Creating value with sustainable production based on real-time simulation

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DOI: 10.4324/9781003054214-1

Creating Value with Sustainable Production based on Real-Time Simulation

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Abstract

This chapter describes research into physics-based real-time simulation from a business perspective and provides guidance for further studies. Despite the increasing amount of research into simulator-driven design and production, little progress has been made towards understanding the complexities of its implementation, its effect on business models, and how it can best be applied to create value for the customer. There seems to be agreement in the literature that this type of digital transformation of industry is beneficial, but many of the business issues remain unclear. The following paragraphs seek to encourage a new way of looking at real-time simulation studies. The chapter concludes with an illustration of sustainable value creation using real-time simulation and digital twinning and a number of concrete suggestions for questions that should be answered in future research.

Keywords: real-time simulation; digital twin; sustainability; sustainable production; sustainable value creation; business opportunities

1.1 Introduction

There has been shift away from technology-driven design and production towards sustainable value creation (Kaewunruen and Lian, 2019; Ukko *et al*., 2019). Traditionally, product and service development decisions have been made by experts tasked with directly addressing development issues. Their decisions have been based, for the most part, on relevant technical aspects. The focus, however, is moving away from purely technical aspects and moving towards enhancing the user experience and customer value. To address this trend, many manufacturing companies are reconsidering and re-engineering their existing product processes so they can become more competitive.

Advanced and persistent usage of key enabling technologies will be fundamental to success, and as the new enabling technologies are implemented to provide future products and services, user and customer needs must be better addressed and increasingly fulfilled (cf., Jones *et al.*, 2020; Ukko *et al.*, 2020). Accordingly, product processes must be reconsidered so the broader spectrum of stakeholders – beginning with supply, encompassing all internal organizational functions, the user and ending with aspects of recycling or disposal – are closely engaged (Kokkonen *et al.*, 2020; Nasiri *et al.*, 2020). The critical task is to develop the necessary techniques and toolsets needed in design and manufacturing to enable new sustainable business opportunities.

Often, new products embedded with innovative digital solution functionalities such as Internet of Things (IoT) are verified and validated by building and testing prototypes. In general, the prototyping process includes detailed design, parts procurement, prototype assembly, verification and validation testing, results assessment, and redesign. Each step in this process consumes time, which delays the commercialization of new innovations, and money, which results in more expensive product development in which customer needs may not be completely fulfilled. On top of wasting time and money, in many cases the manufactured prototypes cannot be used, as such, in follow-on prototyping, which contradicts the idea of sustainable production. New digital approaches for the design, prototyping, and testing of new machines make it possible to account for human-interaction and customer needs early on in new product development. Getting the earliest possible feedback from the end-user or any other stakeholder promises to significantly reduce costs while increasing sustainability in product and production processes and providing more configurable product families for multiple market niches. (cf., Zhong *et al.*, 2015; Tao *et al.*, 2019; Zhou *et al.*, 2020)

Digital design methods have been available and in use for decades. The computer aided design (CAD) tools have been available since the 60’s. The development of digital design tools has progressed from clumsy 2D blueprints to realistic 3D models that can enhance, for example, studies of manufacturability and assembly in engineering development and not on the factory floor.

Another level of advancement was achieved when static objectives were combined to form systems in which virtual parts could move relative to each other and accurately simulate the real machine behaviors of actual machine parts. It sounds simple, but on the theoretical level, this breakthrough required a comprehensive mathematical interpretation of the complete system. Armed with these models capable of accurately simulating real-life mechanisms, researchers have been able to come up with more advanced and sophisticated methods to describe the motions of the mechanisms.

Technical solutions driven by real-time simulation and digital twins based on real-time simulation are rapidly developing, and their application, from a technical point of view, is constantly becoming easier and more cost effective. However, meaningfully applying digital twins requires business understanding (Qi *et al*., 2018; Kokkonen *et al.*, 2020). Digital twins need to enable new business, or at least enhance existing business processes, and therefore deliver value that is greater than the costs of their implementation. Consideration should be given to how the digital twin can deliver significant business benefits over the traditional digital product development process. In the traditional digital product development process, there is no real-time utilization of the digital product model and product or system and the continuous linking of the collected information. Despite growing interest, there is lack of research on which characteristics of digital twins contribute to the different uses. In terms of new business opportunities, the whole concept needs further development.

This chapter describes research into physics-based real-time simulation from a business perspective and provides guidance for further studies. It addresses the following two questions:

- What is the meaning of real-time simulation in contemporary business practice?
- And, how does real-time simulation contribute to sustainable production?

The immediately following paragraphs present the potential of real-time simulation in sustainable production. Then, suggestions for future research are summarized.

1.2 Reflections on sustainable production based on real-time simulation

As already mentioned, digital tools enable more sustainable business operations (Saunila *et al*., 2019; Ukko *et al*., 2019). However, to dive deeper into value creation from digital methods, stakeholders of a company including managers, business owners, personnel, investors, and others must understand the state-of-art of available digital methods as well as the current company status with respect to the use of digital methods. Prerequisites for taking full advantage of digital tools include knowing and understanding existing capabilities and having the required human resources, calculation power, and software licenses. Digital models of the equipment that will be used to build value are also needed. In modern business operations, the digital models are already a part of the product management system. However, the digital model itself is only the first step towards creating tangible value out of the virtual counterpart of the physical systems.

As part of the research being reported in this book, representatives of several Finnish manufacturing companies from different industrial sectors were interviewed. These companies are in the frontline of taking the advantage of simulation tools for research and development, and simulation is a big part of their product development footprint. The company representatives interviewed included technical experts, already well-aware of the advantages of simulation, as well as other non-technical stakeholders. These comprised business managers and decision-makers.

The diversity in the group of company experts made it possible to explore the bigger business perspective instead of just focusing on technical issues. The results of the interviews are reported in the chapters of this book. The main takeaways from the interviews were that the technical people do not have a clear idea of how simulation can be best applied to increase customer and company value. Moreover, the business managers and decision-makers do not understand how much potential for value creation the digital tools really have. It is an interesting situation that suggests there is an enormous business opportunity looming in the background.

The traditional way simulation is used is as a digital counterpart of the physical system, especially in the earliest stages of product development. The benefits of exercising digital instead of real prototypes are easy to justify economically. However, from the technical perspective, they offer an even more significant advantage. A digital model can be adjusted, tested, and redesigned in a matter of hours, whereas the manufacture, testing, and redesign of a prototype takes weeks and

months. The ease with which a virtual prototype can be manipulated encourages engineers to be more creative and promotes the development of new innovations and methods. Innovations are naturally a key to success in the global marketplace, therefore modern simulation tools accelerate, both directly and indirectly, the overall sustainable growth of the companies that use them.

Simulation tools are also being used in sales and marketing, where they are also bringing a clear competitive advantage. The most advanced simulators feature a complete operator cockpit sitting on a motion platform, a realistic 3D simulation model of the machine (already customized in customer colors), a realistic model of the customer-specific environment, and a high-end graphical user interface. The simulator package allows the customer or end-user to immersively and realistically operate the simulated machine and experience its performance. Even though it seems like game play, the results of scientific experiments and industrial feedback demonstrate that having such a simulator builds trust and enhances the branding of the equipment manufacturer. Customers can configure the simulation model enabling them to try out different equipment options, such as motor and gearbox or other functional accessories, before making their purchase decision.

The above-mentioned use-cases are the most obvious, and simulators have been used for such purpose in recent years. However, new business initiatives are planning for broader use of digital tools to create even more value that that coming from product sales. The additional value can be built, for example, by exercising simulation tools to make operations more efficient (cf., Jaiswal *et al*., 2019; Khadim *et al*., 2020; Pan *et al*., 2020). Different drive cycles or maneuvers can be simulated to define the execution of the operation for the fastest working cycle, safest driving path, lowest fuel consumption, *etc.* The difficulty of such an approach is to justify the money savings for the end-user and to innovate suitable performance-oriented business models.

Another example of added value is the usage of digital counterparts of the physical systems for virtual measurements and condition monitoring. Virtual measurements are software algorithms that use measured data from the real machinery to complete its virtual model with real-life input data. This approach enables the virtual model to imitate the maneuvers of the actual system, and instead of installing additional measuring sensors in the real physical machine, the virtual model

can be exploited to estimate the performance parameters of the machinery. This is particularly interesting for measuring parameters or details that are hard to reach due to machine geometry, are located in a harsh environment, or are difficult to measure by other means.

Further, this approach makes it possible to perform more comprehensive condition monitoring and fault diagnostics during the lifecycle of the machine improving its overall performance. The additional value for the end-user is the amount of received data from the system using a limited number of sometimes very costly sensors. From the value creation aspect, the more accurate analysis of the machine conditions and better predictability of typical failures enables performing predictive maintenance to extend service intervals and cut direct service costs.

If the digital models are sufficiently accurate and the virtual model functions in real time in parallel with the actual system, the model can give the driver or operator additional information about the machine as it operates. The simulation model can estimate different physical performance indicators such as load conditions, forces, velocities, accelerations, and mechanical durability. The additional virtual data can be presented to the operator in the form of numerical values, alarms, or warning lights via a graphical interface. Again, the additional information is clearly valuable for the end-user, yet it remains the responsibility of the original equipment manufacturer to design a business model that results in more customer value and subsequent added revenue.

1.3 Origins of the book

The need to take simulator-driven design and production to the next level by developing and evaluating a number of community-based real-time simulator-driven processes led to this writing and publication of this book. The intent is to narrow the research gap between the technical and business aspects of implementing the new digital toolset and clarify how this type of digital transformation of industry will improve company effectiveness, increase customer value, and maximize business potential resulting in sustainable value creation. In addition to scholarly interest, this type of approach is relevant for policy makers and company managers in the areas of research and development, the service businesses, commercialization, and customer service for all stakeholders.

Therefore, despite the increased amount of research on simulator-driven design and production, there seems to be little progress in understanding the complexities of the subject from a business perspective. The literature strongly suggests that this type of digital transformation of industry is beneficial, but exactly how value will be created seems to be the black box. Accordingly, this book tackles the questions:

- How can real-time simulation improve the effectiveness, customer value, and business potential of production processes?
- And, how will real-time simulation help industry to be more sustainable, more cost effective, more energy efficient, and more capable of responding to local and global societal challenges?

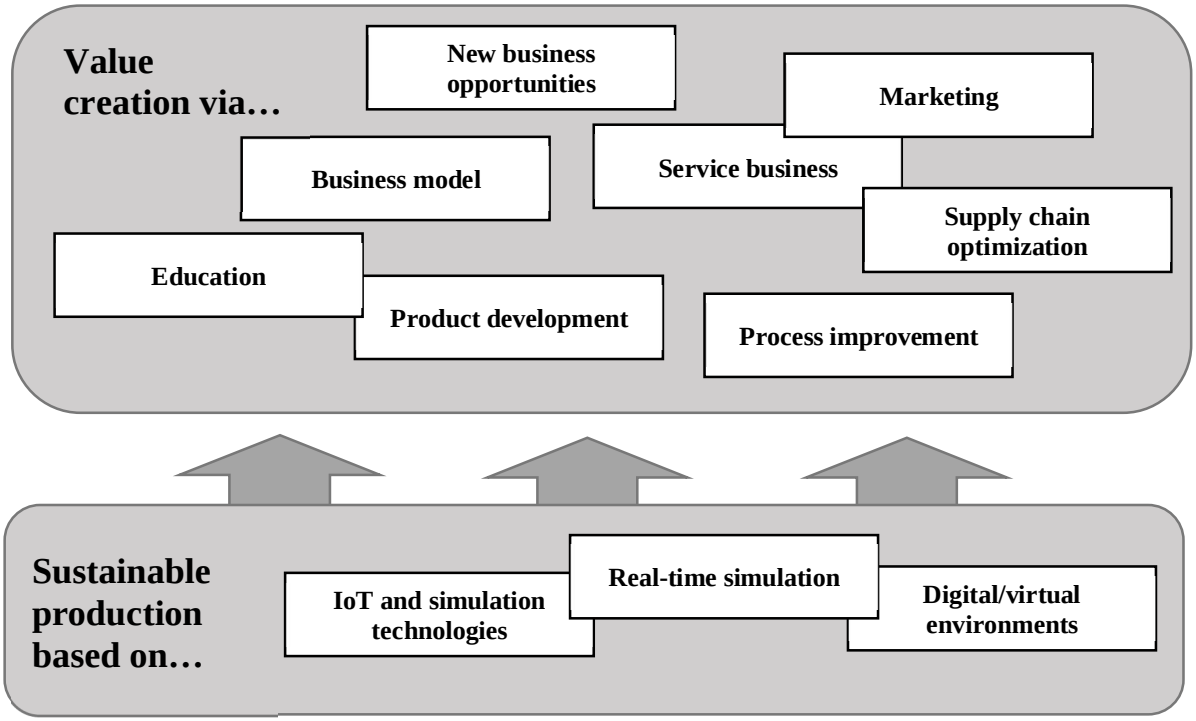
These questions can be answered by encouraging a new way of looking at real-time simulation studies. The complementary and multi-disciplinary perspectives of the book ensure both the technical and economic viability of the solutions provided to answer the questions.

Each chapter provides its unique view of sustainable production based on real-time simulation, but there are common themes. By reviewing actual industrial cases and presenting relevant academic research, the big picture is framed from four interrelated viewpoints: the industrial need for sustainable production, the development of game-like virtual environments, capturing customer value and enhancing the user experience, and establishing business value. Academic research into the interface of physics-based real-time simulation and business management is multidisciplinary. Therefore, this book provides implications to management research in areas as diverse as strategic management, manufacturing and operations management, marketing, industrial economics, and product lifecycle management. Further research will be required to clarify the mechanisms through which sustainable value creation can be achieved via real-time simulation and its related technologies.

1.4 Future research directions

There are clear signs that the benefit of incorporating the business perspective into real-time simulation studies is acknowledged in practice and theory. The chapters of this book show that real-time simulation and its related applications, such as digital twinning, can be utilized in a variety of company operations that not only affect its business, but also impact society at large. This book argues that real-time simulation contributes to sustainable value creation, for example, in terms of product development, marketing, and service businesses (See Figure 1.1.).

Figure 1.1. Sustainable value creation with real-time simulation and digital twins



For example, from a macro perspective, real-time simulation and its extensions can greatly impact sustainability performance. The research concerning real-time simulation has mainly focused on the physical modeling of products and production systems, where modeling refers to the process of representing a physical entity in digital forms that can be processed, analyzed, and managed by computers (c.f. Qi *et al.*, 2020). In addition to physical modeling, the results of the chapters together with some prior studies show that, for example, digital twins can be used for simulation, monitoring, diagnostics, prognostics, optimization, and for the training of users, operators, maintainers, and service providers. This book indicates that in addition to using real-time simulation for physical assets, digital-twin technology can be applied to non-physical modeling

that in all forms can provide comprehensive support for decision-making covering a wide range of company operations (c.f. Vijayakumar, 2020).

The chapters of this book indicate that potential benefits of digitization are manifold and include increases in sales or productivity, innovations in value creation, and novel forms of interaction with customers. From a theoretical point of view, the book significantly supports and contributes to the expertise related to digital twins and especially real-time simulation. The book promotes the application of real-time simulation in industry, the exploitation of business value, and the implementation of new science-intensive commercial innovations. However, in the future, the most significant innovations should be combinations of physical and non-physical solutions. Consequently, future research must understand and utilize digital twins and real-time simulation as a complementary product or complement to physical products that can be licensed and scaled. A novel aspect for future research is to examine different types of solutions through a variety of perspectives. Table 1.1 offers several topics and research questions for future research.

Table 1.1. Suggestions for future research

Perspective	**Suggestions**	**Possible research questions**
Strategic management	Strategy-driven approaches to technology implementation Ecosystem formation	How could real-time simulation and digital twins change strategic management practices? Which information will be necessary for decision making? How to manage business ecosystems around real-time simulation and digital twins?
Performance management	Measuring and managing value of novel technologies	How to measure and manage performance with the assistance of real-time simulation and digital twins? How could real-time simulation support the development of performance measurement?
Operations management	Tactical approaches of managing digital transformation	How to facilitate operations with real-time simulation and digital twins? What kind of operational implications do the adoption of real-time simulation and digital twins can have?
Production planning	Digital transformation of service production	How could real-time simulation and digital twins impact on the redesign of production planning? Which are the main barriers that companies will have to face?

Innovation and technology management	Technology-driven transformation and renewal	Are innovations in simulation created for identified business need, or are new innovations triggering new business needs? How to facilitate continuous business renewal with real-time simulation and digital twins?
Supply chain management	Managing digital transformation beyond organizational boundaries	How does the adoption of novel technologies increase transparency and visibility in the supply chain? How could real-time simulation and digital twins be used for the governance of the supply chain?
Industrial marketing	New product design with the assistance of novel technologies The role of different types of capabilities	How different solutions suit for different industries? How to leverage new service business as well as generating new business models around real-time simulation and digital twins? What type of functionalities should be connected to digital twins to use them to generate new business?

1.5 Conclusion

This book provides a comprehensive overview of potential opportunities and the business value proposition related to implementing sustainable production using physics-based real-time simulation. It offers a framework for a rethinking and shift in mindset of how real-time simulation changes the way products are manufactured and services are produced.

Already established as an important part of product development, the application of physics-based real-time simulation to improve marketing and business practices is new. This book describes the environment and offers the reader insight, accounting for all the relevant engineering areas, into a number of business opportunities associated with the new approach. The foundation of the book is to establish that physics-based real-time simulation will make possible the development of new products and services that will increase customer value and open up new business opportunities.

The book includes views from academia and industry to offer a truly holistic approach. The scientific novelty of the book is built upon the following two premises. Entire community-based, real-time, simulator-driven environments are developed and evaluated. And, rather than examining purely technical aspects, the discussion focuses on enhancing user experience and business value.

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