Increasing Ramp-Up Performance By Implementing the Gamification Approach

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Abstract

Rapid product lifecycles and a growing product range lead to an increasing number of production ramp-ups. This basically leads to an increasing importance of efficient ramp-up processes, reducing ramp-up costs and ramp-up time become more and more the focus of attention. Furthermore, linked to the decreasing quantities, there is a growing importance of low volume productions, characterized by low automation level and high work contents. One of the most important key challenges in ramp-up of low volume production systems is the qualification of employees. The training process is usually set up in accordance with the Four-Step-Model, a state-of-the-art method for training in the context of production developed decades ago under different circumstances in production. In order to meet the actual market challenges, a new method is required. For a few years the Gamification Approach has become more and more apparent. In a new approach, Gamification is used in order to improve learning efficiency in production ramp-up. For this purpose the four step model is extended by a new one, the Gamification Step. The new model is the basis for a game which has been developed in cooperation with a German car manufacturer. The purpose of the game is to increase the efficiency in learning the assembly sequences. © 2014 The Authors. Published by Elsevier B.V. Selection and peer-review under responsibility of the International Editorial Committee of the “2nd International Conference on Ramp-Up Management” in the person of the Conference Chair Prof. Dr. Robert Schmitt.

Keyword: Ramp-Up, Qualification, Gamification Approach

1. Introduction

In recent years, industrial companies have found themselves in a field of high pressure for innovations. In consequence, manufacturers need to serve lower product lifecycles and higher level of customization as well as to achieve more differentiation from competitors. Therefore, an increasing product variety can be observed. In consequence, the number of units per product tends to decrease. This leads to a growing importance of low volume production systems.[1, 2, 3] The changing market demands also lead to a rising number of production ramp-ups. In addition to high needs regarding product- and process quality, the ramp-up time and one-off costs have to be reduced. A high ramp-up performance, characterized by high process and product quality, short ramp up times and low costs, has a high influence on the margins of profit regarding the whole product life cycle.[4] In low volume productions – particularly in the automotive industry – with high cycle times, where tasks are mainly executed manually, workers need to fulfill higher demands in terms of quantity and size of work tasks. Therefore, qualification is a very important factor in production ramp-ups. To achieve a sufficient qualification level is one of the most crucial aspects for a successful production ramp-up.[5] Whereas automotive production systems have experienced fundamental changes during the recent years as outlined above, the qualification of workers is accomplished with qualification methods and systems which were developed decades ago and thus under different premises due to the production system.[6] This Paper provides an approach to enhance the qualification process during production ramp-up in a low-volume context.
2. Background

The paper emphasizes three fields of research concerning the Gamification Approach in production environment. The context of ramp-ups and low volume is described at first. Secondly, learning curves as well as methods for the worker qualification are outlined. Additionally, principles of the Gamification Approach are encountered.

2.1. Production Ramp-Up in Low-Volume Context

The term production ramp-up describes the phase in product and production development processes, in which the prototype production is converted into the series production.[7] Especially for complex products it is necessary to design the ramp-up in several phases. These pilot series must fulfill the following key tasks, according to WANGENHEIM[8]:

- Increase of production output
- Securing the stable reproduction by adjusting tools and facilities to series conditions
- Qualification of workers
- Providing a number of products for testing and presentation

Generally, there can be identified three phases during the ramp-up, the initial pre-series, zero-series and the increase of output up to the series level. In the pre-series prototypes are produced under similar premises like in series production for the first time. The testing of equipment and components is crucial to identify and solve problems at an early stage. With the zero series, production processes advance towards series conditions, e.g. target times are shortened. Supplied parts are already produced in regular series processes by the suppliers. Moreover, series tools are used to make last adjustments, which become necessary with the change from prototype to series parts. The approval for the series production is given upon the results after the zero series. During the increase to series output level, the first customer product is produced and finishes with the achievement of the desired number of output. Its acceleration is represented by the ramp-up curve.[9] The ramp-up phase can be defined as a project, so the classic project targets with the dimensions cost, time and quality are valid.[4, 10, 11] Even though there are regularly no differences between the demands for quality regarding low and high volume production systems, the other dimensions have to be considered. The importance of ramp-up costs increases with lower quantities. The lower the quantities are, the bigger is the portion of costs of one-off expenditures for each product. The significance of the time dimension is still growing, even in low volume production systems.

The impact of qualification processes on the ramp-up time is high, especially in manual production systems with complex processes. High effort has to be spent on qualification and training, so there’s also an essential linkage to the ramp-up costs. Especially in low volume production systems work tasks do not have a highly frequent repetition during ramp-up. Hence, the workers need to be qualified to be prepared for start of production at last without having the possibility to train their skills with many pre-series prototypes.

2.2. Learning Curves and Worker Qualification

For developing means to enhance the qualification process, with regard to time and cost reduction, the nature of learning needs to be revised, initially. According to BOWER, learning is the change of behavior or of its potential by a person with regard to a certain situation, which bases upon repeated experiences in this very situation.[12] In the fields of manufacturing, learning has the purpose to enlarge the state of knowledge by processing information. For this, channels are necessary to assimilate the information. The channels can be divided into an observitive one, a verbal, a mental and an active channel.[13] Moreover, learning processes are often visualized by so called learning curves. The learning curve theory emerged in the first half of the 20th Century in the context of production and over the years it went through several extensions and adjustments. In figure 1 the evolution of the learning curve concept is illustrated qualitatively. Overall, the curves represent the fact that the labor input declines over time with a quantifiable learning rate. The basic learning curve concept is shown in the first graph. The CRAWFORD curve was modified by members of the Stanford Research Institute, who found out that former experience has an impact on the starting point of the function. Further research by DE JONG suggests defining a lower limit as assembly tasks cannot be carried out in an infinitesimal time span. At last, ULLRICH combines the three learning curve approaches into one curve (see figure 1).[14] This concept by ULLRICH is referred to in the following passages.

![Qualitative Learning Curve Model](image)

Figure 1 Qualitative Learning Curve Model

Though, one fact may not be misconceived as it is pointed out by TERWIESCH. As the learning curve refers to the cumulative number of product output and declines with every produced unit, the assumption that the learning curve is independent of managerial decisions suggests itself. In fact, there exist more drivers than the cumulated number, which influence the decline of the curve, i.e. the learning rate.[15] The learning rate is shaped by the form of qualification.

A standard qualification process for workers in assembly is the Four-Step-Model according to REFA (see figure 2). As the name of the model reveals, it consists of the four modules.
preparation, demonstration, execution and completion. The preparation takes place before the real qualification process starts. It is implemented to give the new worker an idea of his work environment, to get in contact with colleagues and to get to know the designated workplace. As the preparation is a general introduction into the work environment, it is not considered part of the actual qualification process, because it does not contain the preparation for a specific work package. The preparation is followed by the second step, the demonstration. Work tasks are shown at least once, before the worker can carry them out by himself. After that, the worker begins with the execution of single tasks of the work package under the supervision of the trainer. Successively, he will learn to execute the whole work package, which leads to the fourth step. The completion covers the time span between the capability of executing all work tasks and his complete autonomy. The worker is completely qualified when he has gained full control over the process, i.e. when he can assemble correctly by adhering to the takt time. Comparing the four channels for information processing mentioned above with the Four-Step-Model, it shows that the demonstration stresses observable and verbal learning, execution and completion include an emphasized active learning. The mental channel is only used consistently, if a worker is motivated and actively thinks the process through. An unmotivated worker will not retrace the work package in his mind, e.g. after the execution, but rely on what the instructor tells or shows him.

Fig. 2 Four-Step-Model according to REFA

The described training method has a stiff framework and order that is adhered to. For vast assembly tasks in the low-volume context this stiffness is likely to cause a lag in the pace of learning, due to the size and complexity of work contents. This derives from the premise for this training system is that the work task has short cycle times and has very simple sequence structure.[6] Hence, an extension of existing training methods is missing to qualify workers with a high flexibility and efficiency under the actual circumstances in the low volume production systems.

2.3. Gamification Approach

Previously, it was underlined that training systems must be extended for their enhancement. As the title of this paper already mentions, Gamification is the depicted approach to aim for a higher motivation, more flexibility and a higher efficiency. According to a definition by DETERDING, Gamification is “the use of game design elements in a non-game context”.[16] That means that not only games themselves, but also single game elements may serve for the purpose to gamify non-game contexts. These game elements are mentioned in table 1 below.

<table>
<thead>
<tr>
<th>Game Elements</th>
<th>System</th>
<th>Challenge</th>
<th>Interactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Players</td>
<td>Rules</td>
<td>Feedback</td>
<td></td>
</tr>
<tr>
<td>Abstraction</td>
<td>Emotional Reaction</td>
<td>Quantifiable Outcome</td>
<td></td>
</tr>
</tbody>
</table>

Thus, a game is a system (see Table 1), players have to master challenges in an abstract environment by interacting with it and adhering to specific rules. Hereby, a quantifiable result gathers an emotional reaction by its resonance. DETERDING[18] names this form of interaction skill atom. By formalising the central elements of game, the skill atom is the smallest unit which cannot be separated without losing the game character. Another trait of a game’s character is the pull principle, which attracts a potential player at first sight. Moreover, once playing, the player has got the motivation to continue playing until the end of the game. To deploy the pull principle, two prerequisites have to be fulfilled. It has to obvious what the player’s objectives in the game are and it has to be easy to survey, how these objectives can be achieved. Nevertheless, the pull principle is a subjective perception and is dependent of the player’s preferences and game experiences. [19]

CUGUN and ALFRINK [20] have published a method for the development of Gamification applications. This method divides the Gamification Development Process into three steps. The conception is the initial step to analyze the problem and to work out the rough concept. The playtesting is a repetitive step thereafter to develop a prototype as well as to alter and upgrade it by a hands-on process. The delivery then marks the moment when the application is used in its designated environment for the first time.

3. Purpose

The research objective is to enhance the training strategy for workers in low volume assembly systems by implementing the Gamification Approach. The desired outcome is that workers are qualified more efficiently regarding the necessary qualification time span and being more flexible on product and process changes within the ramp-up. Hence, the goal is to increase the learning rate. The worker’s individual learning curve and learning rate, respectively, are influenced by several intrinsic and extrinsic factors. Three of them, the monotony, influence of breaks and the intrinsic motivation will be scrutinized in this context. Monotony causes a mental fatigue which slows down the learning process. In general, oblivion is an effect that emerges after breaks. It can be described as “retrogression alongside the learning curve”[14]. Moreover, the learning curve decreases with a high learning rate, which is directly influenced by the worker’s motivation. The more motivated
person will learn the working content much faster than a person with less motivation. The objective is to erase the negatives and to use the positive effects to strengthen the performance of the qualification system. The Four-Step-Model introduced above does not use specific methods to achieve a higher performance by considering these effects.[12, 14, 21]

Before developing methods to enhance the training strategy, it is useful to detail the research objective. This objective can be divided into two dimensions. The primary goal in this context is to maximize productivity. In a qualification process, this means to accelerate the productivity increase. Figure 3 represents a schematic graph for the production capacity over time. There is a time lag of the productivity development in reality compared to an ideal curve which would emerge in an optimized learning environment.

![Fig. 3 Target of a Fast Productivity Increase](image)

The second dimension considers the workers themselves. They are, in fact, the customers of a qualification system. This is why the support of their intrinsic motivation is crucial to enhancing the qualification system. Specifically, it is a challenge to combine the learning with the inherent motivational state, the intrinsic motivation.[22]

4. Methodology

The methodology is divided into two parts. For an enhanced application of the Gamification Approach into the work flow, the conservative four step qualification is scrutinized to discover its weaknesses, see chapter 4.1. After identifying weaknesses, it is described in chapter 4.2, how Gamification elements serve to eliminate those.

4.1. Integrating Gamification into the Qualification System

For the practicability of Gamification in the qualification process, not only its purpose must be determined, but it must also adhere to cost efficiency. Gamification is not to qualify the worker in all aspects including sensorimotoric skills. It is thought to be an additional tool to enhance the learning rate. Hence, there are other capabilities, which must be learned in the same period to be fully qualified. As pointed out in chapter 2.2, the qualification step preparation does not belong to the learning process technically. It is obvious that the mental channel – i.e. the mental and imaginary prosecution of assembly tasks – is not used consistently (cf. chapter 2.2). This means that no qualification step emphasizes the mental dimension of learning. Hence, the demand for Gamification with its suitability to activate the mental channel is to close this gap by adding it to the qualification model. A possible placement of Gamification in the model is given in figure 4. This illustration integrates the concept of Gamification into the course of the Four-Step-Model. It is shown that all channels for information processing are addressed. In consequence, the model is enlarged to a Five-Step-model.

![Fig. 4 Alignment Step-Models and Information Processing](image)

As the objective of integrating the Gamification Approach into the training process is fulfilled, the model now contains five steps and addresses all channels for information processing.

Furthermore, it is aspired to make the step model more flexible. Up to this point, the order of modules in the step model was preset like shown in figure 4. If steps two to four in figure 4 are separated from the rest, one can recognize that these modules already cover every channel for information processing. Additionally it has to be taken into account that different learning types exist. In this context this means that a person has got preferences regarding the channels of information processing and does not learn with equal effectiveness by using any of the channels. A repetitive process of the three modules (Demonstration, Gamification and Execution) can be established by extracting these. This extracted process sequence can be considered as a modular circle. Thus, the order of the modules can vary and the emphasis can be adjusted to the individual learning type. This is an individual adjustment with which the qualification system gains more flexibility.

4.2. Deployment of the Gamification Approach in Low-Volume Assembly System

As it has been outlined before, a Gamification Approach can be integrated into an existing qualification system. It has to be determined in which form Gamification methods achieve the cognitive training of workers.

During the learning process a change and enrichment of association with regard to the learned matter is taking place.[23] To fulfill work tasks, the worker has to have the cognitive association with mainly three things: necessary tools, assembled parts and the sequence, in which the first two are used. These elements can be put into hierarchy, with tools and parts being a subsystem of the assembly sequence...
Gamification by adjusting the player’s mode to a game that can be played by more than one player.[14, 21]

5. Application

One of the research motives was to find enhancements for qualification systems which are applicable in the assembly environment. So, the application took place at a low-volume assembly system of a car manufacturer in Germany. The product is characterized by a completely new structure, a new developed hybrid power train and the mix of not only different, but also new materials. In consequence, during the ramp-up phase the challenges and complexities exceed those of average ramp-ups of new product generations. In addition, the worker has to cope with vast work packages within a takt time of approximately 30 minutes and a high complexity level.

The developed Gamification Application is called “Sequence Poker”. The method by CUGUN and ALFINK presented in chapter 2.3 was used. Its play board and equipment are shown in figure 6. The play board contains a numerated box for every assembly task. For every box, there is a card containing an assembly task. The number in the box represents the position of the corresponding card in the assembly sequence. Moreover, the equipment consists of a cube and points. The game can be played in a group together or in a challenge against each other. Playing in a group avoids the danger of diminishing the cohesion. A neutral player, called “bank”, is needed as well. In the beginning every player or group gets points as a stock. The game starts with one player who throws the dice and the thrown number determines how many cards are outlaid randomly by the bank. At this point, all the players or all groups of players need to decide whether the cards are in the right position and sequence or not. Additionally, they bet points on their decision. If the decision was correct, they get double of the bet points back, otherwise they lose their points. The goal is to reach a predetermined amount of points.

A Gamification Application has to be perceived as a game and not as a different type of process documentation, which has to be learned by the worker. This is why the increase of intrinsic motivation and the potential to accelerate the qualification process have to be proven in trials to assure a practical feasibility. The motivation can be proven by playing
the game with employees. This type of trial was accomplished to define and change rules as well as to see if the game is suitable to train workers. Two game prototypes have been used in this case with the sequences of the door and the cockpit preassembly. Employees from the door preassembly area participated in these trials. They played the known sequence from their workplace and learned the sequence for the cockpit playing the Sequence Poker for half an hour. In the end, they made no mistake concerning the placement of work tasks to their assigned field. One key advantage of the game is that it idealizes the content of a 30 minute assembly sequence to a play board, so that the whole work package can be captured in a simple manner. Besides, in every round not only one player is active, but all of the players participate to decide, which work task is assigned to which number in the sequence. Thus, learning the sequence happens steadily during the game.

An indicator of economic efficiency can be delivered by a comparison of the performance of the conventional qualification method and the designed Gamification Application. Therefore a trial process was developed with two types of trials. The first trial contained the stations demonstration, execution and a test, the second one demonstration, a gamification run and another test. The trial objects have been a LEGO racecar and a lorry, which consists of the same parts, i.e. their assembly has an equal level of complexity. But their sequence is totally different with 18 and 20 process steps, respectively. The time for execution and gamification run was limited to ten minutes each. The test enclosed the task to bring the learned assembly tasks into the right order. Finally, these two test variants have been analyzed and their relative correctness has been compared. The analysis has been done in two different ways. First of all, the number of correct answers was compared. Therefore, the answers must have the right sequence and position in the test. Then, in a second step, correct answers were counted upon the premise that answers are correct if two or more answers are in the right order, independent of their position. Both types of the analysis of results show very similar outcomes.

6. Results and Discussion

The result for the first test (conservative training) was an average 7.46 right answers of 18 process steps. The second test (gamification run) showed 8.55 right answers in average. This is a test advantage for the gamified trial of 13%. Yet, this result bases on a number of 22 persons, i.e. 44 entities. The results are summarized in table 2.

<table>
<thead>
<tr>
<th>Description</th>
<th>Racecar</th>
<th>Lorry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Process Steps</td>
<td>Nₚ = 18</td>
<td>Nₜ = 20</td>
</tr>
<tr>
<td>Average of Right Test Answers</td>
<td>rₚ = 7.46</td>
<td>rₜ = 8.55</td>
</tr>
<tr>
<td>Difference of Right Answers</td>
<td>Δ = rₜ-rₚ = 8.55-7.46 = 1.09</td>
<td></td>
</tr>
<tr>
<td>Quotient</td>
<td>Δ/ max( rₚ,rₜ) = Δ/rₜ = 1.09/8.55 = 0.13 = 13%</td>
<td></td>
</tr>
</tbody>
</table>

Even if the sample data have no statistical relevance, they are an indicator that Gamification has a positive impact on the qualification process. With regard to the trials, the higher number of right answers in the gamification run shows that this type of training could increase the efficiency of the qualification process. However, the conception of the trials allows the presumption that the effect of Gamification in the real assembly environment could be even bigger than the result from the trials. Hence, Gamification not only serves the individual learning, but also the organizational learning due to its playing mode in a group. Furthermore, the feedback by the workers was that the game is fun. They were surprised that a game can support them by learning the sequence of their work packages.

In consequence, implementing the Gamification Approach in the training process in assembly systems can make a contribution to reduce ramp-up time and costs and therefore increase ramp-up performance. But there are still some open issues. Even if positive effects could be shown, the gained results have to be verified by further trials, preferably in other companies and industries. In addition, a significant invest has been necessary in order to implement the gamification approach. A monetary assessment hasn’t been accomplished in order to prove the positive effect on ramp-up performance. The whole potential of the approach can be unlocked by implementing further elements in the game beside the sequence like resources and detail process information. Furthermore, the applied game elements can be digitalized in order to reduce the effort for implementing and adjusting. Therefore further research is needed.

7. Summary and Conclusion

The importance of low volume production systems grows. These systems are regularly characterized by complex production processes and high work content for the employees. Training the employees is one of the most important and cost-intensive processes in ramp-up. The Four-Step-Model, which is used by industrial companies since decades, can be extended by the implementation of Gamification elements. A new Five-Step-Model has been developed. Furthermore the effect of implementing the Gamification Approach has been tested within the ramp-up of a low volume assembly system in cooperation with a German car manufacturer. The application shows that implementing the Gamification Approach in qualification processes can reduce the qualification time and increase the productivity and therefore reduce the ramp-up costs and increase ramp-up performance, but further research is needed.

Even if the first industrial application has been completed, there is a need to extend the trials in order to verify the gained results. The use of Gamification elements can be reasonable in requalification processes, too. At least, there is a huge potential for extending the implementation of the approach to other processes in industrial companies. For instance, the authors are working on implementing the Gamification Approach in management processes.
Acknowledgement

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