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Digital twinning for purpose-driven information management in production

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Abstract

The current technology push towards Industry 4.0 has provoked companies to gather exponential larger amounts of data. The sheer amount of data, as well as the implicit and explicit interrelations have increased the organisational complexity. As a result, companies lose control, have difficulties in reaching decisions, while unknowingly creating information and knowledge gaps – irrespective of the abundance of data available. Digital twinning technology can be instrumental to this problem. The technology allows for reasoning from the information content, bringing together the current situation and the expected course of process, while simultaneously aiming to predict future possibilities based on the information content. To achieve an effective and efficient implementation of digital twinning technology a purpose-driven approach is proposed. An approach towards defining the purpose can be facilitated by following the 3P characterisation: Purpose, Perspective and Priority. The incorporation of the 3P characterisation will lead information provision that is derived from the defined purpose. This can also be called purpose-driven information management. In this paper two projects are explained that will be used as use-cases to evaluate and validate the theory of purpose-driven information management and the 3P characterisation.

Keywords: Digital twinning; Decision making; Purpose driven information management

1. Introduction

'Digitising the factory' is becoming a growing paradigm in industry, as a means to exploit the advantages of industry 4.0. However, why, if and how this digitalisation addresses any of the urgent and relevant issues is still an open question. This is foremost related to the exponential growth in the organisational complexity of production environments. The increasing complexity is caused by the impression of planning and execution systems, automation, differing perspectives, and control mechanisms at different levels of aggregation. This makes it almost impossible to maintain an adequate and instrumental overview of the entire production environment. Companies may therefore lose control, have difficulties in reaching decisions, while unknowingly creating information and knowledge gaps – irrespective of the abundance of data available. Given this discrepancy between meaningful information and the profusion of data, for companies, Industry 4.0 can feel like an avalanche [1]. The current technology push provokes companies to rush the digitalisation of their factories without defining the reason why they are doing it. Fear of missing out tricks many companies into becoming "data-rich, but insight poor" [1]. Large volumes of data can quickly be accumulated, albeit without the possibility or intention to process, filter or use the data. Even worse, the resulting data overload may hamper the ability to understand and exploit the data purposefully. The sheer amount of data, as well as the implicit and explicit

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interrelations certainly add to the organisational complexity. Therefore, the need increases for an overview and insight in the production environment and its data that decreases the complexity.

The current approach to process improvement may fall short as companies want to make decisions in a more effective and efficient manner. A purpose-driven approach towards Industry 4.0 technologies might therefore be required. With that, the perspective must change from a process-oriented viewpoint to a situation in which a company is in control of its environment and can orchestrate its functions, constituents, aspects and even peculiarities. Likewise, digitalisation becomes a mere tool to allow for overview and decisiveness instead of a means in itself.

In other words, the large amount of complex intertwined data, the lack of insight and overview into the production environment has increased the need for a comprehensive tool that presents the data in an interpretable and understandable representation [2]. A tool that allows different perspectives for a variety of stakeholders, is able to query, analyse data, minimise effort, minimise expertise required and improve decision making [2],[3],[4].

So-called digital twinning technology can be instrumental to this need. The technology allows for reasoning from the information content, bringing together the current state of affairs and the expected course of processes, while simultaneously aiming to predict future possibilities based on the information content. Digital twinning technology aims to present the right amount of data and information to the appropriate stakeholders to make the right decision at the right time.

Every decision requires information, encompassing information on the current state (as-is), the future state (to-be) and the state in between (could-be). More important, however, in most decisions, combined aspects of all these states are involved. As an illustration, it can be imagined that real-time decisions that are made in a production environment have the purpose of keeping the production running as efficiently and effectively as possible. To do this, the future-state ideas for optimisation need to be supported with current-state information and data to evaluate decisions and scenarios in the could-be state.

2. Digital Twinning

The concept of digital twinning addresses the interrelation of the 'as-is', 'could-be' and 'to-be' states as the basis for purposeful and underpinned decision making. Together, these states represent the (development) life cycle of a product or an asset. The digital master ('to-be') captures the definition of the envisaged entity, i.e., the design of the product or asset.

The digital twin ('as-is'), in correspondence with a 'traditional' depiction, digitally captures the current and previous condition of an entity. The digital prototype ('could-be') allows for simulations and what-if analyses linking design intent and actual conditions. Together, these three are referred to as the digital system reference (DSR), shown in Fig 1. Here, the definition of the digital twin is described as a digital version (a conglomerate of data, information, models, methods, tools, and techniques) of a physical asset that represents and simulates its past and current behaviour. This designation explicitly addresses real-time data integration, data analyses and virtual representation as required functionalities.

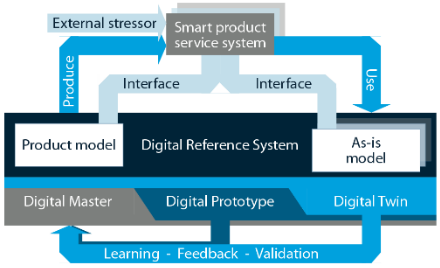

Fig. 1: Digital system reference [5]

As such, the digital twin is the real-world counterpart of the digital master and being the captured and established product definition and design intent. This digital master, therefore, is the idealised or nominal depiction of the product or asset. Evidently, there will be discrepancies between the design result and the existent product(s), and even between the different instantiations of a designed product. This implies that individual products can provide feedback to the digital master, whereas the digital master can be used to adjust the digital twin, for the benefit of both.

It goes without saying that between 'ideal' and 'real' a lot of potential alternatives can be explored, and that is precisely the role of the 'could-be' digital prototype. This digital prototype allows for e.g., simulations of a product's behaviour based on actual data. Alternatively, it may also enable outlining the consequences of design decisions for through-life engineering aspects of a product. Conjointly the digital twin, prototype, and master referred to as the Digital System Reference (DSR), work as a feedforward and feedback triad that can be used for learning, feedback, validation, and optimisation between the levels.

2.1. Use-cases in literature

Use-cases of digital twins are increasing in numbers [6-11] showing the benefits of implementations of the technology. The use of the complete DSR concept in production environments is less common. Most of the use-cases provide solutions that partially covers the concept of the DSR. Current conceptual implementations of digital twins might not solve the underlying problems that are currently visible in industry. Further steps need to be made in the development of digital twinning technology to maintain the growth in implementation and show the added value of digital twinning technology to industry.

The current concept of digital twins is focused on representing the 'as-is' state, while this might not always support the need and solve the problem of industry. To facilitate an effective and efficient solution, the digital twinning implementation should meet the purpose it is intended. Consequently, this might require the integration of the 'could-be' and 'to-be' information. Increasing successful implementation of DSRs next to digital twin implementations will showcase further possibilities around the technology. This will improve the solution to fit the purpose and need of the industry further, therefore, increasing the effectiveness and efficiency of the implemented solution in industry.

3. Purpose-driven implementation

The DSR can be a very effective tool to support industry with their need to create more insight and control in their production environment. The different levels that are combined in the DSR allow for evaluating of the current state and overview of what is currently happening. Furthermore, it allows for the evaluation of the scenario's based on different perspectives. Not only considering the current situation but also the 'to-be' situation in the future and the 'could-be' situation in between. This allows the stakeholders to look at decisions from different perspectives and situations, without having to test scenarios in their running production environment physically.

One main reason for this is that, with the DSR, the outcome of activities can become the main driver for the improvement of the development cycle, rather than the habitual choice of pre-defined (sets of) processes. In other words: the activities themselves do not evolve the product definition, as designed; they are merely the tool to achieve the evolvement towards a finished product. In using the DSR to facilitate a feedback loop, control can be aligned with the information, content, and the potential outcomes of decisions. Therefore, improving the activities and decisions instead of controlling the decision processes. With that, the focus is on the outcome of the production cycle, making it purpose-driven and information based.

The specific functionalities that are included in the instantiated DSR are dependent on the purpose and need of the specific company. Consequently, DSRs are similar in their core but will always be unique because of the defined and implemented functionalities. Defining the right functionalities for the DSR to fit its intent, requires a purpose-driven approach to the implementation of digital twinning technology. It is therefore required to define and evaluate the purpose of the DSR in its environment carefully. The approach towards defining the purpose and requirements that need to be included in the DSR can be done by following a 3P characterisation: Purpose, Perspective and Priority.

3.1. Purpose

The purpose can be defined and evaluated by using tools such as interviews and workshops. Preferably this is done with all the stakeholders, ranging from the company owner to the employees that will be interacting with the technology. Including stakeholders is required to implement a DSR that can fulfil its goal, is able to support the user in making decisions, and earns its investments back. By investing time into the initial evaluation of the goal and purpose of the DSR, an optimal solution can be created that positively affect the whole production environment instead of a local optimum.

When talking to stakeholders, it needs to become clear what the importance is of the DSR from their perspective and what their role is connected to this. It is essential to define which decisions are made on which level and why. By determining what the essential information, functionalities, and requirements are, the precise role of the stakeholders in the entire process can be established. Doing such interviews also allow conversation on current critical points in the process and identifying the parts that are important to include. This results in a list of critical components, perspectives, decision points, requirements, functionalities, and required information that needs to be considered when implementing the DSR. The output of the discussion with stakeholders will allow to establish the purpose and functionalities that will lead to an effective implementation of the DSR.

3.2. Perspective

As previously stated, the quality and impact of decisions is dependent on the available information. This information requirement is dependent on the perspective. Since multiple users will interact with the DSR, it should be able to present perspective dependent information to the user. Therefore, the perspectives per user/ stakeholder group need to be defined, to facilitate information that is dependent on perspective. The perspective can be determined based on the information already gathered and by determining what information is required for decision support at each level of aggregation.

3.3. Priority

Based on the defined and determined requirements around the purpose and perspective, priority could be assigned to the requirements of the DSR. The priority setting includes decisions on which components need to be included, the level of detail that is required, the required data and the sensors, and which visualisations are required. The resulting priority will support the effective and efficient implementation of the DSR. By starting small with the implementation and development, the DSR stays flexible for changing needs and allows for intermediate evaluation of users and user experience. This allows optimising the DSR during the process of development.

Following the purpose-driven 3P characterisation, namely, Purpose, Perspective, Priority, helps to define and implement DSR that is tailored to its designed purpose and will be more effective and efficient in supporting the user with its decisions and need for insight.

4. Digital Twinning for decision support

The purpose of implementing digital twinning technology results from a need in industry to create insight, optimise production, reduce defects, and improve control. In many production environments, humans are the most unpredictable factors. With that, the quality of decisions relies on how knowledgeable, lucky and experienced the decision-maker is, and, furthermore, on the information available [12]. Obviously, highly experienced employees are more capable of foreseeing the consequences of decisions than employees with less experience. Yet, the sheer availability of experienced employees should not be determinative in

decision making, nor should decision making rely extensively on experience.
Often in companies, clarity of why, by who and where decisions are made is lacking. Consequently, effective decision support and automation in decision making are becoming increasingly important in production environments. Furthermore, tools and technologies that decrease the required knowledge level and allow for effective and informed decision making are growing in importance. The DSR allows for the interrelation and analysis of different data and information sets for decision support, while accounting for the various perspectives involved. Therefore, it can be a foundation to support decision making in the production environment.

4.1. Orchestrator

An orchestrator aims to give direction to the activities in a given environment; its role can be described as the "co-ordination of enterprise elements to produce a desired effect". Essentially, an orchestrator serves as a control system for a dynamic production environment. It can engage in manual as well as in autonomous decision making. An orchestrator thus builds upon the DSR and supports in decision making in production, based on the data and information provided by the DSR.

An orchestrator allows for decision-making to be divided over different levels of control, while simultaneous determining the decision space [13]. How the decision space and control levels play a role in decision making is influenced by the company strategy. For the definition of the control space the 3P characterisation can be instrumental. The characterisation helps determine which decisions are permitted on each level. This can reach from fully autonomous decision making to decisions limited to e.g., navigation or prioritization.

When using the DSR for the provision of the appropriate information, and combining it with an orchestrator, an efficient tool is developed that can form the basis for effective and efficient information management and decision support. A conceptual model is presented in Fig. 2.The advantage of the DSR in combination with the orchestrator is that it can interrelate between not only the current and historical data (as-is) but also the 'could-be' and 'to-be' data. This allows for what-if analysis that can support decision making by visualising different scenarios. Next to that, the defined control levels can support limiting the information that is available based on the purpose and perspective that is required for the user.

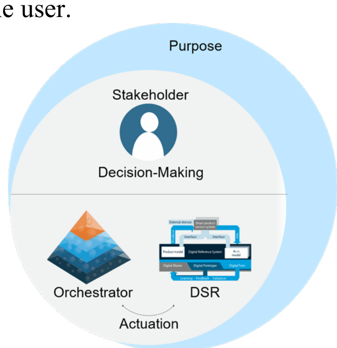

Fig. 2: Conceptual model purpose-driven information

Based on the idea of presenting the right, information, to the right person at the right moment, the DSR in combination with the orchestrator should decrease the required knowledge level to make effective and efficient decisions. Next to that, it should support the decisions on different levels of aggregation and control. The concept of focusing on the purpose first, with the use of the 3P characterisation, will make sure the DSR and the orchestrator are able to fulfil its designed intent. Consequently, the functionalities, requirements and most importantly the information is dependent on the defined purpose. The incorporation of the 3P characterisation will lead to information provision that is derived from the defined purpose. This purpose-based information provision can also be referred to as purpose-driven information management.

5. Purpose-driven information management

In industry, the tendency is to plan and control in terms of the processes and activities rather than in terms of the envisaged outcomes of these activities – being the information content. The cause for this can be traced back to the control mechanisms that have become rooted in the way industry looked at ordaining operations and optimisation. Furthermore, it can be related to the current technology push for digitalisation. This push, however, unfortunately comes without a clear set of specific steps. Next to that, use-cases that should function as showcases for companies that want to transition to Industry 4.0 often are focused on showing the capabilities of the technology. By aiming at showing all the capabilities, the focus on the benefits for the user and industry is lacking. This is also the case for the many implemented digital twin concepts in the field. Therefore, when implementing digital twinning or Industry 4.0 technologies, companies are looking at digitalisation based on the way optimization has always been done, which is based on process improvement and standardization.

A hundred years ago, industry was introduced to Taylorism, focusing on optimisation of productivity through activity analysis and process definition. With a focus on maximizing profits by producing more goods at low costs, industry learned that control on production environments could be increased by formalising processes.

As a result, industry currently does not put information as leading for defining their processes. The human mind has been biased to look at action and processes first and then determine what information is required. Process-based optimization is, in essence, not wrong, but when looking at implementing decision-making tools and digitalising production environments, the current way of thinking may limit an effective and efficient implementation of new technologies.

Furthermore, nowadays, the objectives of industry have expanded from only maximizing profit to short delivery time, quality, diversity, and flexibility. These new objectives are not always reachable with the mere use of process formalisation, for example, because they stem from different, potentially even contradicting or competing perspectives.

It is necessary to start defining processes based on the quality, flexibility and time factors that are required, followed by the information need, instead of the factors and information resulting out of the process. Only then will industry be able to achieve the new objectives. Consequently, the firm focus on process formalisation and standardisation needs to be release. A change in mindset towards putting purpose-driven and information as leading allows improvement in the information flows and support of decisions. This approach results in not only speeding up activities and increasing them but optimizing them in a smart way based on information.

The benefit of the developments around digitalisation and digital twinning technology is that data and information become more widely available. With that, a broader range of optimalization options has become available next to the standard process optimization. Therefore, it is proposed to make information leading in the process when implementing digital twinning and industry 4.0 technologies. This will solve the current issues where the information management and digital infrastructure needs to be fully tailored to the current process when starting with digitalisation. It also prevents acquiring large amounts of data that increase the complexity of the puzzle to facilitate an overview and control of the production environment.

When information is put leading over the process, the decision support can be improved, without overloading the stakeholder with information. This reduces the complexity of the information system and creates an information management system that facilitates and supports the process.

The DSR as purpose-driven information management system can facilitate the process in the production environment and provide the right information at the right moment. This can increase the control on the production environment, not by having direct influence on the activities but by explicitly facilitating the information flow and decisions making. Moreover, providing a sound foundation for decision making allows for more adequate management of related and consequent activities and process.

6. Digital Twinning use-cases with purpose-driven information management

To test, evaluate and co-develop the concept of the DSR and purpose-driven information management, two use-cases will be used. The aim of the use-cases is to develop and validate a methodology for the effective and efficient implementation of digital twinning technology and to apply and evaluate the theory of purpose-driven information management in production environments.

6.1. Use-case: Digitalisation of bike factory

The first use-case is based on a research and implementation project with a bike manufacturer. The purpose of the project is to support purposeful growth, insight and control while maintaining the flexibility that is required for their high customisable products. The company already recognised and established that steps in digitalisation must be taken to obtain the overview required to achieve these goals. Especially, with respect to advanced plans to scale up production by establishing additional production facilities. Furthermore, a request for the implementation of digital twinning technology was done.

An initial analysis is done to make sure the digitalisation steps and digital twinning technology will be implemented in an effective way with the assurance that it will also fit its intent in the future. The analysis consists out of workshops that map out the current vision, state, information, and processes at the company. Even though the focus lies on the business process and the transformation of the processes, process mapping should be seen as a tool to understand and bring together information needs, identify information gaps and decision points. By looking at the process map from that perspective, the opportunity arises to talk about why current things are structured the way they are.

Based on the output of the workshops and the result of the initial analysis, the requirements for digitalisation and the DSR will be defined. One of these requirements is flexibility. Flexibility has always been a high priority in the company as customisation is what makes their bikes special. Consequently, their current approach is based on design by least commitments. The company only fixes process steps, actions, or decisions if it is required. This approach will become more complex when starting to upscale to additional locations. Certain decisions should not be available for employees on the floor. For example, design decisions and configure to order options must be fixed from the engineering department and only the bike configurations should be communicated to the production environment. This will reduce the errors and improve quality consistency on the product.

It is visible in the company that communication between departments is not optimised, this could result from the fact that there are information gaps and limited information management. Therefore, this is an interesting use-case to further develop and validate the approach towards effective implementation of a DSR. Furthermore, showing the benefits and approach towards the implementation of purpose-driven information management. The implementation will allow the company to close the information gaps, implement different perspective to optimise information management, create more insight and control, and have an effective implementation a DSR.

By keeping a purpose and information driven mindset throughout the project, (and with the usage of the 3P characterisation) steps towards a digital bike factory will be made. First by making sure the information management is in place and then by optimizing the process in an effective and smart way. The challenges will be to change the mentality from the current process, thinking towards how we can facilitate everybody in the best way possible. So, we provide the right information, at the right time, to the right person. The use-case will allow testing, further development, and implementation of the DSR concept and the theory of purpose-driven information management.

6.2. Use-case: Orchestrating engine shop

The second use-case is based on a project at an engine shop. The function of the engine shop is to check, clean and repair aeroplane engines. The aim of the project is to provide more insight into the engine shop and improve the efficiency. The engine shop processes are fully defined into rigid an information management system. Next to that, the process is over defined with quality checks to assure safety of the engines that does not allow for much flexibility.

Attempts to improve efficiency and throughput times based on process formalisation do not make much improvement. Therefore, the company requires a different approach towards optimization and has expressed their need for more insight into the current way of working to identify optimisation options. Similar to the first use-case an initial analysis was done to map out the current way of working, the existing information flows and the decisions that are made with the use of the 3P characterisation.

It became clear that the as-is information in the system was minimal and did not reflect what was happening in reality. This is caused by the information management to be adjusted to the existing process. Optimisation became difficult based on the lack of information for the management but also for the employees working in the engine shop. The implementation of a DSR can support what-if scenarios and allow for testing of optimisation options without interrupting the running operations. Next to that, by investigation where the information gaps are based on the purpose and required perspectives the as-is information in the system can be improved to match more with reality. Therefore, this is an interesting use-case to implement and validate a purpose-driven approach towards the implementation of digital twinning technology.

The implementation of a DSR in the engine shop will improve the information management to better fit its purpose. In combination with an orchestrator, the DSR can facilitate the support and automation of decision making in the engine shop. The use-case will function as a demonstration for the benefits of following a purpose-driven approach towards information management. Furthermore, it validates the efficiency of using digital twinning technology in combination with an orchestrator for decision support.

7. Conclusion

The concept of the DSR can be a valuable next step in supporting industry in their initiatives towards not only digitalisation and Industry 4.0, but, more generic, their decision making in general. The results of the use-cases indicate that taking a purpose-driven approach towards the implementation of digital twinning technology will allow for a more effective and efficient solution to the industry needs. It is expected that, with the use of the 3P characterisation and by implementing purpose-driven information management, the information foundation is developed to further optimise and implement digitalisation technologies. This will result in an effective solution that is optimised for its use and users. With that, digitalisation explicitly becomes a mere tool to establish more and better overview and decisiveness, for all stakeholders and perspectives involved. Critical guidance is required to point out the habit of process thinking. This guidance also facilitates discussions and provides different viewpoints, while influencing new technology acceptance and implementation aspects at different levels of aggregation. Moreover, such discussions allow for evolving specification of purpose and goal definition.

The DSR, together with the orchestrator, has much potential to become a widely used foundation for decision support in production environments. When following the 3P characterisation, making the purpose explicit and involving all stakeholders and perspectives, the DSR can facilitate purpose-driven information management in production environments. Such an integral approach allows companies to interrelate their overall strategy with the decision processes at all levels of aggregation.

More purposeful and effective implementations of the DSR will make the technology more tangible for industry, which will lead to the further development and research possibilities on the topic of digital twinning. This requires companies to switch from process thinking to information-based working and put the 3P characterisation in practice more often. To achieve this, information flow needs to be put on a higher priority than the process to create more space for outside of the box solutions towards optimisation in production environments. Therefore, in releasing process-oriented thinking, more room will be created for information management and purpose-driven approaches. This allows for a more effortless, efficient, and effective way for companies to transition towards more purpose-oriented decision making, for example in the implementation of digital twinning technology and industry 4.0.

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