From Data to Decisions: A Method for Evaluating the Strategic Value of Digital Twins

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***Abstract*—Digital Twins are gaining increasing attention in research and practice as one of the most exciting technologies within Industry 4.0. They enable new business models, increase efficiency, and provide a basis for differentiation strategies. This paper develops a method to evaluate the strategic benefits of Digital Twins based on the phases of the product lifecycle and a Balanced Scorecard approach. The strategic benefits cover the entire product life cycle, with the highest potential presumed in the production and service phases. The method proposed in this paper serves as an orientation aid and a tool to support a holistic investment decision for companies. It allows for a more comprehensive understanding of the strategic benefits of Digital Twins and their potential impact on the product lifecycle. The research is based on a literature review regarding Digital Twins and approaches to evaluating their strategic benefits. The paper contributes to the existing body of knowledge on Digital Twins by proposing a novel approach to evaluating their strategic benefits, specifically in the context of the product lifecycle. The findings provide valuable insights for companies seeking to implement Digital Twins and develop new business models.**

Keywords—Digital Twin, Industry 4.0, Strategic Benefit, Product Lifecycle Management, Balanced Scorecard

I. INTRODUCTION

In today's rapidly changing world, manufacturing companies face increasingly demanding challenges. Driven by evolving societal and economic developments, the traditional focus on expanding production volume has shifted towards meeting individual customer needs [1,2]. With a growing diversity of product specifications and a trend towards smaller batch sizes, complexity is on the rise. Meeting these demands requires production processes that are both flexible and efficient, while also being capable of responding quickly to market changes [3].

Moreover, companies are under pressure to reduce delivery times, cut costs, and stay competitive in an ever-changing landscape [2]. They are also facing a new challenge – the world's changing environmental consciousness – that is compelling governments to take increasingly stringent protective measures. Under these conditions, companies are struggling to maintain their competitive edge against the rising tide of start-ups and expanding businesses [4].

Smart manufacturing – a paradigm of intelligent production processes – is designed to optimize production capabilities in response to the challenges mentioned above [5,6].

At the heart of intelligent manufacturing are Digital Twins, which are effective tools for smart, data-driven factories [6,7]. A Digital Twin is a virtual replica of a physical object that allows companies to digitally simulate and manage the object's entire lifecycle [8]. Digital Twins can help to increase production efficiency, achieve competitive advantages, and improve both lifecycle management and resource efficiency [4,9]. The technology's disruptive potential has attracted increasing attention from industry practitioners [10,11]. According to [12], the Digital Twin market is projected to reach $156 billion by 2030, with an average annual growth rate of 39% starting in 2022. [13] predicts that by 2021, half of all large industrial companies will be using Digital Twins, achieving 10% efficiency gains.

Despite the benefits, companies must make an initial investment decision before Digital Twins and their associated advantages can be realized. This decision is among the most critical a company will make, with long-term implications that require a holistic evaluation. Traditional investment evaluation methods that focus only on financial considerations and fail to account for long-term strategic benefits are inadequate [14]. The long-term potential benefits of new technologies, such as Digital Twins, make it essential to evaluate them holistically. Failing to do so can lead to negative outcomes and hinder their adoption [15].

Thus, strategic benefits must be a critical consideration in the investment decision process. Failing to account for these benefits can impede the adoption of new technologies, while considering them can drive business success. Such success has been seen in companies that have implemented Digital Twins, enabling them to reduce costs, improve product quality, and increase overall efficiency [10,9].

This paper aims to evaluate the strategic benefits of Digital Twins as an investment decision for manufacturing companies. Therefore, an approach is presented that considers the specific aspects of a Digital Twin.

II. State of the Art

The term "strategic benefit" refers to the non-quantifiable benefits that a product or service can provide [16]. In economic theory, the concept of "utility" refers to the ability of a good or service to satisfy specific needs. The benefits of a product or service can be subjective, based on the user's perception of how well it satisfies their needs, or they can be inherent in the product itself [17]. These benefits are referred to as "utility potentials" or "utility effects".

In the field of IT solutions, the benefits are a primary factor in determining their economic viability [18]. Benefits can be quantified or non-quantifiable, and quantifiable benefits can be further divided into monetary and non-monetary categories [19]. Direct benefits are those that can be directly reflected in a company's financial statements, such as cost savings. Indirect benefits, on the other hand, represent a theoretical financial potential, such as time savings through process optimization. [14]

Strategic benefits are those that cannot be quantified in terms of quantity, and are also known as qualitative or intangible benefits [20]. These benefits are not immediately measurable, and their evaluation can be problematic. However, strategic benefits can provide significant advantages over the long term, such as increased competitiveness, improved quality, enhanced company image, and greater customer satisfaction [14].

While traditional investment analysis methods may not consider strategic benefits, they can have a significant impact on the long-term success of a project. Strategic benefits often arise from investments that may take time to materialize but can provide advantages beyond the immediate scope of the investment. For example, reducing development costs through the use of Digital Twins can be considered a strategic benefit, as the impact may not be immediately apparent but can be significant over the long term. [19]

In this context, strategic benefits are defined as those that have identifiable and quantifiable impacts within three to five years. By focusing on the long-term effects of strategic benefits, rather than simply categorizing them by their evaluation potential, it is possible to identify the true value of these benefits and their impact on the overall success of a project. [18]

According to a comprehensive literature review with focus on the strategic benefits of Digital Twins, we identified 14 publications that describe the application of Digital Twins, which can be broadly categorized into two approaches. The first approach involves authors discussing the benefits and impacts of Digital Twin applications without explicitly differentiating between operational and strategic impacts. These applications are typically categorized based on the product lifecycle, although different versions of this framework are used. The second approach focuses on the specific effects of individual Digital Twins on concrete business models or provides a general summary of the impact of new technologies in the context of Industry 4.0 at the business model level. To achieve this, various concepts such as the Business Model Canvas, Value Proposition Canvas, or Sustainable Business Model are utilized.

A. Focus on product life cycle

Several authors have written about the design, development, and applications of Digital Twins. [21] differentiates between data-based and system-based Digital Twins and discusses various benefits, including improved transparency, product quality, and shortened time to market. [10] structures the applications based on the product-service system life cycle and highlights the benefits of minimizing development risks, improving maintenance, and tracking recycling paths. [22] focuses on concepts, technologies, and industrial applications of Digital Twins and offers recommendations for implementing them in different phases of the product life cycle. [23] views Digital Twins as an integral part of the product life cycle and provides examples of how they can enhance product design, manufacturing, and service. [9] sees Digital Twins as enablers for integrating data from various perspectives and discusses how this integration can improve competitiveness, production efficiency, customer satisfaction, and employee satisfaction.

B. Focus on business models

[24] studies the impact of Digital Twins on business models through four case studies and identifies benefits such as improved product optimization and system understanding, leading to new business concepts such as Equipment as a Service and Predictive Maintenance. [25] extends this concept to Prescriptive Maintenance and developes a sustainable business model based on Servitization. [3] proposes a platform for Digital Twins, offering data-based services in product development, production, and service, with the potential for third-party service providers. [26] develops a sustainable business model framework for a network of such platforms, providing an overview of product life cycles, supply chains, customer experiences, and service quality. [27] explores the integration of digitalization technology and business objectives, highlighting the importance of data-driven strategies and the advantages of using Digital Twins to gain transparency, objective insights, and flexibility in production environments.

C. Combination of product life cycle and business models

Some authors combine both the business model and strategic benefit potential approaches when examining the applications of Digital Twins in product lifecycle management. [6] provides a literature review of the benefits of Digital Twins in both product lifecycle management and entrepreneurial innovation. They find that Digital Twins can lead to sustainable product development, increased efficiency in production processes, and a range of business benefits, including optimized resource allocation, increased production output, and reduced costs. [4] also examines both aspects of Digital Twins but focusses on developing a unified standard for their architecture and highlight their ability to enable intelligent manufacturing and decision support. They identify additional benefits such as the development of new, performance-based business models, simplified management of production facilities, optimization of logistics processes, and effective fulfillment of stakeholder requirements.

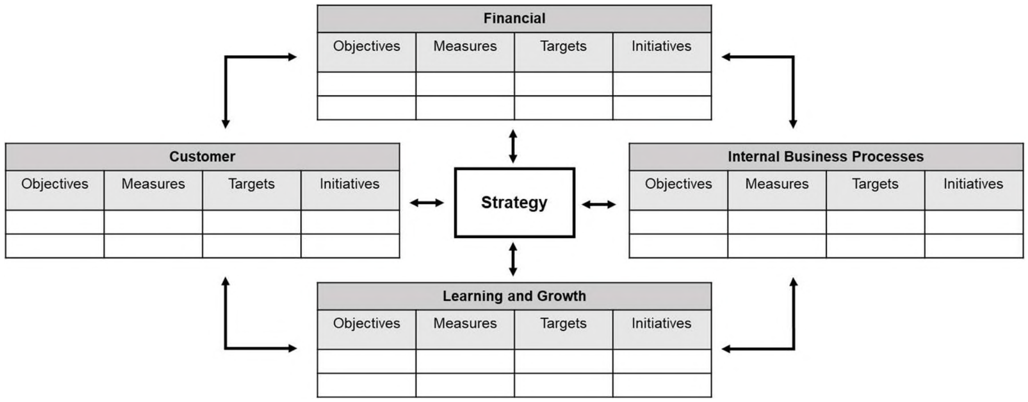

Fig. 1. Classical Balanced Scorecard

III. Method for Evaluating the Strategic Value of Digital Twins

When investing in new technologies, the strategic perspective is just as important as traditional investment valuation using financial indicators [28]. However, since the strategic benefit of an investment is not immediately measurable, a different method needs to be used [14]. This is introduced in the following.

A. *Classical Balanced Scorecard Method*

The Balanced Scorecard Method (BSC) is a well-known and suitable approach for developing and implementing strategies, especially in the context of digitization and Industry 4.0. It was developed in 1992 by Kaplan and Norton and was originally intended as a pure performance measurement system [29]. However, due to its high flexibility and simplicity, it is now mainly used as an instrument for strategic business planning and control [30].

The BSC provides a framework for the strategic leadership process and explicitly supports the implementation of strategy into business practice [28]. It allows the inclusion of non-financial metrics in addition to financial metrics, resulting in a stronger alignment of all functional areas with the corporate strategy [29].

The BSC uses four perspectives: Financial, Customer, Internal Processes, and Potential. Specific goals are derived from the corporate strategy for each perspective, along with associated metrics and benchmarks for measuring goal achievement. Measures are also presented to help achieve the set goals. [29]

The Financial perspective is an overarching entity that sets the direction of the goals and metrics of the other perspectives. It shows how the company's results are affected by the implementation of the chosen strategy.

In the Customer perspective, strategic goals are reflected in relation to specific customer segments. As customers are the source of company profits, this perspective describes how their needs can be met, with customer satisfaction and customer relationships often being considered.

The Internal Business Processes perspective ensures that the internal business processes critical to achieving business goals are appropriately aligned and efficient.

The Potential perspective, also known as the Learning and Development perspective, provides the basis for achieving the goals of the other perspectives by providing the necessary infrastructure. This includes the company's own employees, and therefore factors such as employee satisfaction, motivation, or knowledge fall into this category. The Potential perspective also considers innovation and the development of new capabilities.

In summary, the BSC, which can be seen in Figure 1, is an effective tool for businesses to develop and implement strategies, providing a holistic approach that integrates financial and non-financial metrics and aligns all functional areas with the corporate strategy. [31]

B. *Adaption of the perspectives*

The BSC can be adapted to different situations or conditions [14], and the number of perspectives can differ from the original four defined by [29]. Therefore, in addition to the original version of the BSC, there are now also adapted versions. For example, [30] shows an adapted BSC for use in Industry 4.0, while [32] adapts it for IT controlling. However, there is no specific BSC model adapted for Digital Twins.

Adapting the classical BSC model is not always necessary, as new technologies can also be evaluated using the original four perspectives. For instance, [33] uses them to evaluate industrial product-service systems, [34] for supply chains in the Industry 4.0 context, and [35] for an intelligent manufacturing system. Nevertheless, for this particular model, adapting the classical BSC is necessary for several reasons.

First, this methodology aims to explicitly analyze the strategic benefit of using Digital Twins, which includes long-term effects on the competitive situation. The overarching Financial perspective, however, is too limited since it mainly focuses on the financial metrics of the company, which cannot sufficiently represent these strategic effects. Therefore, instead of the Financial perspective, this model employs a Competition perspective, which serves as the overarching perspective of the BSC. This expands the original financial perspective by including a long-term consideration of the impact on the company's competitive situation.

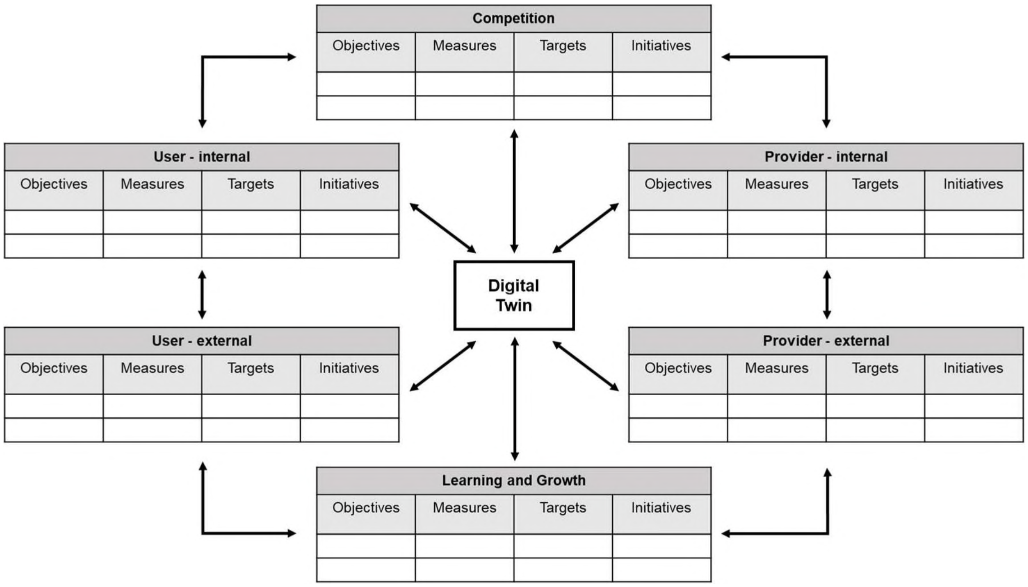

Fig. 2. Adapted Balanced Scorecard

Second, the methodology aims to determine the benefits of Digital Twins for a company. However, a company can benefit from Digital Twins in different ways, as it can be a user, a provider, or both simultaneously. Therefore, the strategic benefit differs in the two perspectives, with regard to internal business processes as well as customers. Since this model is not limited to companies that combine both perspectives, an isolated representation of the strategic benefit is reasonable for such companies. Thus, instead of just a Process perspective, this model distinguishes the strategic effects of Digital Twins on internal business processes using a User perspective-internal and a Provider perspective-internal, depending on the type of use. This breakdown is also made for the Customer perspective, as different potential benefits arise. Since Digital Twins can affect the entire external network of the company, this limited view is also expanded, and the impact on all external stakeholders of the company is considered. Based on the customer perspective of the classical BSC, the perspectives of User perspective-external and Provider perspective-external emerge. An allocation of the Competition perspective and the Potential perspective is not necessary, as the strategic goals do not differ significantly in the two perspectives, User and Provider.

The fourth perspective of the classical BSC, the Potential perspective, can also be used in its form to evaluate Digital Twins and does not require adaptation. Therefore, the BSC adapted for evaluating the strategic benefit of Digital Twins, including its six perspectives, is shown in Figure 2.

The use of the adapted BSC involves identifying potential Digital Twins applications for each phase of the product life cycle. This allows for a comprehensive understanding of the different ways in which Digital Twins can be utilized. Strategic benefits for each of the six perspectives are then derived from these potential applications, and these benefits are integrated into the adapted BSC model as objectives. The Digital Twin applications that enable these objectives are identified as measures and linked with their corresponding goals. This way, it is possible to determine exactly what types of Digital Twins are needed to achieve a particular objective.

IV. Discussion

The paper discusses the evaluation of the strategic benefits of Digital Twins. One critical discussion could focus on the limitations of the chosen methodology and the potential impact on the results. For example, while the structured literature review provides a standardized approach for identifying research gaps, subjective decisions around search terms and inclusion criteria could result in relevant publications being missed or irrelevant ones being included. Additionally, the use of multiple methods to answer research questions could balance out individual method weaknesses but may also introduce bias or limitations to the analysis. Finally, the use of operational metrics to derive strategic benefits may not fully capture the intangible benefits that Digital Twins can provide, such as increased innovation or competitive advantage.

V. Conclusion

In conclusion, Digital Twins are a technology that has immense potential for industrial companies. They allow for new business models, increase efficiency, and provide a basis for differentiation from competitors. However, the strategic benefits of implementing Digital Twins must be carefully evaluated before investing in this technology. The classical BSC represents a common method in science as well as in practice for the evaluation of strategic benefit. However, the classical approach is not adapted to specific aspects of the Digital Twin and is therefore only suitable for evaluating the strategic benefits to a limited extent. Therefore, in this paper a method to evaluate the strategic benefits of Digital Twins based on the BSC method was presented.

Despite the potential advantages of Digital Twins, there are still obstacles to be overcome, such as the lack of industry standards and differing views on future business directions. Nonetheless, Digital Twins are poised to become a must-have technology for companies. The method developed in this paper provides a structured approach to evaluate strategic benefits of Digital Twins, but further research is needed to fully understand the costs and direct and indirect benefits of implementing this technology.

In the coming years, Digital Twins are expected to rapidly evolve, and companies must begin exploring this technology early on, as implementation can be both time-consuming and costly. By building upon the method developed in this paper, future research can create a comprehensive tool for investment decision-making. Overall, this paper has demonstrated the strategic benefits of Digital Twins and laid the groundwork for further research in this area.

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