GAME-BASED LEARNING TO SUPPORT THE DEVELOPMENT FROM LEAN PRODUCTION TO DIGITALISED PRODUCTION
GAME-BASED LEARNING TO SUPPORT THE DEVELOPMENT FROM LEAN PRODUCTION TO DIGITALISED PRODUCTION

Ozan Yesilyurt, Viorel Petrut Draghici, Dennis Bauer, Laura Körtling, Dr. Andreas Bildstein

Prof. Dr.-Ing. Thomas Bauernhansl

Fraunhofer Institute for Manufacturing Engineering and Automation IPA
Stuttgart, Germany
# Table of contents

Table of contents........................................................................................................4

Abstract .........................................................................................................................5

1 Introduction..................................................................................................................6

2 State of the Art .............................................................................................................8
  2.1 Digitalisation Technologies......................................................................................8
  2.2 Simulation games...................................................................................................8

3 Concept for the simulation game ...............................................................................10
  3.1 Requirements.........................................................................................................10
  3.2 Target group description.........................................................................................10
  3.3 Solution approach..................................................................................................10
  3.3.1 Agenda...............................................................................................................10
  3.3.2 Sample product..................................................................................................11
  3.3.3 Organisation......................................................................................................11
  3.3.4 Findings for participants....................................................................................13

4 Implementation of the simulation game .....................................................................14

5 Evaluation of the simulation game ............................................................................16
  5.1 Method for evaluation............................................................................................16
  5.2 Results from participants’ feedback.......................................................................16

6 Conclusion and Outlook ............................................................................................17

7 Reference list ............................................................................................................18
Abstract

The developments of digitalisation, also referred to as the fourth industrial revolution, lead to a fundamental change in industrial production across all sectors. Industrial production is currently often organised using lean production methods. These methods are changing, and digital tools for production will increasingly be used in the future. The digital transformation of the production causes challenges in the manufacturing industry. Firstly, some companies have none or few competencies in this field and do not know the advantages for the company itself as well as for the employees caused by the digital transformation of production. Secondly, the role of employees in production is changing and they are often reluctant to adapt to these continuous changes.

Simulation games are dynamic models for the game-based simulation of a system with the aim of better understanding, evaluating and designing systems. The artificial environment of a simulation game imitates the functions of a real environment and situation in which the players can gain experience and make decisions without pressure or real consequences. Therefore, simulation games are seen as an adequate approach to qualify employees in manufacturing industry.

The simulation game developed by Fraunhofer IPA uses active learning methods to achieve higher learning outcomes than the comparatively passive conventional method of frontal teaching. Two production methods are implemented and combined in two different rounds of the simulation game. In the end, the advantages and disadvantages of the different types of production are discussed with the participants. The main goal of the simulation game is to understand the basic principles and backgrounds of lean production and digitalised production in general.

The result of this work is the elaboration and implementation of a simulation game which meets the requirements and learning outcomes described above. In the context of the simulation game, three fields of action and directions of digitalisation in production are emphasized, namely efficiency, transparency and the generation of data.

Keywords: Simulation game, digital transformation, lean production, digitalised production, game-based simulation
Introduction

Industrial production is the basis of prosperity in many countries. This fact has also been recognised by the EU Commission, which in 2012 set the target of increasing the share of industry in gross value added in Europe to 20 per cent by 2020. Globally, the USA and China, for example, are also working on reindustrialisation and thus an expansion of industrial production (Bauernhansl et al., 2018). According to the Oxford Dictionary, production is defined as “making of articles on a large scale using machinery; industrial production” (Oxford Dictionary, 2019). More specifically, production is a transformation process in which natural resources are used to produce high-value products. This value-creating process is performed by people using tools and machines in factories (Westkämper and Löffler, 2016). On a more technical level, production can be seen as a series of processes for which raw material, semi-finished products, components, and auxiliary materials are necessary (Westkämper and Decker, 2006). In recent years, production has been influenced by the trends of lean production and digitalisation, described hereafter.

Lean production greatly influences the manufacturing industry since the majority of manufacturing enterprises have established lean production systems following specific lean principles (Dombrowski, Richter and Krenkel, 2017). Lean production focuses on the continuous improvement of production processes and the elimination of waste while simultaneously aiming at achieving high qualities, low costs and short lead times (Mrugalska and Wyrwicka, 2017). Nonetheless, companies are facing new challenges with the rapid development of digitalisation (Dombrowski, Richter and Krenkel, 2017). By its synonym “Industrie 4.0”, it describes the fourth industrial revolution, after the invention of the steam engine, industrialization and the beginning of the computer era (Bauer et al. 2019). The specific term “Industrie 4.0” was first used in 2011 and is widely explored in Germany through its status as a strategic initiative of the German government, but a consistent and comprehensive definition for the term still needs to be established (Dombrowski, Richter and Krenkel, 2017; Mrugalska and Wyrwicka, 2017).

It is certain that digitalisation influences technologies, systems and processes alike and thus has an impact not only on activities on the shop floor, but also on indirect areas of the value chain like planning or product development (Dombrowski, Richter and Krenkel, 2017; Dregger et al., 2018). This leads to a high demand for appropriate competence and qualification measurements of employees (Bauer et al., 2019). Relevant literature proposes a combined approach of imparting theoretical knowledge as well as practical application with a clear work process orientation for developing new competencies (Bauer et al., 2019; Pittich, Tenberg and Lensing K., 2019). In order to simultaneously facilitate learning as well as to increase the motivation of learners, game-like approaches may be used (Abele et al., 2017). So-called educational games or serious games, for example, show clear signs of typical game design elements and allow for entertaining or amusement, while also supporting learners in improving skills or understanding new subjects (Abele et al., 2017). When looking at the context of production, certain key factors for improved learning have been identified, like the active involvement of participants, hands-on learning, the solution of real problems, real-time interactions, issue-based discussions and interdisciplinarity (Perini et al., 2017). Deriving from these key learning factors, several appropriate educational approaches for the manufacturing industry have been identified, among these being serious games and simulation games (Perini et al., 2017). Several simulation games for a manufacturing context have already been developed, as later described in chapter 2.2. But in order to further close the knowledge and practice gaps between the
manufacturing industry and game-based learning approaches, more game-based approaches targeting different disciplines of the manufacturing industry need to be developed and evaluated, especially taking aspects of digitalization into consideration.

The path from lean production to digitalized production brings along great opportunities but also new challenges. Employees must be enabled to actively and autonomously address these challenges through appropriate measurements. Therefore, Fraunhofer IPA has developed a simulation game to support employees with the development of these new competencies. The simulation game simulates the production of an exemplary product by using different digital technologies. The goal of this simulation game is to sensitize and prepare employees for the advancing digital transformation by allowing them to experience the challenges from transitioning from lean production to digitalized production inside a simulated, yet realistic environment.

The research process and structure of the paper are based on the applied research approach (Ulrich and Schwaninger, 2001), which focuses on the importance of practical relevance in the research process. The structure of the paper was aligned accordingly (see Figure 1).

Figure 01: Structure of the paper according to (Ulrich and Schwaninger, 2001)

Chapter 2 gives an overview of the state of the art and sets the basis for the developed simulation game. Chapters 3 and 4 present the overall concept of the simulation game and its implementation. After an evaluation of the game in its current state and deriving implications for future developments in chapter 5, chapter 6 concludes with a summary and outlook.
2
State of the Art

2.1 Digitalisation Technologies

Digitalisation has a great impact not only on the daily life of employees but also to their work on the shop floor as well as in indirect production areas (cf. section 1). Four main aspects of how work systems will be designed in the future have been identified: connected, context-sensitive, assistive and intuitive (Bauer et al., 2019). Connected work systems are possible by cloud computing and service-oriented architectures. While there are different levels of cloud computing, most tangible for the user is Software-as-a-Service (SaaS). SaaS describes the provision of software by a provider without the customer having to take care of infrastructure or operations (Bauer, Stock and Bauernhansl, 2017). Depending on the exact configuration, the services can also be designed as microservices, which means an encapsulation of fine-grained functionality (Götz et al., 2018). Combined in an event-driven architecture, an efficient information flow for processing events in connected applications can be established (Luckham, 2010).

A work system is context-sensitive if it provides information, based on the current process step (Bauer et al., 2019). An example of a context-sensitive work system is the manufacturing execution system (MES). It offers a meaningful functional addition in order to plan and control all manufacturing processes, to ensure process transparency and to map the flow of material and information within the supply chain (VDI, 2017). Today’s manufacturing execution systems will evolve from monolithic software systems towards increasingly modular manufacturing systems, with a focus on multi-disciplinary process integration (Seibl and Theoba, 2017).

Assistive work systems can be divided into digital and physical systems. Physical systems, such as lightweight robots, assist in the actual physical task, while digital systems, e.g. mobile devices for augmented reality, assist the task by providing relevant information (Bauer et al., 2019). Application scenarios for mobile devices on the shop floor are extensively described in the literature (Leyer, Richter and Steinhüser, 2019; Neugebauer, 2019). One trend for the future development of mobile devices are wearables, which bring mobile applications even closer to the user (Bauer, Wutzke and Bauernhansl, 2016). Wearables can be characterized as providing the user information and interaction with information anytime and anywhere, which is often described as always on and always accessible (Mann, 1998). Other than mobile devices, wearables aim at hands-free operation (Huang, 2002).

Work systems can be described as intuitive, if they are not only physically ergonomic but also usable regarding information, combined with new interaction concepts (Bauer et al., 2019).

2.2 Simulation games

Simulation games are a mixture of various modern teaching methods, such as collaborative learning, active learning and simulation. They represent the opposite of traditional teaching methods, which are usually characterised by verbal frontal teaching. It has already been proven many times (Silberman, 2009; Womack, Jones and Roos, 1991) that modern active teaching methods can achieve more learning success than the comparatively passive conventional method. Simulation games do not only impart knowledge about scientific content but also practice the creative application of
this knowledge. Empirical studies have shown that game-based learning approaches achieve higher learning outcomes than the comparatively passive conventional method by frontal teaching (Pivec and Dziabenko, 2005; Prensky, 2003).

Table 1 shows the content of some developed simulation games with a focus on production developed by Fraunhofer IPA, other companies or university institutions. The following features listed below are used to describe the gaps in the simulation games:

1. focus on digitalised production control (MES)
2. the target group of simulation games is students and workers
3. quality process of production is implemented
4. manufacturing processes of production are implemented
5. key performance indicators (KPI) for production are considered

Table 1: Gaps in following simulation games

<table>
<thead>
<tr>
<th>Simulation games</th>
<th>Feature 1</th>
<th>Feature 2</th>
<th>Feature 3</th>
<th>Feature 4</th>
<th>Feature 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Silva, Xambre and Lopes, 2013)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>(Tamaas, 2014)</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(Hidayatno, Moeis and Raditya, 2014)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>(Blöchl and Schneider, 2016)</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(Fuhrmann et al., 2016)</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>(Blöchl, Michalicki and Schneider, 2017)</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>(Hübl and Fischer, 2017)</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(Gross, 2018)</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(Böhm and Leipoldt, 2018)</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(Vin, Jacobsson and Odhe, 2018)</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

The gap numbers indicate that the developed simulation games have a focus on production and fulfil some of the features (2-5) described above. However, the digitalised production control (MES) was not considered in the listed simulation games, which indicates that a new simulation game is needed to fill this gap.
3 Concept for the simulation game

3.1 Requirements

The overall target of the developed simulation game is to build up an understanding of digitalisation with the participants. Since lean production is widely known in the manufacturing industry, as described in chapter 1, these principles are set as a common ground and participants can learn how approaches from lean production and digitalisation may be combined. To be more precise, the developed simulation game should aim at showing the fundamental background, principles and goals of digitalisation. Participants can become familiar with possible changes, effects and advantages in an engaging way. By playing an active role in the simulation, each participant may learn how to shape the change processes inside the company themselves and build up their digital competencies. Furthermore, the changes due to digitalisation should become tangible by the active role of participants. Additionally, participants of the simulation game may also learn which challenges specifically manufacturers of multi-variant products face within digitalisation and which company business areas can be identified as most affected, influenced and changed by digitalisation technologies and approaches.

3.2 Target group description

The target groups of the simulation are divided into two main categories: university students and employees of production companies. In order to introduce the topic of digitalised production in a playful way and to make the economic connections and technical changes visually comprehensible in the production line, it is important to consolidate the theoretical knowledge and to create a knowledge transfer with the help of a simulation game for practical implementation. With the simulation game concept customized to the study profile, the universities should be able to enrich the teaching portfolio with innovative, exciting content and make seminars more interesting for students.

According to a Bitkom survey (Bitkom Research, 2016), 50% of companies in Germany do not know what economic and social changes digitalised production will bring and 53% of enterprises are aware of their employees’ insufficient skills. With the help of the simulation game, employees will be encouraged to try out new digital tools for a digitalised production without fear. They may understand the basic principles, backgrounds of lean production and digitalised production in general. Additionally, they may find out, in which areas digitalisation brings the greatest impact, most interesting benefits and most severe challenges. Ultimately, they will be enabled to transfer the gained knowledge to their own work area.

3.3 Solution approach

3.3.1 Agenda

As stated in chapter 1, a combined approach of transferring both theoretical as well as practical knowledge is recommended for developing new competencies. This means, that e.g. a presentation should always be followed by a hands-on session, to apply and foster the newly gained information. Both topics – lean production and digitalisation – should be handled in theory and practice. The hands-on sessions should also contribute to the goal of actively engaging participants and enabling them to handle a digitalised
work environment. Therefore, the simulation game should be conducted in a workshop that lasts at least half a day, since shorter formats do not offer the same depth. An exemplary agenda of such a half-day workshop is mapped in the following table 2. It should be noted, that a break and time for setting up the simulation game before and between the rounds is not included here.

Table 2: An exemplary agenda for a simulation game in the form of a half-day workshop

<table>
<thead>
<tr>
<th>Agenda point</th>
<th>Proposed duration</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>30 minutes</td>
<td>presenting the goal and principles of the simulation game, clarifying expectations for the workshop</td>
</tr>
<tr>
<td>(2)</td>
<td>30 minutes</td>
<td>presentation on lean production, transfer of necessary background knowledge</td>
</tr>
<tr>
<td>(3)</td>
<td>1 hour</td>
<td>hands-on session 1 or simulation game round 1: lean production, feedback session</td>
</tr>
<tr>
<td>(4)</td>
<td>30 minutes</td>
<td>presentation on digitalisation, transfer of necessary background knowledge</td>
</tr>
<tr>
<td>(5)</td>
<td>1 hour</td>
<td>hands-on session 2 or simulation game round 2: digitalisation, based on a lean approach, feedback session</td>
</tr>
<tr>
<td>(6)</td>
<td>30 minutes</td>
<td>evaluation, discussion, Q&amp;A</td>
</tr>
</tbody>
</table>

3.3.2 Sample product

The participants should use real materials to manufacture real products, so that the real production systems are faithfully represented to the participants. Another requirement is to represent the general goal of digitalised production, namely to help the company to respond quickly to the different customer needs and adapt their production. To show this special feature of digitalised production, the product should offer several product variants. Additionally, the product should be computer-based, so that not only the assembly part is considered in the simulation game, but also the software implementation. Considering these three requirements, a simple programmable robot, which comprises different assembly and programming variants, is appropriate for the simulation game.

The chosen product is a low cost programmable robot, which comprises of a metal chassis, a microcontroller and different sensors. It resembles a car, which is why it has an advantage over other product types, because each participant has previous knowledge and a personal connection to vehicles and their components.

3.3.3 Organisation

The simulation game comprises two rounds, five workstations and four different roles. The production line consists of a sequence of five workstations:

1. Motor Assembly: two small electrical motors and two wheels are mounted on a metal chassis;
2. External Parts Assembly: a rollerball and a line-follower sensor (reflective photoelectric sensor) are mounted underneath the metal chassis, 4 brass studs on top and an ultrasonic sensor or a LED-display on the front side;
3. Control Unit Assembly: the Arduino control box, AA-batteries or Lithium-ion batteries are mounted on the metal chassis and the cables are connected;
4. **Final Assembly**: pre-existing software programs are installed on the Arduino control box;

5. **Quality Assurance**: the assembly of the final product is checked and the correct execution of the software program is tested;

During the simulation game, the participants can play any of the following roles:

- **Customer**: places or orders for any of the 6 product variants;
- **Production manager**: creates production orders and tracks the production time for each product. This role is available to the participants only in the first round of the simulation game. In the second round, this role is fulfilled by a MES.
- **Operators**: work at the five workstations to fulfill the production orders. In the first round, they follow instructions printed on paper for each product variant, while in the second round they use tablets and follow instructions provided by the MES when NFC-tags are scanned.
- **Observers**: monitor all running processes and present their observations at the end of each of the two rounds;

In the first round, arrangements are made to create a production line with lean principles. In Figure 2, each station is connected to another in a line. It shows the flow principle of lean production. Figure 2 also represents, that the material flow (blue arrow) runs from the “motor assembly” workstation to the customers. The material is handed over when the next station is ready to produce it. In order to enable this step, information exchange between employees is required. Therefore, the information flow (black arrow) in this round runs in the opposite direction of the material flow. If the customer orders a new product, the production manager has to ask at the last workstation, whether the product is ready to deliver. The worker at the “quality assurance” workstation has to communicate to the worker at the final assembly station. In this sequence, the order information finally reaches the first workstation of the production line. With the help of this rule, the pull principle of lean production is realized in the simulation game.

![Figure 2](image)

**Figure 2**: Material and information flow of the first round

After the first round, some adjustments are made as described above. First, the one-piece flow principle is integrated into the second round. This means that the direction of the information flow (black arrows) and the material flow (blue arrows) is the same (see Figure 3). Secondly, there is a new order system. The customer can create an order directly in the MES with the help of a web shop application, which runs on the mobile device of the customer. Finally, an MES is also used for real-time tracking of a product’s manufacturing processes, for KPI calculation, digital assembly instructions, production manager tasks and app-based quality assurance of products.
3.3.4 Findings for participants

Feedback to participants is essential for each simulation game since participants learn best by playing an active role in game-based learning, followed by a self-reflection and feedback by one or multiple trainers (Vin, Jacobsson and Odhe, 2018). Therefore, feedback in the developed simulation game is integrated between the rounds as well as a wrap-up, when finishing the simulation game. Between the rounds, self-reflection is the most important step. Each participant summarises his or her experiences and assesses what went well or wrong. This enables the audience to understand the other roles of the simulation game and their needs. Identified improvements can be implemented within the boundaries of the simulation game in the following round.

Wrapping up the simulation game, feedback is divided in two parts. Firstly, participants repeat the described self-reflection. The trainer has to moderate these processes more strictly than between the rounds to guide participants in discovering changes in their working conditions, tools and roles caused by digitalisation. It is most important to address the fears of the participants by showing them the advantages of digitalisation without ignoring the challenges leading to these fears. Secondly, feedback is provided by KPIs comparing the game’s rounds. While addressing participants’ fears is a rather emotional feedback, comparing KPIs is fully rational showing the benefit of digitalisation by traditional production KPIs. Therefore, cycle times, profit, delivery reliability and work in progress are evaluated in this simulation game.
In this section, the implementation of the simulation game’s concept is described. A production line is simulated in both rounds and adjustments are made concerning the information and material flow. A paper-based production system is implemented for the first round and is replaced by a digitised one in the second round.

To meet the requirements set out in chapter 3.3.2, six variants of a low-cost programmable robot comprising a microcontroller and different sensors were chosen as the product for the simulation game. Figure 4 pictures the paper-based production line of the simulation game. Five participants receive a catalogue of instructions and construct the product. As described in the concept chapter, the production manager communicates with the customer. The customer has a product catalogue, can select and order the product. After the product is ordered, the production manager creates a production order on a paper and then makes a request to “quality assurance” workstation, whether the ordered product is already at the station. After the ordered product is completely assembled, the production manager hands over the product to the customer and notes important KPIs in his production order sheet.

Figure 5 describes the MES-based production of the simulation game. Xetics LEAN software (XETICS GmbH, 2019) is used as MES. All participants use a mobile device that communicates with the MES in real time. These mobile devices have an NFC reader that scans the NFC-tag of the product. When the NFC-tag is scanned, the NFC-tag information (production order’s number) is forwarded to the MES. Using this information, the MES finds the correct assembly instructions for the product and sends them back to the mobile devices. The assembly instructions of robots are then
Implementation of the simulation game illustrated on the mobile devices of the workstations. Fraunhofer IPA developed a webshop app for the customer. With the help of this app, the customer can order different product variants and automatically create a product order in the MES.

Figure 5: MES-based production (second round)
Evaluation of the simulation game

5.1 Method for evaluation

After the simulation game is finished, evaluation sheets are distributed to the participants to receive their feedback. The evaluation sheets ask the participants to rate statements regarding the content and the execution of the simulation game. A 5-point rating scale is used: 1 – very good, 2 – good, 3 – satisfactory, 4 – sufficient, 5 – not sufficient.

5.2 Results from participants’ feedback

In comparison to other existing simulation games, this simulation game focuses on the digitised production control to show the impact, changes and advantages of digitalisation in production. According to the survey results, 93% of the participants (Figure 6) learned the principles and definition of digitalised production with the help of this simulation game and 85% of the participants (Figure 7) understood that a digitalised production makes processes more transparent.

Figure 1: Results of the statement “Through the simulation game, I understood what digitalised production means and what principles are behind it.”

Figure 2: Results of the statement “The second round showed that digitalised production makes processes more transparent.”

Figure 3 and Figure 4 show that the simulation game aroused the interest of more than half of the participants so that the expectations of these participants were fulfilled. Thus, the goals of the simulation game defined in the concept chapter were achieved.

Figure 3: Results of the statement “The simulation game encouraged my interest in digitalised production.”

Figure 4: Results of the statement “My expectations regarding the simulation game were fulfilled.”
The transformation from lean production to an assembly line supported by digital technologies confronts companies with the great challenge of preparing employees for this change in the shortest possible time and ensuring that they understand and accept this change. For this reason, a simulation game has been developed by Fraunhofer IPA to enable a better understanding of the existing and new production structures and processes.

This paper first gives an overview of the state of the art, which provides the basis for the developed simulation game. Then the overall concept of the simulation game and its implementation are presented. The simulation game consists of two game rounds. In the first round, the simulated production is set up according to lean principles. The second round is carried out with the help of a MES. After each round, a feedback session is held to discuss the advantages and disadvantages of both methods. At the end of the simulation game, both rounds are compared. Finally, the simulation game is evaluated, and the implications for future developments are derived.

The simulation game presented in this paper contributes to a better understanding of the impact, changes and advantages brought by the digital transformation of production to manufacturing companies and their employees. It emphasizes three fields of action and directions of digitalisation in production, namely efficiency, transparency and the generation of data. The results of the survey in practice show that almost all the game participants learned the definition and the principles of digitalised production as well as understood that a digitalised production makes processes more transparent. Furthermore, the majority of the game participants expressed an increased interest in digitalised production and felt that their expectations regarding the simulation game were fulfilled. Thus, the learning goals of the simulation game were achieved.

As future developments, it is planned to add a logistics and shipping station to the simulation game and integrate a chaos round to present a production type to the participants, that does not even apply lean principles.


