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This is a Author's accepted manuscript (AAM) version of a publication
published by Routledge

in Real-time Simulation for Sustainable Production : Enhancing User Experience and Creating
Business Value

DOI: 10.4324/9781003054214-17

Copyright of the original publication:

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Please cite the publication as follows:

Holopainen, M., Ukko, J., Saunila, M., Rantala, T. and Rantanen, H. (2021) The digital twin combined with real-time performance measurement in lean manufacturing, In Ukko, J., Saunila, M., Heikkinen, J., Semken, R.S. and Mikkola, A. (Eds.) Real-time Simulation for Sustainable Production: Enhancing User Experience and Creating Business Value, Routledge, London. DOI: 10.4324/9781003054214-17

This is an Accepted Manuscript of a book chapter published by Routledge in Real-time Simulation for Sustainable Production: Enhancing User Experience and Creating Business Value on 31 May 2021, available online: <http://www.routledge.com/9781003054214>

**This is a parallel published version of an original publication.
This version can differ from the original published article.**

The digital twin combined with real-time performance measurement in lean manufacturing

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Abstract

This chapter examines the advantages that a digital twin and real-time performance measurement brings to lean manufacturing. The lean manufacturing approach improves operational performance and provides sustainable value by omitting activities that do not add value. One way to promote continuous improvement is to visualize lean processes in real time, for example, by utilizing a digital twin with the desired functionalities. To explore the benefits of utilizing a digital twin, an illustrative case is presented that describes the application of a lean strategy to facilitate the maintenance services process in real time with a digital twin. Chapter reveals that a digital twin combined with real-time performance measurement improves process monitoring and control, positively impacts the quality of leadership and the customer relationship, enables worker engagement in the lean process, increases collaboration and integration among different levels, and facilitates communication. The chapter should prove useful for anyone considering a digital-twin implementation.

Keywords: digital twin, performance measurement, real-time, real time, lean, visualization

13.1 Introduction

Lean production refers to a business philosophy that aims at eliminating waste and creating value (Womack and Jones, 1996). According to van Assen and de Mast (2018), visualization plays an important role in Lean production. In fact, in their article they say that the application of visual controls and techniques is a marked feature in Lean. One of the most prominent visualization techniques used in modern production is the digital twin, which is a digital replica of a product, process, or system. Effective application of modern visualization techniques such as the digital twin can improve the transparency of manufacturing processes, influence people's behavior, enable continuous improvement, encourage shared ownership, and support management by providing more accurate information (Tezel *et al.*, 2009).

The rise of new visualization techniques such as the digital twin provides new platforms that can also enable performance measurement systems to react more rapidly (cf., Horváth and Szabó, 2019; Yin and Qin, 2019). Other studies have focused on the importance of visual performance measurement to lean manufacturing and continuous improvement (Eaidgah *et al.*, 2016; Bititci *et al.*, 2016; Tezel *et al.*, 2009). The utilization of visualization as a part of management activities of companies also promotes communication (Larsson *et al.*, 2017; Bititci *et al.*, 2016; Eaidgah *et al.*, 2016) and can enhance information flow (Eaidgah *et al.*, 2016). In addition, the utilization of visual management systems can support ongoing strategy development and implementation, facilitate performance measurement activities, and enhance collaboration (Bititci *et al.*, 2016).

Implementing digital twins offers a number of advantages that can improve the management practices of manufacturing companies in general (Liu *et al.*, 2019; Min *et al.*, 2019; Wang *et al.*, 2019; Zhou *et al.*, 2019). However, research into the advantages that digital-twin-based real-time performance measurement can bring to lean processes is lacking. Thus, the purpose of this chapter is to explore the benefits of digital twins and real-time performance measurement in the lean processes of a manufacturing company. By examining the processes of an assembly manufacturing company as a contextual example, this chapter focuses on the potential benefits of using digital twins from the perspectives of the subject case company's maintenance services process and its stakeholders. Looking at the empirical real-life case will make it possible to gain an in-depth

understanding of the advantages that the utilization of digital twins and real time performance measurement provide.

The rest of the chapter is structured as follows. First, the contextual background of the chapter is presented including literature from lean management and lean processes, as well as from performance measurement and the utilization of digital twins as a part of performance measurement activities. Presented next are the empirical examination of the digital twin and real-time performance measurement application and the methodological choices and data gathering. Finally, the results are presented and discussed before offering conclusions.

13.2 Context and background

13.2.1 Lean approach and Performance measurement

Lean thinking is about eliminating waste and creating value. Womack and Jones (1996) summarized the lean approach as five key principles: specifying value, identifying value streams, making value flow (by eliminating waste), letting the customer pull value, and pursuing perfection or continuous improvement. In turn, Pavnaskar *et al.* (2003) claim that true advances, however, come from exposing manufacturing waste. For this purpose, Shingo (1992) identified seven different types of manufacturing waste: overproduction, waiting time, transport, inventory, motion, defects, and processing. Similarly, Shah *et al.* (2003) showed that the lean production philosophy focuses on avoiding seven cardinal wastes and on respecting customers, employees, and suppliers (Schonberger, 1986). In this study, the focus is both on the processes (eliminating the waste) and on promoting the daily work of employees and management and improving customer relationships. The lean approach aims to shift responsibility to lower levels rather than depending on direction from leadership. It promotes a team-based multi-talent work environment to ensure operational flexibility, and it encourages continual training, learning, participation, and empowerment (Olivella *et al.*, 2008). According to Eaidgah *et al.* (2016), taking information to the process owner level can impact daily workflow by giving workers more responsibility for their own processes, enabling their participation in decision-making, and encouraging them to participate in continuous improvement projects.

Adopting lean processes requires big changes to the management of operations and production. For best success, management practices, methods, and tools should be completely overhauled. Vartiainen (2007) suggested that adapting to new working methods means adjusting the physical environment to meet the requirements of the task, enabling the digital environment to use different spaces and make knowledge and information sharing possible, and altering the social environment to support the new working methods.

In this context, performance measurement systems are also needed to rapidly adjust to the changes in the operating environment brought about by adopting lean processes. The performance measurements should ensure the company achieves its purpose, plans and targets, and organizational control. Any process in which a person (or group of persons) intentionally affects what another person, group, or organization will do should be monitored (Tannenbaum, 1968). According to Nudurupati *et al.* (2016), performance measurement systems must be more dynamic to respond to constant changes in the external environment. They explain that organizations must deal with different varieties and volumes of data to gain a competitive advantage, which forces them to refocus their measurement efforts to include evaluation of performance over a wider network involving various stakeholders. Traditionally, performance measurement has suffered from an inability to capture real-time data to represent actual situations (Hwang *et al.*, 2017). In general, there seems to be a consensus that the fundamental purpose behind performance measurement may be changing. The emphasis on control is diminishing, and the emphasis on learning is increasing (Bititci *et al.*, 2012).

13.2.2 Digital twins and Performance measurement

The rise in digital technologies, such as digital twins, makes available new platforms to enable the rapid reactive ability of performance measurement systems to facilitate learning (Horváth and Szabó, 2019; Yin and Qin, 2019). According to Horváth and Szabó (2019), for example, applying continuous real-time performance measurement data to corporate managers can improve their decision-making and the quality of their employee and company performance appraisals. Yin and Qin (2019) suggest that a smart performance measurement system may provide flexible and

customized operation as well as interoperability and intelligent real-time feedback features to measure, monitor, and improve collaboration in product design. In general, there has been scant empirical research into how the new digital technologies, such as digital twins, support the way organizations measure performance. Most digital twin studies focus more on the engineering of the platform and less on its application (Martinez *et al.*, 2018). However, there is some empirical evidence revealing the general level benefits of digital twins.

Defined as the digital replica of the physical assets, digital twins provide huge potential for interoperability and fusion between the physical world and the digital world of production (Liu *et al.*, 2019). Digital twin models assist companies in adapting to the changing operating environment (Qi *et al.*, 2018; Min *et al.*, 2019), making decisions (Liu *et al.*, 2019; Wang *et al.*, 2019), reducing design time (Tao *et al.*, 2019; Zhong *et al.*, 2015; Wang *et al.*, 2020), optimizing production (Zhong *et al.*, 2015; Qi *et al.*, 2018; Bao *et al.*, 2019; Min *et al.*, 2019; Wang *et al.*, 2019; Zhou *et al.*, 2019), and improving financial value (Zhong *et al.*, 2015; Min *et al.*, 2019). Tao *et al.* (2019) present that the digital twin is mostly used for fault diagnosis, predictive maintenance, and performance analysis. Relatively few efforts have been devoted to more innovative design processes or innovations. Zhou *et al.* (2019) suggest that production optimization can be accomplished via an intelligent analysis and decision-making process enabled by dynamic knowledge and skills.

Information collected and stored by a digital twin is presented in a digital form to discover, analyze, manage, and optimize to improve production performance (Bao *et al.*, 2019). Digital twins reduce challenges caused by physical distance and thus assist in detecting machinery status and monitoring component health (Qi *et al.*, 2018). A digital twin also facilitates customer engagement by giving them the opportunity to see both the physical and digital version of a product (Tao *et al.*, 2019). This engagement reduces design time, because product details are shared with customers early on giving them the opportunity to influence development and ensure the product fulfills their requirements (Wang *et al.*, 2020).

13.3 Methodology

This chapter explores the benefits of the digital twin and real-time performance measurement for a lean manufacturing company. The research was based on a qualitative case study conducted with a Finnish assembly manufacturing company. A qualitative research approach is appropriate when the study focuses mainly on the perceptions and experiences of people. Empirical data were gathered in 2019 using several qualitative data collection methods including focus groups, semi-structured interviews, observation, and the utilization of secondary data.

A player in the drive technology industry, the subject company delivers customized drive technology solutions to its customers. This includes maintenance services and products from other OEMs. Maintenance services represents a significant and continuously growing share of the annual turnover, which is about 41 million euros at present. This research study focused on the maintenance service process for gear motors and industrial gear units. The process comprises many different steps, beginning with the customer service request and product receipt and ending with product delivery and billing. Responsibility for carrying out these steps is shared among various departments. Significantly, suppliers and customers also influence the process.

Data collection for the study was divided into four main phases: 2 focus groups, observation and utilization of secondary data, and semi-structured interviews. The research process began with two focus group meetings between representatives from the subject case company and the research group to discuss the context and the planned content of the research. This was followed by two weeks of observation by the research team of the maintenance services process. This observation and utilization of the company's own secondary data helped the team to develop a preliminary understanding of the process steps and the current state of the maintenance services process and subsequently identify any process development needs. The last phase, semi-structured interviews complemented this view.

The aim of the interviews was to collect information on the current state of the maintenance services process, establish a possible target level for the maintenance services process, and define the benefits to the company of the digital twin and real-time performance measurement. Initially, the focus was on what kind of information is needed by workers and management from different departments within the company and what challenges are faced in daily operations. At the same

time, a possible target state was defined. Target definition focused on getting information from the interviews on how workers want to carry out daily operations, what kind of process information they would want to see, and what would be possible indicators to monitor and control processes in real time. Finally, the last part of the interview explored the benefits of the digital twin and real-time performance measurement of the maintenance services process for the company, its employees, and management.

In total thirteen interviews were carried out in the offices of the subject company to learn about their maintenance services process steps from different department level perspectives and to ensure that worker voices were being heard. Representatives from the operational level, sales, and management were interviewed. More specifically, the interviewees included two service technicians, two service engineers, one dispatcher, one service manager, two sales engineers, two area sales managers, one sales manager, one factory manager, and the CEO. All interviews were recorded and transcribed. Interview durations were from 40 min to 80 min. After collection, the data was analyzed independently by a single researcher, and then the research group as a whole discussed the results to establish a common view. Finally, the results were discussed with the company.

13.4 Advantages of the digital twin and real-time performance measurement

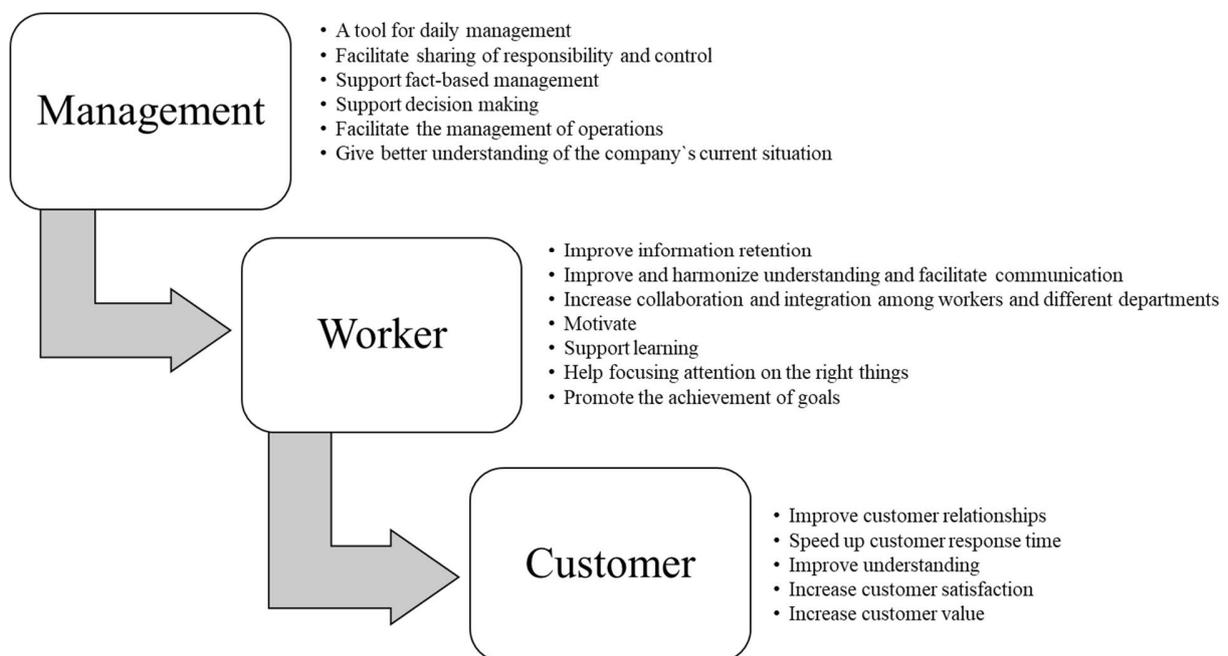
A digital twin provides real-time information about process operation; the current state of the process, its history, and possible future directions. This chapter examines, how real-time performance measurement of the lean process and process information could improve operational process performance, support Lean principles, and promote the daily work of employees and management. The advantages that a digital twin and real-time performance measurement brings to the subject case company are examined from the perspectives of the stakeholder and the process.

13.4.1 Advantages to stakeholders

Real-time lean-process performance measurement and process information can be used for different purposes. With a digital twin, the company can monitor and control the maintenance

services process and its performance in real time. This solution will give stakeholders better information visibility and give better accessibility to management, sales and customer service, process planning and scheduling, and operational workers. In the following paragraphs, the focus is on how a digital twin and real-time performance measurement can improve the daily work of employees and management and promote better customer relationships. Figure 13.1 illustrates the benefits to the stakeholder.

Figure 13.1. The advantages of the digital twin and real-time performance measurement to company`s stakeholder



Management

In the subject case company, the digital twin and real-time performance measurement were regarded as a daily management tool to support everyday management by providing real-time information of the process and its performance. The digital twin and real-time performance measurement of the process were also seen as part of Lean manufacturing, supporting the accomplishment of Lean principles, and sharing responsibility with lower levels: *“It helps with daily management, because the idea is not that management tells everybody to do something, but*

rather that we have a process, everyone has a role to play in it, and then with visualization and Lean, everybody can see what is really going on and react to it.”

In addition to the above, the digital twin and real-time performance measurement was seen to support fact-based management, facilitate the sharing of responsibility and control of the process, support decision-making, facilitate the management of operations, and give better understanding and knowledge of the subject company's current situation. With help from the new visualization techniques, management enjoyed easy access to the real-time information about the process and its performance regardless of time and place covering areas such as maintenance products information, their lead times and target times information, information about the process work load and resources, warehouse information, employee information, and so on.

Worker

Interviews revealed that the digital twin and real-time performance measurement of the process enables worker engagement in the lean process by giving transparent information of process performance. The benefits for the workers were classified into the following.

- improving information retention,
- improving and harmonizing understanding,
- facilitating communication,
- increasing collaboration and integration among workers and different departments,
- motivation,
- supporting learning,
- focusing attention on the right things, and
- promoting the achievement of goals.

One of the interviewees described the improvement in information retention as follows. *“If I see a green or red ball, I still remember it in my dreams, but if I see black text on white background, I forget it easily.”*

In the subject case company, workers face information and communication challenges. The information, such as lead times, is monitored manually and on a case-by-case basis. In some cases, the correct information is hard to find, it is scattered across different locations, and the reliability of the information may be poor. Communication between departments regarding process operation was also perceived as challenging. With the digital twin and real-time performance measurement, essential real-time information is found in one system, solving many of the communication challenges. *“With digital twin and information visualization, we would speak the same language about things. We don’t need to speculate about things, and it could help us to understand each other better.”*

The digital twin and real-time performance measurement also helped workers to focus their attention on the right things and better achieve goals such as maintenance lead times. *“When you could see are you on the way achieving goals, you could personally lead your own work to make it.”* In the subject case company, the achievement of lead time goals is linked to reward systems. With the digital twin and real-time performance measurement, goals become more transparent to every worker, enabling workers to see the impact of their own contributions to achieving them. This also increases worker motivation and efficiency.

Customer

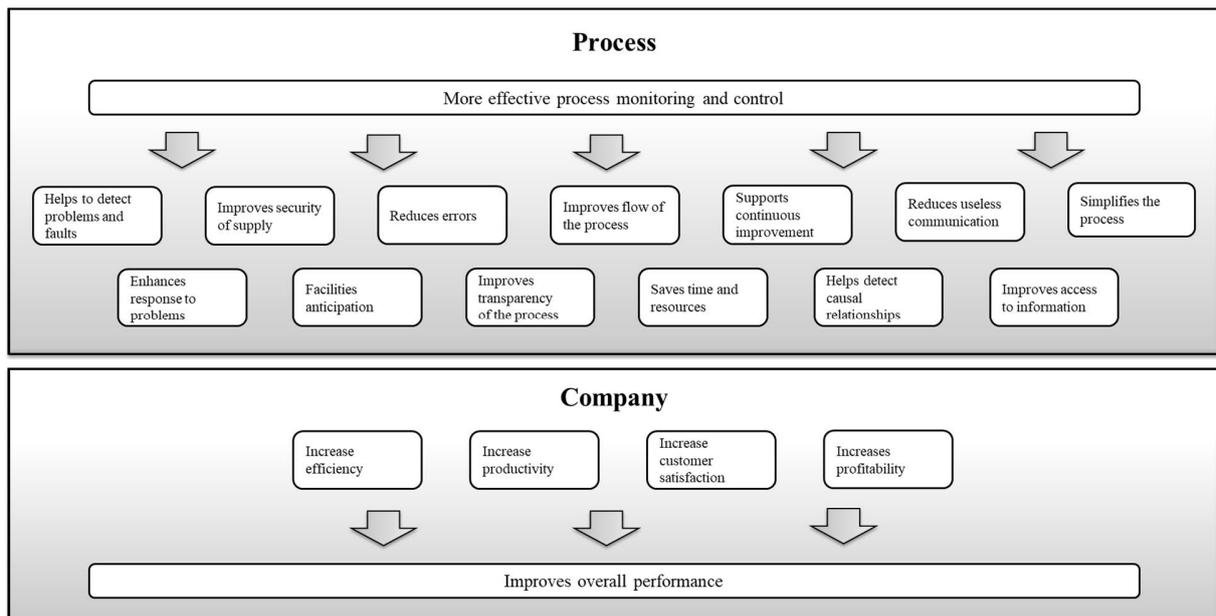
Creating value for the customer is one of the key principles of Lean. In this paragraph, the discussion is about how the customer benefits from the implementation of a digital twin and real-time performance measurement. The implementation potentially impacts customer relationships, understanding the process from the customer's perspective, shortening customer response times, and increasing customer value and customer satisfaction. The digital twin and real-time performance measurement helps to develop customer relationships. *“If customers come to visit us, they will see from our metrics that our delivery times have been met, how much goods we have and have left, and so on. Visualization would also make it easier to present our working spirit for visitors.”* In addition, they help to meet customer performance challenges in the company, such as slow customer response times. *“Perhaps even the customer could be shown statistics on their*

maintenance service, such as what's the benefit of their faster response time, so they can improve their own efficiency, when answering to our questions.”

13.4.2 Advantages by process perspective

The benefits of the digital twin and real-time performance measurement were also considered from the process and the company perspective. From the process development point of view, this distinction was particularly important. By enhancing the performance of the process, cause-and-effect relationships can be identified and marked for improvement to improve the overall performance of the company. Figure 13.2 illustrates the benefits of the digital twin with respect to the performance of the maintenance services process for the subject case company.

Figure 13.2. The advantages of the digital twin and real-time performance measurement to the performance of the process and the company



According to the case study, many process benefits can be achieved through implementation of a digital twin and real-time performance measurement. The digital twin and real-time performance measurement of the process improves process monitoring and control, helps detect problems and enhance response to those problems, improves security of supply, facilitates anticipation, reduces

errors, increases transparency, improves flow, saves time and resources, supports continuous improvement, helps detect causal relationships, reduces useless communication, improves access to information, and simplifies the process by making it more visible. One of the most important of these benefits is the improvement of process monitoring and control, which can be seen linked to other benefits. Enhancing process monitoring and control can also help in meeting the performance challenges of the maintenance services process, such as difficulties in finding the right information and achieving reliability targets, traceability challenges of the different factors, such as lead times, communication and information sharing challenges between departments, and achievement of the performance goals.

In the subject case company, process monitoring is currently done manually, which takes time and resources and leads to the introduction of errors. With the digital twin, monitoring and control is more automated, and resources can be freed up and allocated to core operations. The potential benefits for the subject case company are not mutually exclusive. For example, more efficient process monitoring can also lead to faster delivery times, which in turn can contribute to increased customer satisfaction and value. Improving the process with digital twin and real-time performance measurement can also impact efficiency, productivity, and company profitability as well as its maintenance service, eventually leading to an overall performance improvement.

13.5 Conclusion

This chapter reports on a qualitative case study that was conducted with the cooperation of a Finnish manufacturing company. The purpose of the study was to explore the advantages that a digital twin and real-time performance measurement offers for the Lean manufacturing process. The study focused on these benefits from the perspectives of the subject case company's maintenance services process and its stakeholders. The study's main contributions are as follows. Firstly, the study shows that the digital twin and the real-time performance measurement improved the maintenance services process. According to the results, the main benefits were improved process monitoring, control, and transparency. The results also reveal that the digital twin and real-time performance measurement of the lean process positively impacted the quality of leadership and customer relationships. Secondly, the digital twin implementation facilitated operational level

performance measurement by providing real-time material and information management about the order-delivery process. This was realized via the digital twins, because they enabled worker engagement in the lean process, increased collaboration and integration among different levels, and facilitated communication. These will potentially affect productivity, profitability, and finally overall performance.

In terms of managerial implications, what has been learned suggests that to maximize benefits and support Lean principles, the digital twin and real-time performance measurement must be linked to continuous improvement projects. In the subject case study, only one process was considered, however, the digital twin and real-time performance measurement can also be used to develop the company's other processes. Also, the benefits of digital-twin-based real-time performance measurement can be enhanced by integrating the system with other company systems. Further research considering the implementation of a digital twin is recommended to determine the added value of digital twinning and real-time performance measurement to the company's maintenance service. Further studies could also examine the characteristics and uses of digital twins with larger data sets.

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