work based on another model of the same authors, which is discussed in their previous paper [3]. The study will shortly discuss the original model as proposed in the research paper by Barth et al. [4], followed by the changes made to fit this model to the use case of Port of Twente. The use case will be discussed in Section 5 in more detail. The structure of the model is as follows. Firstly, there are three timeframe dimensions which are shown in the top right corner, as can be seen in the filled in model in Figure 1. This is done to highlight the fact that DTs work using historic data to improve the present and innovate for the future. Thus, historic data is the basis. This data can be from several different sources, which are split up in three categories in the model: external systems, such as the weather or traffic data and any other external factor one can think of that is relevant for their use case. There are internal systems which are used to gather data of the business processes and use this to improve said processes. Lastly, there are tangible things that can generate data, for example a terminal tractor with sensors can generate data. All these sources are connected with one another to create all the data in a use case. This total package of all data is used as input for the DT, which first categorises each piece of data as either context, customer, or product related data as explained previously. This in turn is then run through smart analysis which uses tools, algorithms, models, and rules to take the unstructured data and turn it into structured data and then into interpreted data. This data can be interpreted by the user of the DT. The DT can also use this data to create services, which becomes external value for the business as these services can e.g., optimise routing of a fleet of terminal tractors resulting in a reduction of total kilometres driven, thus resulting in a reduction of costs and CO_2 emissions. The combination of the services created by the DT and the external value they create is the value proposition, which offers the services demanded by the user, to the user as well as increasing autonomy, optimisation, or control, or a combination of the three of the things the business owns. Consequently, a feedback loop is established in which things generate data in combination with internal and external systems. This data is put into the DT, which generates value proposition out of it, which in turn generates value out of the things again and the loop starts anew. This is the main power of a DT and in this way is shown how that operates and can increase value over and over again.

4.2 Value creation dimensions

Firstly, it has to be noted that there is no way to go into detail of what value the DT implementation will create without looking at the past, present, and future, although these do play a part in the model itself. Therefore, the first step is to take inventory of value creation in the use case in the three timeframes prior stated. A filled in version of this table can be found in Table 3. This table provides a quick way to take inventory of the differences in the use case in past, present, and future when the implementation of the DT is successful. It gives six categories: systems (of systems), internal system, external system, Digital Twin, value proposition, and value assessment. These are partly based on the work of Barth et al. [4], as can be seen with the first three categories, but they are appended by the last three to further clarify and steer to more tangible value of the use case in the past, present, and future. This is the first step before filling in the module itself. Regarding quantitative analysis of the value creation dimensions, there is none in the work of Barth et al. [4]. Therefore, a table has been created which is an add-on to the model in order to make a first step towards quantifying the value creation as a scientific contribution of this study.

4.1.1 External value creation

The proposed model by Barth et al. [4] has three different value creation dimensions. There is external value creation, which includes the categories service scope, smartness maturity, and system hierarchy level. These all have in common that they are value that is created towards clients. Service scope focuses on the availability, quality and performance of services provided by the use case assessed and what value a DT can add here. Smartness maturity is about control, optimisation, and autonomy of processes. Lastly, system hierarchy level takes inventory of all the systems, systems of systems and potential Smart Connected Products (SCPs). These are all denoted in grey in the model.

4.1.2 Internal value creation

Internal value creation is the second value creation dimension. This dimension focuses on the inner workings of the company and how these create value for the business. With more production focused businesses this includes product life cycles and product management levels. The second of the two can be applied to services as well, the first one is a bit harder to, especially in regards to the specific use case discussed in Section 5. This is the first of the changes made to the model, because Port of Twente does not produce products with a lifecycle per se. It could be argued that a terminal tractor has a life cycle, but this is outside of the scope of this particular study due to the focus on the value the DT implementation creates. The last category of internal value creation is the generations/time category, which focuses on the three timeframes as discussed in the paragraph above.

4.1.3 Data resources

The last of the three value creation dimensions as proposed by Barth et al. [4] is the data resources. This category focuses on the sources, categories, and formats of the data generated in the use case. Sources covers things that generate data, the quality of said data, and the performance data of the business process(es). Categories splits up data across customer, product, and context data. Formats has three stages: unstructured, structured, and interpreted which is the steps data has to undergo to be able to be used by the user of the DT. This is the basis of the model and the main way the value is modelled.

4.3 Changes and extensions to the model

As explained in their paper, Barth et al. [4] made this model as a framework for an *"application-oriented DT"*. Yet it is assumed that besides it being application-oriented, it also has the physical product it is the DT of, instead of the possibility that the DT is of either one or multiple business processes. Which is more common in the logistic world, due to the fact that the product is a service and not a tangible product that is sold. Because of the this, the first and biggest change made to the model is that the product cycle has been removed. Other changes are smaller and are mostly based on the specific situation of the use case and would also change if another use case was used. For example, Port of Twente has Havenmonitor, which is a software used to visualise historic data and therefore is already part of the smart analysis Port of Twente does and will probably be integrated into the DT as to not lose access to the historic data for the DT. In the next chapter the changed model will be discussed in depth using the use case. The last change that is made to the model is the swapping out of a product life cycle for a service life cycle as there is no physical product that the use case has, but a service. The service life cycle as shown in the model below is based on the product life cycle as Barth et al. [4] used, but with the steps of a service life cycle in the context of a DT implementation. Outside of the model, a table is added which has been discussed in Section 4.1 to start paving the way to quantifying the value a DT can offer, as that is an area which is severely understudied as of writing this paper. Technically it is not part of the model, but it is recommended to use this as a starting point as it makes it easier to fill in the model and later on quantify value.

5 USE CASE: PORT OF TWENTE

This section will discuss the model applied to the use case and the reasoning behind it. After a brief introduction to the context of the use case in Section 5.1, the first step, the table, will be briefly discussed in Section 5.2. Followed by the physical system of systems in the use case in Section 5.3. In turn, Section 5.4 discusses the data sources of the use case. Section 5.5 contains how these data sources will be used in combination with internal systems to create internal value. Lastly, Section 5.6 examines the external value this internal value creates for Port of Twente. The model itself can be seen in Figure 1.

5.1 Context

The use case introduced in this section is based on the feasibility study Port of Twente has done about implementation of a DT in combination with Autonomous Guided Vehicles (AGVs) as terminal tractors for the XL Bedrijvenpark Almelo. A business park in Almelo which is located next to the Twentekanaal and the highway, an ideal location for logistical companies and warehouses to work together. In order to illustrate this cooperation, the following scenario is presented of the journey a container would make if the DT were implemented. First, the container arrives on a ship in the port of the business park. CTT is notified that the ship has arrived to deliver containers. Important to note is that CTT is the organisation that does all the container handling for Port of Twente, therefore it is one of the stakeholders in this use case. Consequently, the container is lifted of the ship by a crane and put down on the quay in a specific spot chosen by the crane operator. This information is put into a system, which means that the planners and the DT can easily check where this container is stored. Then, the planners and/or the DT can check when the warehouse that has ordered this

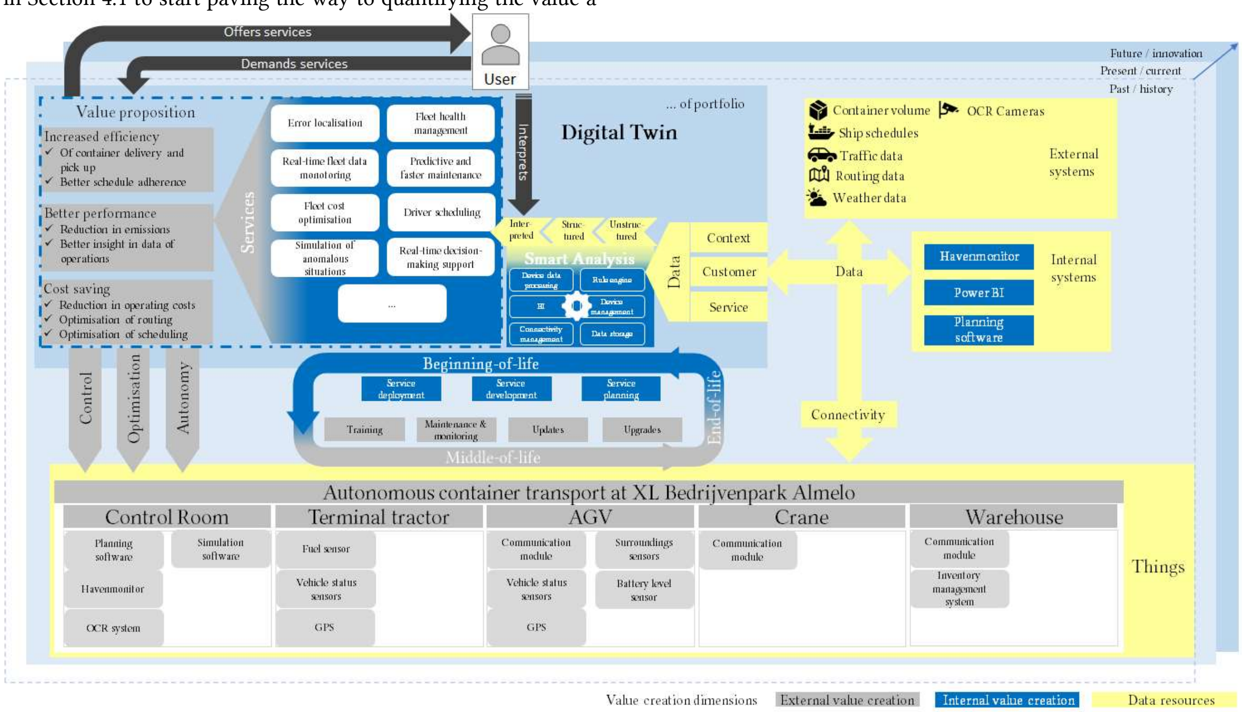

Figure 1. The model applied to the use case of Port of Twente.

Table 3. An overview of value creation of Port of Twente in the past, present, and future.

Components	Past	Present	Future
Systems (of systems)	Every company in this project has their own system of systems.	There is some communication between the different systems of systems, e.g., the delivery of containers from CTT to warehouses.	The DT will create a family of systems of systems by connecting all systems of systems to streamline communication by using smart connected products (SCPs) to gather data about the systems.
Internal system	Every company has their own software suite.	Every business has their own software suite.	The DT will use an internal software suite to use the data generated by the internal systems of the use case participants to run smart analysis for an overall improvement of service(s).
External system	The value propositions and systems of systems are unique to each company. Electronic data interchange with external systems on transactional basis.	Cooperation between businesses increases the intertwining of value propositions and systems of systems between use case participants. External data sources are utilized individually.	The DT can monitor and manage the day to day of the use case which results in a tight-knit cooperation between every actor in the use case. External data sources are made available for all actors in the DT.
Digital Twin	No use of DT and smart systems to use historical and current data to improve business processes.	A start in using smart systems coupled with data to improve business processes. Limited systems and assets are integrated.	The DT can improve business processes by accessing historical and current data and in turn use this data to simulate potential future scenarios. Based on this management decisions can be automated.
Value proposition	As discussed previously, value propositions are unique for every use case stakeholder.	Due to cooperation between actors, there is an increase of value propositions intertwining. Value is created based on data interchange and supply chain integration. Transparency increases.	The DT will increase the visibility, optimisation of and control over the systems of systems within the use case. In combination with the future AGVs, this would also result in an increase of automation.
Value assessment	Every business assesses their own value themselves using their own goals and metrics.	Value assessment has to keep in mind the cooperation with other use case actors. Value assessment predominantly is focused on the stakeholder's perspective. The goals and metrics for joint value creation are determined on a case-by-case basis.	All value assessment will primarily be based on the DT, because services are offered centrally for all use case stakeholders. Actors may create additional value for themselves. Goals and metrics are agreed upon mutually.
Quantification	Every business has their own way of quantifying their own value, for example, KPIs based on their business processes.	Quantification is still predominantly individualistic, in the sense that value creation is mainly seen as something that a business does on their own, even with cooperation between businesses being the norm currently.	With the DT taking over management of all business processes within the use case, the question arises if business need to quantify their own value within the process(es) they participate in.

container wants to have it delivered and plan it in accordingly. This is delivery can be done with either an AGV or a manned terminal tractor and the DT can help the planners assess which option, in which timeframe and with which route, etc. would be best. When the container is delivered, the warehouse systems are notified, and people will unload the container whilst the terminal tractor/AGV goes to another job. After the unloading, the DT is notified of this and will propose the best options to pick up this empty container to the CTT planners, which will have the final say. With the planners' permission, the DT can assign a terminal tractor/AGV to pick up the container which consequently gets delivered back to the quay where it came from and later on loaded on another ship to be brought to another destination to be filled once again and shipped off to another customer.

As of July 2023, Port of Twente has finished feasibility research to assess if implementing a DT in combination with AGVs would be possible at XL Bedrijvenpark Almelo, a very basic prototype of a DT has been made, and this is a first step towards a coherent business case.

5.2 The past, present, and future

In order to establish the value, the potential implementation of the DT will create for the use case, a good first step is to look at the past, the present, and what this innovation of the business processes will bring in the future. Therefore, this table is created as previously discussed in Section 4.1 and can be found in Table 3. The guiding thread in this table is the transition from businesses within the cooperation of Port of Twente working alone, to actually becoming a cooperation. In order to increase efficiency, the businesses start working together more closely. A DT implementation would increase this cooperation even more.

The current state of transition is focused on getting XL Bedrijvenpark Almelo from the present as shown in Table 3, to the future with a DT implemented in combination with AGVs that deliver and pick up containers. Thus, from going to some communication between different systems of systems from different companies e.g., warehouses being able to schedule a container delivery with CTT, all could be automated as the DT manages an 'umbrella' system that encompasses all systems of systems found within the business park. A guiding thread throughout the past, present, and future is that every step is moving towards closer cooperation between different businesses that all have their own part within a supply chain. Especially for the use case at hand, since Port of Twente is explicitly created to stimulate cooperation between logistical companies in the area of Twente. The implementation of a DT would be a next step in increasing cooperation between businesses at XL Bedrijvenpark Almelo.

This is facilitated by the data gathering opportunities in the form of IoT devices as an example. Currently, IoT devices are getting implemented in business processes as a way to gather new data and create new insights manually. With a DT, this would be done automatically, with the possibility to tune KPIs on the fly resulting in better insights for less hassle.

The two most major changes between pre-implementation and post-implementation of the DT in the use case are in value creation and quantification. Due to the nature of DTs, the more data it has access to, the more accurate it will be in its simulations which naturally stimulates data sharing, and in turn cooperation. Consequently, value creation and quantification are moving from an individualistic approach, i.e., every business only focuses on their own, towards a more general and open approach in which companies can point to a process they are part of. Indubitably there is still the firm's own input into said process, however, it cannot be seen as separated from the process anymore.

5.3 The physical system of systems

The physical system is all the things that are necessary to handle the containers as long as they are on the terrain of the business park. For the sake of the brevity, the focus of the physical system is on the systems that can be found in XL Bedrijvenpark Almelo. Thus, ships that deliver and pick up the containers are left out of consideration. Which leaves five distinct systems within the system: control room, terminal tractors, AGVs, cranes, and warehouses. Control room is a hypothetical system at this moment as the implementation of such a central hub for the XL Bedrijvenpark Almelo is still in consideration, for now the operators of the control room would be planners of CTT. Terminal tractors and AGVs do fulfil the same tasks within this process of container handling but are distinct enough from each other to warrant the splitting up, and adding to the model, of the two. How they interact with the process of container handling has been discussed in Section 5.1. This system of systems is what creates external value for Port of Twente at this moment. In later sections it is examined how the DT can add to this external value creation.

5.4 Data sources

Data sources are from three distinct areas in the use case. First, the physical systems as discussed in the prior section use SCPs e.g., IoT devices to generate data and send this to a central data hub. Second, internal systems that are already in use such as the ERP systems of warehouses, planning software of CTT, havenmonitor, and others also send data to the DT for use. Third, external systems also create data which can be used by the DT. Think of historic container volumes, ship scheduling, weather data, etc. As can be seen on the right side of the model, all these data sources are input for the DT.

5.5 Data processing

With the data gathered as discussed in Section 5.4 as input, the DT first segregates it into three different categories: context, customer, and service. Context data is the data generated by external sources as it is used by the DT to look at the context of the problem, which in this case would be the business park itself. Customer data is everything related to the clients, which in this case would be the warehouses and their orders, and down the road might even include their customers' data if a family of DTs would be implemented. The service data is everything that is necessary for the service of container handling to operate.

After the data has been split up into their respective categories, smart analysis is applied to said data in order to structure the data, making it possible to interpret the data. This is done using a collection of standard tools, algorithms, rule engine, etc. as well as own software in the form of havenmonitor for example. This software is used to visualise and store historical data, giving it a role to play in data gathering as discussed in Section 5.4 and a role in making the data interpretable for the user.

The last step of data processing of the DT is using the interpretable data to create services, for example, predictive and faster maintenance of the fleet of terminal tractors and AGVs and use these services to create actual value.

5.6 From data processing to value proposition

This actual value is the value proposition of the model. In this use case, the services of the created by the DT can create external value in three ways. Firstly, it can increase efficiency of the business processes. With the DT to help the planners of CTT, they have a powerful tool to help with decision-making during the planning process, resulting in better schedule adherence and more efficient delivery and pick up of containers. Secondly, better performance can be achieved with better insight in day-to-day operations data and using this for simulation. In turn, this can result in a reduction of emissions by, for instance, routing optimisation. Besides reduction of emissions, this also has the added benefit of cost savings. Optimisation of routing and scheduling will likely reduce operating costs, as less kilometres are driven on a yearly basis and less downtime of vehicles will be achieved to name a few examples.

All these value propositions ultimately result in more autonomy, optimisation and control for Port of Twente which directly impacts the business processes and therefore the physical system of systems, or as they are called in the model, the 'things'. As for the quantification, the closest estimation that is currently available is to look at similar processes that have been simulated in other ways and see if there is any quantification based on that.

6. DISCUSSION

As Barth et al. [4] also discuss in their limitations section of their study, there is a certain percentage of assumptions and bias that goes into modelling value creation of a DT, as it is a novel technology that is just now getting implemented into business processes. Secondly, every use case has their own priorities, which can be seen when comparing the use case of Port of Twente of this paper with the one of Shiptec used in the paper by Barth et al. [4]. Besides, modelling always loses some of the nuance such technology implementation will create, which needs to be kept in mind. The power of the model is mainly in showing the interoperability of all the factors at play at a basic level, making it understandable for the stakeholders. On the other hand, there is no quantitative analysis within the model as will be discussed in Section 7.3.

Due to the focus on one use case in this study, generalisations are lost which means that this study is harder to apply to other use cases directly. It is unclear whether there is a distinct overlap between implementation of a DT in different use cases, as the use case of this study and the one used by Barth et al [4] are too dissimilar to make any conclusions.

The most pressing limitation of this study and any other discussed in this report, is the step to actually quantify the value creation is missing. By reason of the novel interest within the scientific community for DT implementation, research into quantification of DT implementation is still in its infancy.

7 CONCLUSIONS

The study set out to answer the following two questions: (1) How to assess and measure the business value of DTs, and (2) how these assessments and measurements can be visualised clearly. During the study it became clear that measuring business value of DTs is not well researched which meant a shift in focus from measuring to visualising, which will be discussed more in depth in the future work sub section of the conclusions.

In this section the answers to these questions are discussed in Sections 7.1 and 7.2, and an avenue for further research is proposed Section 7.3.

7.1 Research question 1

The first research question was focused on reviewing the literature to give a basis on which the answer of the second question could be built. In the end, the answer to this question is as follows. To assess and measure the value of digital twinning, the first step would be to visualise the workings and value creation of the DT one would want to assess. The main power of DTs is to allow reiterative simulation of data generated in the business processes, resulting in incremental optimisations. The best way to assess and measure how this can improve business processes is to model it. This can be done with the model that Barth et al. [4] propose, although some changes had to be made in order to fit it to the logistical context of the use case this study used. Regarding the measurement of value creation through digital twinning, there is close to no research into this integral part of business decisions.

7.2 Research question 2

As was concluded by answering research question 1, the best first step to assessing and measuring value creation by digital twinning in a business process is to model it. The best model suitable for the use case of this study was a modified version of the model proposed by Barth et al. [4] as it clearly shows the circularity digital twinning inherently has as discussed in Section 6.1. Though, the model is applied to a use case that is completely different from the use case of this study, thus several things had to be changed to fit the use case at hand more closely, and to answer the research question. The use case Barth et al. [4] use is a DT with a focus on a single ship in a fleet of cruise ships, with a focus on ship use optimisation and everything that comes with it. The use case of this study is the container handling at XL Bedrijvenpark Almelo. The biggest difference is the level on which these two DTs operate, as the ship one is a DT of an instance, whilst the container handling is one of a portfolio of DTs ultimately, as later on the AGVs, the warehouses, etc. will also have their own DT that operates in the DT of XL Bedrijvenpark Almelo. Thus, creating a big family of DTs which all interact with each other and creating value together. Another big difference was that the focus of this use case is a service, as opposed to the product, being the ship, in the use case used by the creators of the model. This difference is solved by remodelling the product life cycle into a service life cycle to show how the service(s) in the use case can evolve by the use of the DT. As for the measuring part of the research question, there is not much research in this area which meant that new avenues had to be explored. To make a start of quantifying the value creation, a table has been created based on the work of Barth et al. [4] and own insights in cooperation with Port of Twente to at least put on paper how the implementation of a DT in the use case can create value for Port of Twente. This way, future research can use this as a basis for quantitative study of value creation for this particular use case.

7.3 Future work

There are several avenues for future work that can build upon this study. First, as discussed in the limitations Section 6.3, a time constraint limited the scope of the study which translated to a small literature review. An extensive literature review might show new insights for value creation of DTs. Secondly, due to the novelty of the technology, research has been expanding dramatically in the last couple of years and there are still apparent knowledge gaps, for example, in quantification of value creation of DTs. This is especially important for businesses as they need a way to quantify the decision to implement a DT, as just mere assumptions will not be enough to convince investors.

As for the model itself, at the moment of publishing there are no other use cases than the two discussed in this paper that have been applied to said model. Due to this, no generalisations can be made, and validation of the model is inadequate to actually appraise this as the way to visualise value creation by DT implementation. As well as the fact that the model does not quantify any value which, as discussed in the previous paragraph, is important for business decisions. A start has been made by adding the table overview of past, present, and future value creation, but this alone is inadequate for actual quantification of value. Furthermore, the use of DTs can also lead to new business models that have a different approach to monetisation, something that has been left out of the scope of this research and that is worthwhile to consider for future studies as well.

Lastly, with the current developments in industry where almost anything nowadays generates data, it is expected that DTs will be implemented broadly in the coming years. With the ultimate goal, as also ascribed to by Port of Twente, a self-sustaining and -adaptive family of DTs that can communicate with each other for an ever-growing optimisation of logistical processes. Not just in XL Bedrijvenpark Almelo, but also on a lower level as the warehouses, or higher level as entire supply chains through the Netherlands. Therefore, study into feasibility and quantification of this value creation is recommended to use as a basis for future research.

In conclusion, there is a clear knowledge gap in quantifying this new technology that will become a mainstay in several industries. Secondly, it is important to peer review models and try to use them in distinctly different business cases in order to test their viability for value visualisation.

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