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A Game-Based Approach to Raise Quality Awareness in Ramp-Up Processes

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Today's production systems are complex sociotechnical systems. Both technical challenges, as well as the integration of human employees with their diverse abilities, wants, and needs, must be considered. Due to a growing number of product variants, shorter lead times, and global supply chains, planning production systems is becoming increasingly difficult, both on the technical and human levels. The highly volatile and uncertain character of production systems is intensified by the growing complexity and need for results in shorter decision times for ramp-up management. To handle the increasing complexity, human decision makers must be adequately trained for the ramp-up period. Therefore, the influential factors and their magnitude from both the technical and the human perspective must be identified and understood. This knowledge can help to manage the complexity of ramp-up processes, reduce the disturbances within the processes, and strengthen their overall resilience against failures.

To adequately understand the human and technical factors that relate to ramp-up processes, it's necessary to have an experimental framework. This framework should support the identification and quantification of sociotechnical factors, enabling practitioners and researchers to model suitable interventions. In this article, the authors propose, develop, and evaluate a business simulation game that serves as such an empirical framework. The game is furthermore suitable to train managers before the ramp-up process. The achieved performance in the business simulation game may be used to evaluate a person's suitability for the task and to identify individual training potential.

Key words: game-based learning, human factors, quality management, ramp-up, supply chain management

INTRODUCTION

Industrial manufacturing faces several trends that will likely gain significance in the near future. Increasing product variety and product complexity in combination with shorter product life cycles are some of the global challenges that have an impact on industrial production. A company's production system must be able to react flexibly to rapidly changing customer requirements while also handling the manufacturing of diverse and complex products. These requirements for a production system also affect ramp-up management implicitly. Ramp-up is defined as the phase between development and production, and it is completed when the number of pieces and production quality increase while production costs decrease from small initial production runs to the planned thresholds of the series production. Ramp-up management aims to plan, control, and optimize the described dynamics and instabilities (Filla and Klingebiel 2014). The realization of the product launch according to schedule becomes much more difficult (Schmitt and Schmitt 2013). Insufficient ramp-up management, due to technical or human problems, could result in a postponed market launch (leading to customer migration), low production capacity at high production cost, and costs for product changes. Recent surveys detected a relationship between the timely compliance of product launch and a company's success in different industrial fields. Cumulated gains in the automotive industry can decrease up to 30 percent if the product launch is postponed for six months. A delayed product launch in the computer industry leads to a 25 percent loss of sales (Kuhn and Bandow 2008). During ramp-up, the product is transferred from a planned virtual status to a physical model. The duration of the ramp-up is a critical factor for timing the product launch (Strubelt, Röbig, and Zadek 2013). Fluctuations in demand, production capacity, and performance, as well as constant process adaptations and product modifications, are typical for the ramp-up phase and contribute to its transitional character.

Another major cornerstone in understanding shortcomings in ramp-up management and the development of potential correctives is understanding the human factor and integrating human factors knowledge seamlessly into the technology development cycle. There are at least two major reasons why human factors matter to ramp-up processes. First, production ramp-up is characterized by high cognitive complexity owing to several complexity drivers such as product or process variety (Cunha and Maropoulos 2007). This complexity leads to a low degree of transparency, which in turn complicates decision processes (Zheng and Possel-Dölken 2013). Game-based training can be used to qualify ramp-up managers and decision makers for these complex situations by enhancing their decision-making skills and improving their quality awareness during the ramp-up process (Brauner et al. 2013). Second, both individual cognitive abilities and performance characteristics influence the effectivity and efficiency (that is, quality and performance) of decision-making processes (Brauner and Ziefle 2014). Therefore, knowledge of how human factors impact the quality and performance of decision processes during ramp-ups is important to facilitate effective competence development during ramp-up (Ifenthaler, Eseryel, and Ge 2012) and might thus confer a major edge on competitive markets (Ziefle and Jakobs 2010).

The authors chose a game-based approach to pursue the goal of training decision makers in ramp-up, as empirical evidence shows that it contributes more effectively to the learning process than traditional learning methods (Wolfe 1997; Prensky 2003). Another advantage is seen in the potential to influence learners' attitudes (Vogel et al. 2006) and raise awareness for quality aspects in ramp-up (Zualkernan et al. 2009). Furthermore, game-based training provides a controllable simulation environment that is easier to handle than complex, unpredictable real-world scenarios. Particularly in the complex and safety-critical ramp-up environment, simulation games are convenient since no penalties or damages result from wrong decisions. The developed business game extends existing games by enabling decision makers in ramp-up to make decisions regarding quality and facing them with the arising consequences. Additionally, one can draw conclusions about human factors leading to good game results.

This article examines how game-based training can improve the decision-making ability of human operators in ramp-up processes and how training intervention increases the operator's quality awareness. This new simulation game was developed using quality management principles in order to simulate humans' decision making during ramp-up and the associated effects on process and product quality. In the game, the player (representing stakeholders involved in the ramp-up process) is faced with predefined quality problems, such as damaged parts delivered by the supplier and unreliable production processes that lead to customer complaints. The player's goal is to choose an optimal quality policy that minimizes customer complaints and maximizes company profits. Based on this game, an empirical user study was conducted to validate the game design and the effectiveness of this approach. Also, the authors investigated if the game evaluates employees' potential performance and identifies crucial user characteristics in ramp-up processes. Furthermore, the usability of the game interface is evaluated and the influence of interface design on decision quality is quantified.

This article is organized as follows. First, a literature review describes the role of human factors in ramp-up management and analyzes existing business games for production and logistics. Based on the literature review, the research question is deduced, and the research methodology is described. This is followed by the presentation of achieved research results. Finally, the authors present the results and describe an outlook on the future adaptability and applicability of the game and its simulation model.

LITERATURE REVIEW OF RELATED WORK

The following sections present related work in the area of human factors in ramp-up processes, game-based learning, and game-based learning for ramp-up processes.

Human Factors in Ramp-Up Processes

The success of ramp-up processes not only depends on technical aspects, but also on human factors. This applies both for the personnel operating on the shop floor as well as the production engineers planning the production ramp-up. Goerke and Gehrmann (2014) identified several aspects where human factors influence ramp-up processes. These include bottlenecks in acquisition of skilled personnel, but also difficulties that arise from the lack of motivation or experience of the personnel. Worker diversity is expected to grow further due to demographic changes and the shrinking workforces of many Western societies (Ziefle and Jakobs 2010). Even today, companies have difficulties acquiring highly skilled personnel, and the increasing shortage of young and qualified workers will only exacerbate the situation. To address these workforce problems, companies might rely on older personnel who have higher domain knowledge (that is, job experience) but less experience with modern information and communication technology, as well as modern production engineering and quality management methods. In addition to domain knowledge and digitalization competency, which might differ across workers, differences in workers' cognitive and motivational prerequisites play a major role in work quality. As such, humans' ability to master complexity (Calero Valdez et al. 2015), problem-solving abilities, information processing (Ziefle and Arning 2014), or the individual capability to cope with multitasking demands in time-critical decisions (Mittelstädt et al. 2015) are critical for work performance. The achievement motivation, the extent and the individual way workers can also be motivated for a sustainable performance, differs across cultures and educational backgrounds (Schaar et al. 2014). All these changes in the diversity of the workforce and the increasing pressure on competitive markets challenge human resource managers to master these societal and technological challenges within the adequate management of personnel's competencies (Brauner and Ziefle 2014).

So far, the potential for understanding and predicting human factors as a systematic component within ramp-up management has not been fully exploited. Rather, the susceptibility of human decision processes has been considered an "unpredictable constant" in most technology-driven approaches. Yet, no empirically validated framework exists in which the complexity of sociotechnical systems in ramp-up processes can be identified, assessed, or simulated. Understanding, predicting, and controlling the influence of the human factor allows it to be used as a regulation variable—eventually improving ramp-up performance. Human factors knowledge thus can contribute to the quality of ramp-up performance by understanding human cognition and decision making in production systems and handling uncertainty in complex cognitive decisions.

In this article the authors address these challenges by developing a Web-based tool conceptualized as a framework that serves as a training environment and may also be used to select the most qualified personnel to manage ramp-up processes. A skilled and motivated employee may only need a short interaction with the tools, whereas less qualified and less motivated employees may require longer training sessions with the patient training application. Hence, the authors argue that a cornerstone in understanding the shortcomings in the ramp-up management and the development of potential correctives is to understand the human factor and to integrate human factors knowledge seamlessly into the technology development cycle.

Game-Based Training

Game-based training approaches have several advantages in order to identify and understand the aforementioned role of human factors in production processes. They can be used to educate decision makers in production networks and generate valuable information, usually hidden in real-world scenarios, to gain a better understanding of human behavior in complex and stressful situations (Baldissin 2013). These approaches provide a controllable simulation environment, and since no penalties or damages resulting from wrong decisions have to be feared, the positive effects of game-based approaches on learning are well substantiated, particularly regarding complex or safety-critical scenarios.

One of the first games addressing decision makers in the manufacturing industry was developed in 1932. It dealt with production problems of typewriters and can be seen as a predecessor of today's business games (Faria et al. 2009). In 1956, the American Management Association developed the first commonly known business game called Top Management Decision Simulation, followed by a wide range of different business games. The developments in this sector were further accelerated by the increased use of computers. Empirical evidence clearly shows that game-based approaches contribute more effectively to the whole learning process than traditional learning methods (Wolfe 1997; Prensky 2003). This concerns both the growth of procedural knowledge and the successful retrieval of information from the long-term memory, as well as the locus of control regarding the learned skills (Sitzmann 2011). Games may also positively influence the learner's attitude toward the learning objectives in a thematic field (Vogel et al. 2006) and raise awareness for the topics in question (Zualkernan et al. 2009).

To support decision makers another game-based learning approach, the so-called Beer distribution game, was developed. The Beer game is a multiplayer game that simulates the relation between order quantities and stocks in a supply chain (Goldratt and Cox 2014; Dettmer 1997). The game aims at visualizing the bullwhip effect (Lee, Padmanabhan, and Whang 1997). The bullwhip effect describes the observation that an increase in product demand at the end of a supply chain by the customer is followed by an amplification and oscillation in earlier stages of the supply chain (Disney and Towill 2003; Faria et al. 2009). Goldratt's game is another similar game, where players have to step into different roles within a supply chain. The game is turn based and its aim is to visualize how simple variances in one process step can intensify and consequently influence the quality of the whole process (Prensky 2003; Pfeifer and Schmitt 2014; Philipsen et al. 2014).

Although there are many suitable business game approaches and frameworks that have been used successfully, there has not been a game thus far that addresses the special challenges of decision making in quality management in general and ramp-up in particular.

Game-Based Training in Ramp-Up

Decision making in ramp-up is difficult for at least two major reasons. First, the ramp-up phase is unstable due to ongoing changes in processes and product design. Second, decisions must be made under extreme time pressure to fulfill the predefined launching schedule (Basse, Sauer, and Schmitt 2014; Carvalho 2012). Therefore, the authors developed a business game to support and train decision making in ramp-up to transfer the advantages mentioned previously to ramp-up management. The developed business game trains the player to make fast and meaningful decisions to enhance the awareness of quality in supply chains and production processes (thereby providing a profound understanding of the connections between quality, human factors, and company success).

Therefore, the instructional design of the game follows the idea of cognitive load theory (Chandler and Sweller 1991), according to which human's cognitive capacity is divided into germane load and extraneous load. The less users are distracted by extraneous load, the more cognitive capacity is available for the germane learning process. Hence, the game's simulation models only the most relevant subset of real production processes that are related to the learning objectives. It does not reflect the complexity of real production processes, but lets users understand the basic interrelationships of quality management.

RESEARCH QUESTION

Summarizing, there is a demand to qualify and train employees in order to successfully manage production ramp-ups. Raising the awareness of quality management is identified as an important learning objective. Furthermore, serious games, business simulation, and business simulation games can mediate knowledge and expertise in various contexts. Although some games are specifically designed to mediate production engineering knowledge (for example, the Beer distribution game), at present no serious game or business simulation exists that mediates quality management or production ramp-up knowledge. Consequently, the authors set out to design, implement, and evaluate a game focusing on the aforementioned aspects. The following research questions guided this processes:

- Is it possible to capture the complexity of quality management and production ramp-ups in a business simulation game?
- Does interacting with the business simulation game change the player's attitudes toward quality management?
- What personality factors can be identified that relate to performance in the business simulation game, indicating that:
  a) Some employees may be better suited to handle the complexity of ramp-up processes
  b) The game might serve as an interactive assessment tool to identify the most suitable employees for the task

RESEARCH METHODOLOGY

In the following, the authors represent the system dynamic model. First, they introduce the simulation model of the game, followed by the design of the interface. Finally, they report on a first evaluation of user performance with the system. The user test represents a first empirical validation of the experimental ramp-up game framework and may serve as a valuable environment for the simulation and assessment of workers' performance and for the individually tailored development of training for workers in ramp-up management in the long run.

Development of the Simulation Model

A three-step approach is used for developing the simulation model. In the first step, the contribution of quality management to daily managerial decision-making processes in production is displayed in order to concretize the framework of the simulation model. The second step comprises the development of the simulation model by the implementation of key quality management processes. Based on the developed simulation model, the profit equation is derived in the third step.

Step 1: Development of the Game Framework

The achievement of quality requirements is linked to different aspects (quantity, deadline compliance, and target cost) that determine the general success of the ramp-up phase. Hereinafter quality management and its contribution to daily managerial decision-making processes will be discussed first, followed by a characterization of interfaces with direct functions in the supply chain.

Quality management methods support the control of company processes in a highly dynamic environment. They can be applied to decision making on all corporate levels, from the macroscopic perspective of production networks down to the shop floor where product characteristics and process parameters are monitored (Morfaw 2008). Since the introduction of total quality management principles, quality management has increasingly gained importance for a company's success (Kanji 1995).

In order to specify the framework and the limits of the game model, the following company functions or departments will be set into relation with quality management: 1) supply chain design; 2) demand planning; 3) planning of procurement and purchase; 4) inventory control and optimization; and 5) production planning and control.

1. *Supply chain design* covers the strategic configuration and optimization of procurement,

production, and distribution tasks. Aiming for the configuration and optimization of logistics and production structures with reference to the company strategy (Sichi-Levi, Kaminsky, and Simchi-Levi 2004). Naturally, the decisions in this field have a long-term impact and are therefore highly important. Concerning supplier development and auditing, quality management offers practical methods for evaluating product and production quality. Additionally, the quality management team (Kanji 1995) supports negotiations regarding quality assurance agreements between manufacturer and suppliers.

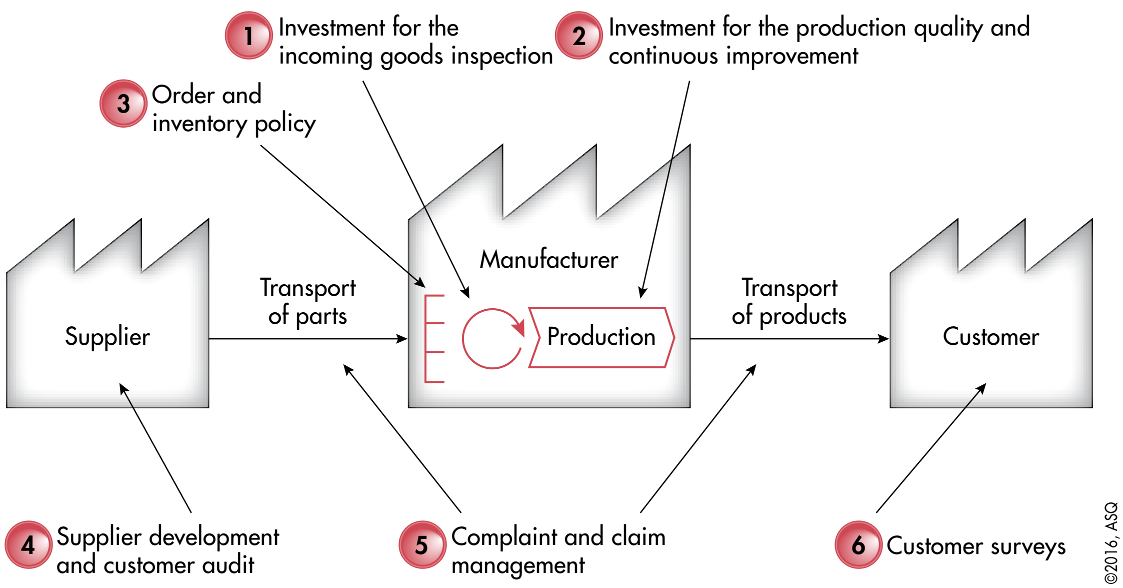
2. *Demand planning* calculates the required materials, components, and modules based on forecasting methods concerning the realization of the production range (Stadtler and Kilger 2008). The result is used to plan the capacity of the production plants. Quality management has many direct interfaces with the customer, for example, in complaint, claim, or callback management, and is thus able to contribute useful information to demand planning (Kanji 1995).
3. *Procurement planning* comprises various methods such as the ABC or XYZ analyses, which are used to make decisions about sourcing policy. Thereby, the trigger point of sourcing (reorder-point vs. frequency) and the elaboration of order quantity (order-up-to-level vs. economic order quantity) are declared. Today's production systems require the consideration of inspection policy and supplier quality level within their sourcing policy. For example, just-in-time production requires the delivery of parts of adequate quality; otherwise, the consequences for the production process can be severe (Sichi-Levi, Kaminsky, and Simchi-Levi 2004).
4. *Inventory control* optimizes inventory levels with respect to the trade-off between demanded service level and low inventory costs (Altay and Litteral 2011). Quality management provides the inventory control department with information about the quality level in production processes, such as reject rates, allowing better inventory planning. Quality management also offers concepts for material control at the shop-floor level, which ensures the separation of good parts, defect parts, parts meant for rework, or rejects.
5. *Production planning and control (PPC).* The Aachen PPC model represents a framework for PPC, with tasks divided into production program planning, materials management, schedule, and costs planning, as well as order authorization and controlling (Schuh 2007). Many quality management functions are integrated into the value stream at the shop-floor level and have to be considered in production management. For example, in order to increase production quality, control workstations are designed and integrated into the value stream. Defect parts or specific subprocesses in manufacturing can initiate changes in the product program or the currently used production technology. Additionally, quality management provides several methods, such as capability studies or statistical tolerance analysis, for process optimization at the shop-floor level (Pfeifer and Schmitt 2014).

Step 2: Development of the Game Model

Two games, Goldratt's game and the Beer game, serve as blueprints for the development of the game structure. The variations of production quality observed in Goldratt's game should be considered, as well as the relevance of order quantity and inventory costs seen transferred from the Beer game. The linear supply chain consisting of supplier, manufacturer, and customer sketches the game environment.

While in the Beer game the player is allowed to make decisions regarding order quantity, the proceedings in Goldratt's game are determined randomly by tossing dice. To enhance the learning effects and improve the decision-making ability with the developed game, the option to decide game actions is required. Therefore, key quality management processes are implemented that allow the player to make decisions about demand planning, inspection planning, and production quality. Figure 1 illustrates the central supply chain and quality management relationships

Figure 1 Concept of the quality-oriented business game.



considered in the simulation model. The following further explains Figure 1.

- *Implementation of influenceable quality of incoming goods* (1): The player can influence the quality of the incoming goods from the supplier. More investments into inspection planning increase the chance of finding faulty parts. This leads to higher quality parts entering the work in progress. Accordingly, higher quality parts are assembled into products, which leads to higher overall product quality. In this case, the player can improve his or her own production quality by increasing his or her investments in inspections, test efforts, and sample sizes. The player needs to consider the trade-off between higher inspection costs (with lower production yields) and higher claims costs due to customer complaints.
- *Implementation of influenceable production quality* (2): Production quality depends on the player's policy for internal processes. Several methods such as in-line testing or machine tools of higher precision can be used to improve product quality. In the game concept, the player can invest in his or her quality level. An investment made into production quality decreases the production yield but can avoid customer complaints and penalties. Hence, the player faces the trade-off decision between preventive and corrective quality costs.
- *Implementation of influenceable inventories* (3): The player must pay attention to the amount of inventory. While a small amount of inventory means lower inventory costs and therefore higher profits, a larger inventory ensures customer demand in terms of quantity. The player has to decide on his or her inventory policy regarding customer demands, supplier quality, and his or her own production quality.
- *Implementation of failure and complaint management* (5): The manufacturer and the customer have an active incoming goods inspection that detects failures. If the manufacturer finds faulty parts from the supplier, it will complain and send them back for a credit. Analogously, the customer will send detected faulty products back to the manufacturer. In such a case, the manufacturer has to pay a fine. The supplier reacts to complaints by adjusting its quality policy. If there are fewer complaints by the manufacturer because of a low inspection policy, the supplier will deteriorate its product quality level in order to reduce its own

costs. If there are more complaints, the supplier will try to improve its product quality. The player, in the role of the manufacturer, will also receive faulty products sent back by the customer. He or she has to choose a suitable quality policy to achieve the highest profit.

- *Supplier development, auditing, and customer satisfaction surveys* (4 and 6): To assess and enhance the quality level of the supplier, the supply chain management conducts audits. Customer satisfaction is generally measured with surveys. These measures ensure knowledge about the quality of the assembled parts within the production, which in turn facilitates the decisions regarding expensive in-line inspections and adapting production quality control.

Step 3: Development of the Profit Equation

The player's main objective is to maximize the manufacturer's profit, which is influenced by distinct costs and sales. Based on the described implementations, the equation for the manufacturer's profit is:

$$Profit = p * n_{esv} - C_v - C_f$$

The product quality perspective targets the maximization of product price (p) and effective sales volume (n_{esv}), whereas the process quality focuses on the minimization of total variable costs (C_v) and fixed costs (C_f). To reference the implemented quality management functions such as demand planning or inspection planning, the parameters effective sales volume (n_{esv}), variable costs (C_v), and fixed costs (C_f) must be linked to them. Costs for the inspection of incoming goods (C_{ii}) and costs for production quality (C_{pq}) are considered as fixed costs (C_f).

$$C_f = C_{ii} + C_{pq}$$

In the developed simulation model, detected faulty parts are returned to the supplier. Hence, the variable costs depend on the number of returned faulty parts. The variable costs are denoted as effective costs of purchased parts (C_{efp}) and calculated by subtracting the credit of returns (C_{cr}) from the cost of purchased parts (C_{pp}).

$$C_v = C_{efp} = C_{pp} - C_{cr}$$

To compute the cost of purchased parts, the number of purchased parts (n_{pp}) is multiplied by the part costs (c_{pp}).

$$C_{pp} = n_{pp} * c_{pp}$$

Analogously, the credit of returns results from multiplying the number of returned parts (n_{rp}) by part costs.

$$C_{cr} = n_{rp} * c_{pp}$$

The previously described implementations consider the customer's reaction to product quality. The effective sales volume (n_{esv}) is the difference between the total number of sold products (n) and the number of returned products (n_{rp}). This relationship is shown in the following equation:

$$n_{esv} = n - n_p$$

Taking into account the subdivision of fixed costs in costs for the inspection of incoming goods and costs for production quality, as well as the returned parts to the supplier and the returned products from the customer, the implemented profit equation is:

$$Profit = p(n - n_p) - c_{pp}\,(n_{pp} - n_{rp}) - C_{ii} - C_{pq}$$

The complexity of the simulation model results from the high interdependency of parameters in the implemented profit equation. As an example: Investments in the inspection of incoming goods lead to more detected faulty parts and returned parts to the supplier. Consequently, the supplier takes measures to deliver parts of suitable quality. This example shows that measures of inspection ensure correct parts but also influence the supplier's quality. That is, investments in the inspection of incoming goods can increase or decrease the profit. On one hand, the profit can be decreased due to higher costs. On the other hand, the inspection of incoming goods can cause better quality of the supplier's parts, which results in a higher quality in the own production. This leads to fewer returned products and increases profit.

Design of the Game Interface

The implementation follows the model-view-controller (MVC) pattern (Gamma et al. 1995) with a realization of the simulation model from the previous section as the model, a controller that maps the user's inputs to the model and the model's outputs to the user, and a user interface layer. From a software engineering perspective, using this pattern offers the ability to easily exchange either the simulation model or the user interface without affecting other parts of the game.

The development of the user interface followed a user-centered and participatory design process, meaning that potential users as well as domain experts were regularly consulted during the iterative development phases (Gould and Lewis 1985). Early focus on the user's tasks ensures that users can efficiently perform their tasks without distraction from other unnecessary functional applications. Here, the application focuses specifically on the previously defined learning objectives and is designed solely to convey this knowledge (Chandler and Sweller 1991; Calero Valdez et al. 2015). The iterative design with frequent user tests ensured that the functionality and usability of the developed software system were continuously improving and that design errors in the simulation model or the user interface were revealed as early as possible.

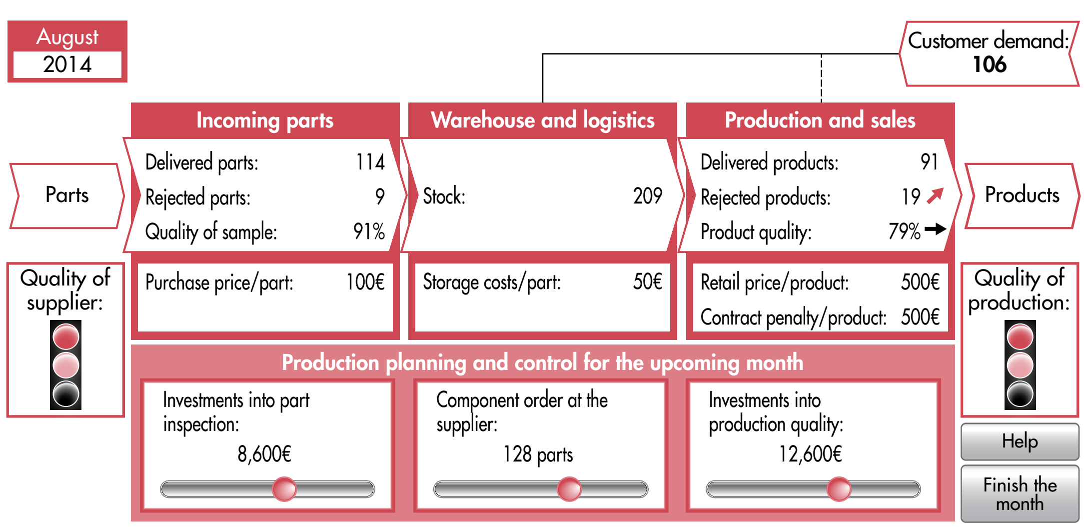
From a technical perspective, the game is realized as a Java Enterprise Platform (J2EE) application and is deployed on an Oracle Glassfish application server with a PrimeFaces front-end. Hence, the game application is accessible through Web browsers without the necessity of additional deployment procedures. The arrangement of the interface elements on the screen models the schematic flow of products and information through a company. Therefore, the interface was separated into thematic blocks, starting on the upper left with the supplier, followed by the incoming inspection, the warehouse, the production, and finally reaching the consumer on the upper right side. In addition to current values, such as orders, investments or quality, and production levels, a detailed billing of the previous month, as well as a diagram with past costs and profit trends, are presented to the player. Figure 2 illustrates the game's interface.

Evaluation of the Business Simulation Game

To validate the efficacy of the business simulation game as a method to train employees to successfully master ramp-up processes, the authors conducted an empirical user study. The study was guided by the three research questions defined previously and focuses on:

1. The suitability to communicate production engineering and quality management knowledge
2. Does interacting with the game have a measurable effect on the player's attitude toward quality

Figure 2 The interface of the quality management game.



management and does interacting with the game increase the achieved product quality in the game mode?

3. Can human factors be identified that relate to game performance?

Evaluation Method

Following the iterative development cycle, the game was evaluated at different times in the process with different evaluation foci. First, the functionality of the game model itself had to be evaluated. Next, the role of human factors on decision making in the game was explored. Finally, the game's user interface was revised to improve its usability and to investigate the impact of information visualization on game performance. The following sections focus on the validation of the game model as well as on an initial examination of human factors and play behavior. More detailed information about the usability engineering process and the positive influence of usability on the (simulated) company profits can be found in Philipsen et al. 2014.

In order to validate the game model and its suitability as a research framework to understand human factors of ramp-up processes, five requirements had to be met and tested:

1. The achieved profits in the game are consistent instead of random for a player over multiple rounds.
2. The player's awareness for quality in production must be improved by playing the game.
3. The players learn to adapt their quality policies more efficiently to the affordances of the production processes.
4. Quality-oriented strategies lead to higher profits in the game.
5. Using the game must be fun to motivate repeated playing.

A Web-based study was conducted to validate the aforementioned requirements. Participants had to play two successive rounds of the game that were framed by a two-part questionnaire. While the first part focused on the player's sociodemographic data, personality traits, and personal attitudes, the second part was used to collect, inter alia, information about the applied strategies during the game and to gather ratings of the game's controllability, difficulty, and entertainment value. In addition, participants had to do pre-post ranking tasks to gather their opinions about the requirements for a successful economic production and the possible attitude changes caused by playing the game.

To rate the players' performances in the game, the profit achieved by the simulated company was taken as the primary criterion. To measure opinions, six-point Likert scales were used in the survey with a minimum scale level of 0 for "nonapproval" and a maximum of 5 for "complete approval." The data gathered were analyzed by using uni- and multivariate analysis of variances ([M]ANOVA) as well as bivariate correlations. The Bonferroni method was applied for pairwise comparisons and Pillai's trace values (V) were taken into account in multivariate tests. The level of significance was set to $p < 0.05$.

Sample Description

The sample consisted of $n = 127$ participants, who played both rounds and completed the survey; 76.4 percent were male ($n = 97$) and 23.6 percent were female ($n = 30$). The participants' mean age was 27.7 ($SD = 7.2$) years. The majority (58.6 percent, $n = 60$) held a university degree as their highest achieved level of education, while 39.7 percent ($n = 50$) had completed high school. Participants' domain knowledge in production management (57.5 percent, $n = 73$) or quality management (67.7 percent, $n = 86$) was rather high.

RESULTS

The results of the study are structured according to the previously mentioned five requirements to the game model.

1. *Consistency of achieved results:* The achieved profits of the first round correlated strongly with those of the second round ($r = 0.730$, $p < 0.01$). Consequently, players who gained a high or low profit in the first round on average achieved a similar profit (high or low) in the other round too.

2. *Raise awareness for quality in production:* Players rated quality-related aspects as more important for economic production after playing the game than before playing. In particular, the increase of the own production quality was ranked as the most important factor (mean rank = 1.8, SD = 0.09) in the post-game survey. This gain of importance, compared to an average rank of M = 2.2 (SD = 1.3) in pre-game rankings, was significant, with V = 0.87, $F(1,123)=10.848$, $p < 0.01$. In addition, there was a slight increase in the player's average personal attitudes toward quality, from M = 3.4 (SD = 0.8) before playing the game to M = 3.6 (SD = 0.7) afterward. Although the average increase was not high, the effect was proven as significant with V = 0.134, $F(1, 35) = 5.422$, p = <0.05.
3. *Learnability:* There was a significant increase in the players' mean profits between the first round and the second round (V = 0.23, $F(1, 126) = 36.6$, $p < 0.01$). The average return rose from M = −19.0 (SD = 258.5) in the first round to M = 76.6 (SD = 218.3) in the second.
4. *The impact of strategies:* Several aspects of the strategies the players applied during the game had a significant impact on the achieved profits. First, players who stated that they took more risks in the game than they would in real life on average achieved lower profits; that is, the level of risk taking negatively correlated with the gained returns ($r = -0.217$, $p < 0.05$). Second, strategies that were dominated by forward planning instead of just reacting to variations in quality and production quantities led to significantly higher profits ($r = 0.184$, $p < 0.05$). Finally, players who stated that their strategy was highly dominated by quality aspects on average achieved higher profits (M = 136.1, SD = 96.3) than players who ignored quality in their decisions (M = 21.1, SD = 280.4). This effect was significant ($r = 0.370$, $p < 0.01$).
5. *Motivation to play the game:* Although participants in pre-tests under laboratory conditions complained about the difficulty and demanding challenges of the game, players stated that it was fun to play (M = 4.0, SD = 0.9). Furthermore, there was a consensus to the question of whether the player would like to play the game again (M = 3.9, SD = 1.2).

Further Findings

There were several findings in addition to the evaluation of the game model. First, it was proven that the level of complexity in terms of spontaneous quality drops at the supplier's or in the player's own production and has a significant effect on the player's mean profits ($F(1, 122)$, $p < 0.01$). Second, game behavior had a significant impact on the achieved profits: Players who made a large number of fine-grained adjustments to their investments performed better than players who made fewer adjustments ($r = 0.303$, $p < 0.01$). In contrast, no significant effects of the players' personality traits on the achieved returns were revealed. A more detailed insight into the research of human factors and play behavior with the help of the game can be found in Philipsen et al. 2014.

DISCUSSION

In this research project the authors modeled and simulated the ramp-up of a production process in a game-based learning environment. This allowed experimentation with the human decision processes in complex production environments. The authors found that the focus on quality control and quality management was a central learning objective that the game must include to convey; that is, high product quality is an important criterion during ramp-up. Consequently, the authors specified a model of the inner company processes and modeled how several operative decisions (that is, investments in quality inspections, inventory levels) influence the company's performance metrics (for example, the production costs and achieved product quality). Following the model's specification, the authors implemented the functional game engine and a Web-based user interface with an iterative, user-centered, and participatory design process. The complexity of quality management was reduced to key quality management processes in order to implement them into the game model.

To evaluate the efficacy of the business simulation game to convey process engineering knowledge, the authors conducted an empirical user study and investigated the influence of the game intervention on several objective and subjective metrics. The results show that the game-based business simulation positively influences all of these metrics. First, the player's attitude toward quality management rises (measured by questionnaires), indicating that he or she will pay closer attention to the correct implementation and observation of quality control loops in actual production ramp-ups. Second, the evaluation furthermore revealed that the realized product quality in the game's simulation model is also increasing.

Summarizing, the authors conclude that the game effectively captures several of the challenges of production ramp-ups and it can furthermore be used to inform and train employees to successfully master actual production ramp-up phases.

This game is especially suitable for quality-oriented production since it demonstrates the complexity in using inspection methods. On one hand, the use of inspection methods leads to knowledge about sources of failures. On the other hand, higher costs occur due to inspection methods. The player must make the right decisions between the poles of transparency and costs. Additionally, users experience that by putting more effort into the quality assessment of the supplier, the quality of the supplied parts can be elevated, which illustrates the complexity of quality management in the supply chain context. Such learning environments can efficiently qualify future supply chain and quality managers to perform well when on-the-job training is not possible or not desired. The Quality Intelligence game (QI game) was specifically designed to convey quality management and supply chain knowledge to trainees. Within the game environment, the trainees can explore multiple approaches to successfully interact with the associated simulation model and to learn how to successfully cope with difficult situations, thereby minimizing the risks during real production processes. With specific training, employees in ramp-up can be educated to improve their awareness for quality management and enhance their decision-making ability with regard to quality management aspects.

The design of the simulation model focused on ramp-up processes and did not target specific product lines or manufacturing branches. To enhance the desired learning outcome and to make it easier for the trainees to relate their game performance outcomes to requirements of their later job, the simulation, the training material, and the user interface should be adapted to the respective case. Naturally, this study represents only a first glimpse into the impact of human factors in ramp-up management, as the implementation and the design of the game framework, as well as a first empirical validation, was the central focus here. To understand the impact of user diversity on the quality of management decisions, age and the level of domain knowledge should be explored, as well as personality factors such as risk perception, stress management, multitasking competence, information processing speed, or the ability to meet complex cognitive tasks. Next, the role of external motivators (additional benefits for high performance), the usefulness of different tutoring systems that support and advise users context-adaptively, or even the impact of different feedback systems (giving workers detailed information about their current performance) could be further experimentally validated. Furthermore, the game environment could be validated regarding different usage contexts and purposes, such as instructing novice learners in professional training and on-the-job training (educational quality), or supporting the personal selection process and assessment (diagnostic capability). Finally, in later iterations of the game—that may be used in follow-up trainings—more complex production lines may be added to the model to meet the increasing complexity of real-life scenarios.

CONCLUSION

This section discusses both the practical implications and the limitations of the developed game model and the conducted evaluation. In the business and production environment in general, and during ramp-up phases in particular, individual differences of the workers and decision makers (for example, expertise, cognitive abilities, motivation, or even cultural differences) on production efficacy, product quality, company product, or production times can be observed. The resulting depth and only partially exploited research field for understanding human factors in ramp-up processes, as well as during operation, has motivated the development of the presented simulation model and research framework, which offers benefits to both research and employee education.

Practical Implications

The developed simulation environment makes it possible to experimentally control the complexity of delivery times, supplier quality, and so on, and the influence on the individual's strategies can be measured. This results in two major application possibilities:

1. The simulation model is suitable for researching both cognitive and affective processes during decision making in ramp-up phases. A better understanding of these processes and the underlying human factors will support the development of more focused and efficient training programs and will thereby help to better prepare employees for the challenges of ramp-up phases.
2. The simulated environment will be used as a test bed to evaluate intervention measures. For example, the effectiveness of a new training intervention can be benchmarked by relating the efficacy of the training intervention with the simulated company's metrics (for example, profits, achieved product quality, stock levels). Moreover, production states that are problematic during ramp-up phases can be simulated and instructed selectively in the developed simulation tool to support training interventions.

Limitations

Despite the aforementioned benefits, the current simulation model, as well as the research that was conducted, still have some limitations. First, the simulation model of the game addresses the most relevant, but still an abstracted and intentionally simplified subset, of the difficulties that can arise in ramp-up process. Missing aspects are, for example, the selection of different suppliers depending on costs, quality, and delivery times, or the choice between different control policies. Fuhrmann et al. (2015) present additional examples for possible model extensions. Second, although the evaluation shows that the game can increase both, the worker's awareness for quality management and the product quality of the simulated company's products, the authors could not yet evaluate the efficacy of the presented training environment in real ramp-up processes. In the future, the authors will evaluate the effectiveness of this training approach on ramp-up processes in the real ramp-up processes. A possible scenario is the evaluation of a ramp-up process in the Demonstrationsfabrik Aachen (DFA) that is associated with RWTH Aachen University. The DFA is a research space between industry and academia that allows the analysis of ramp-up phases of realistic products under controlled conditions (Schuh, Gartzen, and Basse 2014).

Summarizing, the proposed empirical research framework that builds on a business simulation game has the potential to train decision makers to successfully handle ramp-up processes and enable researchers to identify the crucial human factors that need to be supported.

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