MM Science Journal | www.mmscience.eu
ISSN 1803-1269 (Print) | ISSN 1805-0476 (Online)
**Special Issue | HSM 2021**
**16th International Conference on High Speed Machining**
October 26-27, 2021, Darmstadt, Germany
DOI: 10.17973/MMSJ.2021_11_2021172

**HSM2021-2021172**

# USING GAMIFICATION ON THE SHOP FLOOR FOR PROCESS OPTIMIZATION IN MACHINING PRODUCTION

M. Dewald[1*], O. Kohn[4], Y. Dehorn[1], H. Howaldt[1], A. Ebben[2], N. Kratzke[3], F. Janssen[1], M. Weigold[4]

[1]Siemens Energy, Industrial Application, Turbo Machinery, Wolfgang-Reuter-Platz 4, 47053 Duisburg, Germany

[2]Siemens Energy, Generation, Large Rotating Equipment, Rheinstraße 100, 45478 Mülheim an der Ruhr, Germany

[3]Siemens AG, Digital Industries, Center of Competence, Machine Tool Systems, Postfach 30 11 66, 50781 Köln, Germany

[4]Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt, Otto-Berndt-Straße 2, 64287 Darmstadt

*Corresponding author; e-mail: mario.dewald@siemens.com

**Abstract**

The optimization of production processes is even in 2021 still an up-to-date topic, where the use of data is discussed, and the utilization has proven to be effective in specific applications in the last 10 years. Despite increasing access to information directly from the production process and more available computing resources, the data still holds unused potential.

Even ongoing digitalization does not replace a deep understanding of the underlying processes and a focus on online automation misses the potential including expertise of shop floor employees. Thus, besides automation and data-driven improvements it is important to support employees with innovative methods to exploit the full potential of the Internet of Things. Principles of gamification offer an opportunity to incorporate the shop floor personnel, to take their full attention on optimization of the process supporting them in their day-to-day job. Appropriate visualization creates incentives for continuous process optimization.

**Keywords:**

Process optimization; Internet of Things; Machine Tools, Gamification

## 1 INTRODUCTION

Digitalization brings a fundamental transformation in the industrial environment and influences the operational organization of businesses, as well as the production process. For successful operation on the global market, producing companies must face the challenges and take the opportunities arising from the change. Networks of flexible production technologies provide essential information along the value chains in real time, which enable direct exchange of information across companies for optimal organization and control of production capacity based on demands. Another recent trend is the increasing demand of varying customer requirements leading to greater individualization of products, which aim for greater flexibility besides the ongoing optimization of manufacturing costs.

The acquisition of information directly from the production process enables technical and organizational process optimization and thus helps to increase the efficiency of cutting operations reducing waste of unused resources. But the optimization of cutting processes requires expert knowledge and a high invest of time and effort. Compared to a highly automated series production, the optimization is not so efficient in a single-part production environment due to the high manual effort for a small number of workpieces. Therefore, unused data from the production process still holds high potential and can be used to reduce the manual effort.

A systematic and continuous analysis of the information from the cutting process reduces the effort to choose the best cutting parameters and helps machine operators or process engineers to get a better insight. An extrapolation shows the impact of cutting parameters on lead time and production costs. In the end a human expert takes responsibility for actions to iteratively improve the productivity parallel to the production process. Therefore it is necessary to provide tools reflecting the impact of actions on the overall production process to enable fact-based decisions and thus a cost optimized production processes.

## 2 STATE OF THE ART

The computerized numerical control (CNC) of machine tools combines the relevant data about the cutting process and its components like the workpiece and the cutting tool for example. The industrial internet of things (IIOT) increases the availability of information from different sources and provides not only descriptive data about the cutting process and its components, but also historical data. In a connected production environment various devices communicate with each other to set process information into the right context for an overall optimization. Wellmann describes an approach for a context-adaptive productivity increase of NC cutting processes taking into account the huge amount of data along the entire value chain [Wellmann 2019].

In such a human-centered production environment data processing and visualization is required supporting employees on the shop floor to make fast decisions based on insights from data analysis. For a successful implementation of an IIOT application besides the technical preparation of data from the process, the visualization of required information and the design is a crucial element. An increasing trend is the usage of Gamification not only in the internet of things, but also in industrial use cases [Alla 2019]. Gamification can be defined as "the use of game design elements in non-game contexts" [Deterding 2011]. The aim is to engage the user with a gameful design and interaction from typical game design elements.

Different levels of game design elements are described in *Tab. 1* such as game interface design patterns, mechanics, principles, models and methods. In [Hambach 2017] gamification elements like progress and status bars are suggested to support the philosophy of the continuous improvement (CI) process aiming to improve process performance whilst increasing employees' competencies at the same time.

*Tab. 1: Levels and descriptions of game design [*Deterding 2011*]*

| Level | Description |
|---|---|
| Game interface design pattern | Common successful interaction design components and design solutions for a known problem in a context, including prototypical implementations |
| Game design patterns and mechanics | Commonly recurring parts of the design of a game that concern gameplay |
| Game design principles and heuristics | Evaluative guidelines to approach a design problem or analyze a given design solution |
| Game models | Conceptual models of the components of games or game experience |
| Game design methods | Game design-specific practices and processes |

## 3 CONCEPTS FOR COMBINING GAMIFICATION AND INDUSTRIAL IOT APPLICATIONS

### 3.1 Game mechanics

Especially the idea of using gameful designs as a facilitator of motivation and creativity which incorporates shop floor personnel in the development of sophisticated production processes is underutilized today. Embedding the in Tab. 2 described game mechanics can cause enthusiasm and enjoyment, so that the shop floor personal is affected on an emotional level. A scoring game or social points not only give immediate feedback about the impact of actions regarding the productivity of the machining process, but also support improving transparency and setting clear goals. Leaderboards based on this should aim to support positive competition, sharing the best results between machine operators. Harmful competition between individuals leading to decline in productivity should be avoided, for example by rewarding performances of teams instead of individual performances.

*Tab. 2: Common game mechanics [Scheiner 2013]*

| Proposition | Common game mechanics |
|---|---|
| 1 | Game points may support immediate feedback, clear goal, perceived behavioral control, equality, competition and affect |
| 2 | Social points may support immediate feedback, social belonging, competition, clear goal, unlearning and equality |
| 3 | Redeemable points may support autonomy |
| 4 | Levels may support optimal challenge, competition and perceived behavioral control |
| 5 | Leaderboards may support competition and perceived behavioral control |
| 6 | Story may support the elements clear goal, divergent thinking, unlearning, social belonging, and affect |
| 7 | Virtual identities may support affect, equality and perceived behavioral control |
| 8 | Exchanges may support the feeling of social belonging, divergent thinking and unlearning |
| 9 | Collecting may support competition and social belonging |

The gaining of points when a valued activity is conducted will help to keep the focus on the value adding activities and therewith decrease costs of the process.

### 3.2 Performance comparison with concept of a Ghost

Ulmer. et al. presented a sophisticated system to support an easy to do assembly job by the means of gamification [Ulmer 2020]. By using game mechanics supporting intermediate feedback, the worker is forced to compare his or her doing with its own historic performance and from that self-control and personal decision making for processual beneficial adjustments can be derived. The developed process specific key performance indicator (KPI) can either focus on a particular player or on team performance. The concept of a ghost as a comparison to a previous performance is well-known from different existing games. Probably the most famous is one the ghost driver in the Mario Kart series from Nintendo, where a semi-transparent character shows the record of a player's driving performance, see Fig. *1*. This is the idea of visualization of existing information based on already proceeded tasks comparable to the ongoing process. The concept is commonly used in modern game play. Especially with sophisticated graphics and design the ghost concept has reached a high standard with different levels of utilization.


*Fig. 1: Concept of a ghost driver in Mario Kart 8 deluxe by Nintendo*

## 3.3 Conceptualization of gamification in an industrial environment

This section describes a general approach for the conceptualization and implementation of gamification in an industrial environment. Before starting the conceptualization, it is important to outline the use case with domain experts and target users. As soon as the use case for an application has been identified, the design and implementation of the solution is required. This design and implementation process is done using a five-step approach as in *Fig. 2*. The phases are not bound to a strict sequential order. In some cases, it may be helpful to look ahead and start the next phase in parallel or even take a step back and redefine requirements.

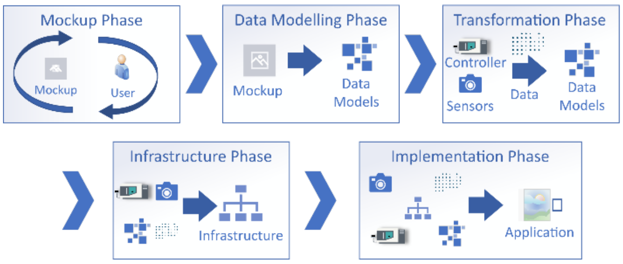


*Fig. 2: Process for design and implementation*

The first step is the *Mockup Phase* to design the desired output, which is in this case the visualization of a “ghost”. During the *Mockup Phase* a wire frame is created and discussed with the target group of the application. In an iterative process the mockup is finalized so that on the one hand the visualization meets the requirements of the use case and on the other hand satisfies the user’s needs. To reach the target group on the shop floor in a human centered production a fast and easy understanding is essential. This can be supported by

- using well known visualization elements like tools and product icons for easy identification,
- using level or completion bars for fast and easy understanding of the “ghost”,
- a clear description of the purpose for a broad acceptance on the shop floor,
- and a transparent calculation of the results to increase reliance.

The result of the mockup is to show the impact of the decisions on the shop floor regarding productivity and costs. Thus, the created transparency allows to optimize cutting parameters for the machining process.

Once the mockup is finalized, the second step is the *Data Modelling Phase* to define the data models based on the desired visualization. The simple data model consists of the current product information, the estimated progress and the ghost from the historical progress.

The third step is the *Transformation Phase* deriving the required data sources and data transformations from the previous phases to make the information available for the data model. This step is responsible for evaluating the available data sources and abstracting the data to match the Data Model. The data sources can be identified into their chronological sequence:

- Simulation data of the process (Process preparation phase)
- Planning data (Process preparation phase)
- Real time machine data (Process phase)
- Human feedback (Process phase)

The *Transformation Phase* uses a flow-based approach to calculate the data model of an application. With this approach the raw data from different sources will be enriched with additional information in each processing layer until all the required information for the data model is available. The KPIs and the Estimated Arrival Time (ETA) is calculated with a multilayer distributed filter pipeline to combine all information to desired output, see *Fig. 3*. In the *1. Layer* checkpoints in process are detected and the performance KPIs for the lap-checkpoint calculated. In the *2. Layer* the laps in the process are detected and the lap performance is calculated based on checkpoint KPIs. In the third or *n$^{th}$ Layer* the estimation is calculated based on recent checkpoints or laps for the next ones. The comparison of the current and estimated performance against the “best performance” is processed in the erfordlast layer.

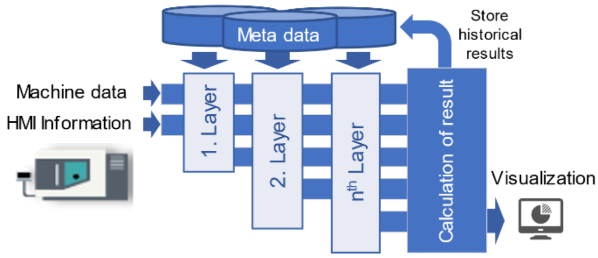


*Fig. 3: Concept for data processing layer*

In the fourth step, the *Infrastructure Phase*, the required IT infrastructure based on requirements of preceding phases is defined. These requirements contain the desired runtime, required disk space, computing power, network throughput, latency and the needed physical connections to IT systems (ERP, MES), machines and sensors. Due to the real-time requirements of the estimated progress, it is essential to gather live data from the machine, the HMI and the shop floor environment. Furthermore, calculating the estimated progress requires sufficient computing capacity combining information from planning and simulation systems as well as machine data and information from legacy IT systems.

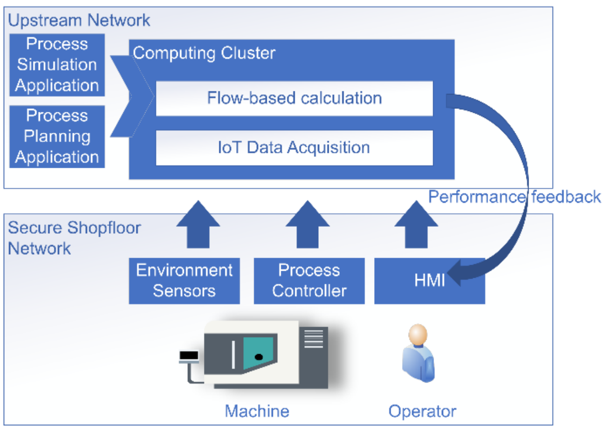


*Fig. 4: Overview of the required infrastructure*

The last step is the implementation of the required components like the physical connectivity, the IT infrastructure, the data transformation and the application in the working environment.

When applying a concept which originated from fully simulated environments like racing simulations for example to the real world, it is essential to gather as much data about the process in the real world as possible. The reason being, in a fully simulated environment the creator of the simulation is controlling the physics and behavior of every aspect and is therefore an all-knowing-being. Whereas in the real world, the laws of physics influence the process, and the machine controller coordinates the process. Since the goal is the perfect estimation or prediction of a process, it is required to gather the influence of physics with additional sensors and get as much information as possible from the machine controller to get as close as possible to the all-knowing-being from a computer game. Furthermore, data from ERP, MES, history databases and preceding simulations is required to calculate the best possible estimation.

## 4 DEVELOPMENT OF A PROTOTYPE FOR MACHING PRODUCTION

### 4.1 Conditions on the shop floor

The central component of a centrifugal compressor is the rotor, which is used to generate the kinetic energy required for the compression process. The core components of the rotor of a single-shaft or gear compressor are impellers, which draw in the medium to be compressed axially and discharge it at an accelerated radial speed. The impeller consists of a hub and regularly spaced blades, which form a diffuser in the space between them (cavity).

Based on the different operating scenarios nearly none of the produced impellers with a diameter more than 1000 mm has the same shape and geometry than the previous one. But characterized by its recurring geometric elements, the component itself offers good comparability of the manufacturing process sequences in the cavities. Milling takes most of the mechanical machining of an impeller at Siemens Energy AG Duisburg (in the following called Duisburg). From the large machining share of 60 % between the blank and the finished part, the great potential for optimizing machining time and component costs through improvements in the milling process can be derived. In the following, the existing setup for milling impellers at the Duisburg location is presented.

In total Duisburg operations produces between 1300 – 1400 impellers per year on 6 different machine tools. The size is varying from 150 mm up to 2000 mm in diameter. Milling of the impellers takes place in several machining operations. Within a machining operation, the tool vector orientation and cutting tools do not change. Roughing is performed in three axes with the vector set. Warpage is to be avoided by uniform material removal by first machining one machining operation (vector n) in all cavities before starting the next machining operation (vector n+1).

Approximately 30 - 45 impellers per year with a diameter between 1 m and 2 m and a blank weight of up to 12 t are produced at the machine tool Trimill HC2520. This 5-axis machining center, based on a gantry design with a high-frequency spindle for heavy-duty machining is equipped with a Sinumerik 840d sl. The machine controller is connected to a Brownfield Connectivity (BFC) Gateway which provides internal machine data with a sampling rate of 200 - 500 ms. To validate results and investigate requirements, the Siemens Industrial Edge is used reaching sampling rates up to 500 Hz.

Roughing is performed using a high-feed cutter with a diameter of 66 mm and a length of up to 400 mm (see Fig. ***5***). Any occurring vibrations have to be avoided by using a vibration damped extension. Quality requirements and inspection criteria of the whole roughing process are not affected by the gamification approach. The challenging cutting conditions lead to a wide range of wear types and tool life differences up to 400 %. Especially the variety of tool life from vector to vector is extremely challenging for an industrial process. Shop floor personnel is always confronted with difficult and fluctuating process situations based on vibration and wear. All together this leads to an annual consumption of approximately 50 kg of carbide inserts on one machine tool. The presented gamification approach does not reflect the tool wear itself as a technological measure. The aim is to make the impact of human behavior on the machining costs more transparent based on machine data.

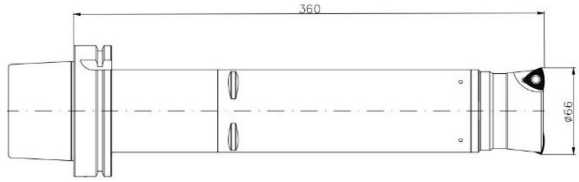


*Fig. 5: High Feed Tool with 4 inserts with 3 cutting edges*

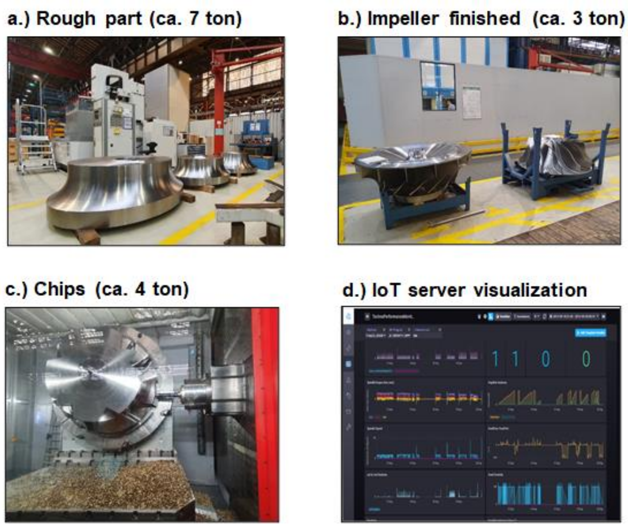


*Fig. 6: Machine and IoT set up in the area of impeller production*

*Fig. 6* shows the current machine and IIoT set up in the area of impeller production. From the blank workpiece in a.) to the finished workpiece in b.) approximately 4 tons of material have to be removed as shown in c.). Even though an IoT-Server provides dashboards as in d.) only visualizing the historical machine data without any further analysis or complex algorithms evaluating the data, the additional information gets more and more attention on the shop floor. A simple visual preparation of the machine data enables additional insights and a deeper process understanding for the machine operator and improves the discussions between operators and supervisors based on historical data.

Information from NC programs help to handle the huge amount of data from the machine controller. Especially for repeating geometric elements like cavities the information from the NC program can be used to structure and filter the relevant data. The recurring geometric elements and the different vectors need to have a sophisticated 3+2 axis roughing process. 13 cavities and 2 of the up to 7 different vectors which are adjusted for having an effective roughing process are shown in *Fig. 7*.

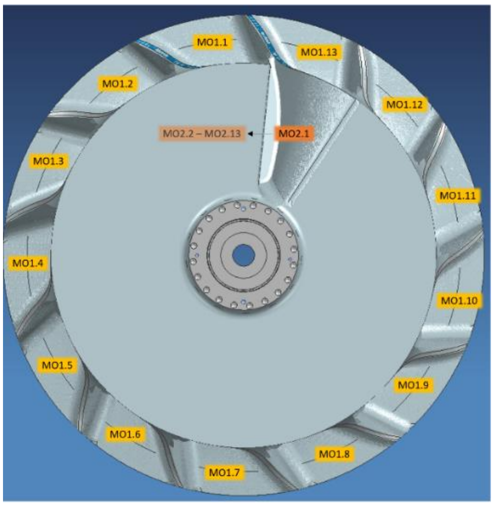


*Fig. 7: Granularization of work sequences in 13 cavities and 7 vectors*

The cavities and the vectors all together lead to a granular number of 91 different specific comprehensible tasks which produce a real time increment. Based on these increments a lot of the data provided from the machine has to be filtered and machine operators have to document every cutting tool insert change with an own developed web application which is integrated in the HMI of the machine. The visualization based on the extrapolated runtime compared to the already done number of NC-programs has been named "**Remaining time monitor**".

The usability and the simplicity of the developed concept, see *Fig. 8*, is the main achievement. Workers are always able to see their own process situation compared to a "best practice ghost" which has been calculated based on the most effective way of work in the past.

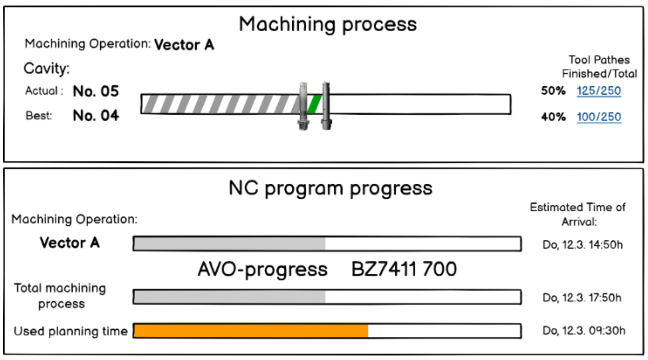


*Fig. 8: Remaining time monitor*

The pure win of such a concept is transparency and simplification. Everybody can follow his best practice way of work and after different users have done their best, the system has a comparable amount of data which can be easily post processed and analyzed due to the most effective way of work. Because of incorporating each performed machining process, every individual has the feeling, that he or she helped gathering the result. This even becomes more tangible, when presenting not only cutting times and number of inserts used, but accumulated costs as shown in *Fig. 9*.

| Cavity | Time (min) | Insert Changes | Process costs (€) | Vf (mm/min) | S (rpm) |
|---|---|---|---|---|---|
| 1 | 13:30 | 2 | 55 | 5000 | 800 |
| 2 | 12:20 | 3 | 65 | 5400 | 1000 |
| 3 | 12:35 | 2 | 51 | 5300 | 900 |
| 4 | 12:20 | 2 | 48 | 5400 | 800 |
| 5 | | | | 5500 | 900 |
| 6 | | | | | |
| SUM | 50:45 | 11 | 219 | | |

*Fig. 9: Accumulated costs for machining time and used inserts*

In all circumstances is recommended to start with visualization of the machine data in real-time first to make the shop floor personnel confident with data and visualization in their day-to-day work environment. Second, incorporate each peer group around the process for co-creating the right KPIs like the volume of machined material or the cutting time for example.

A patent application has been made to the European Patent Office (EPA) under the number 20167182.3 for the content described.

### 4.2 Potential for process optimization

The potential for ratio and cost savings are strongly attached to the branches and the type of business. Most effective results will come in lot size one conditions. In engineer to order (ETO) business you will find inhomogeneous materials, since every rough part can be supplied by different suppliers. Timeslots between similar parts and geometry can be relatively long, so that it is difficult to compare cutting processes based on own experiences. With that in mind it is assumed that the presented supporting system will have a strong impact on cost level.

## 5 BUSINESS POTENTIAL OF GAMIFICATION

To analyze the sensitivity of combining IIoT and gamification in a financial context it is important to define relevant parameters. With the aspiration to raise the productivity of the cutting process by using gamification, the metal removal rate (MRR) in removed volume per time is the distinction from other definitions of productivity.

This definition of productivity is expedient because of the coherence of the parameters feed $v_f$, cutting speed $v_c$, cutting depth $a_p$, and cutting width $a_e$, as in [Klocke 2008], which are part of the collected data. Since cutting parameters have a direct impact on the tool life and thus on the number of tool changes, the required time as well as the number of tool changes have to be considered in the KPI for the productivity in the presented use case. To consider tool changes, the MRR can be extended taking into account the number of tool changes $n_{ToolChange}$ and tool change time $t_{ToolChange}$ as the Net Chip Rate $Q_{Basis}$ in (1).

$$Q_{Basis} = \frac{volume}{t + t_{ToolChange} \times n_{ToolChange}} \qquad (1)$$

*Fig. 10* shows $Q_{Basis}$ affected by $f(v_c, v_f, a_e, a_p)$ and the problem of optimization in general.

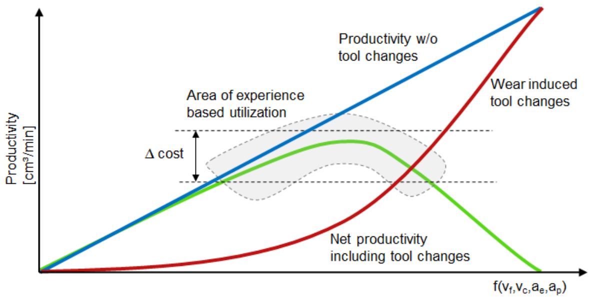


*Fig. 10: Optimization problem: Productivity loss based on tool changes*

Furthermore, the analysis of the productivity by considering $Q_{Basis}$ is convenient because the volume per time ratio is an integrated part of the Overall Equipment Effectiveness (OEE). The sensitivity of productivity increase trough a gamification approach can be evaluated by the comparison of the volume per time ratio with and without gamification support. But it should be noted that process parameter $a_p$ has a significant impact on $Q_{Basis}$. Because $a_p$ depends on the geometry of the blank and finished workpiece, it is defined in the NC program and can not always be changed during the milling process. The result is a missing consideration in the current gamification approach which compares the target with the actual process time in the visualization. Therefore *Fig. 11* visualizes the optimization problem showing the impact on the Net Chip Rate $Q_{Basis}$ for the parameters cutting speed and feed rate.

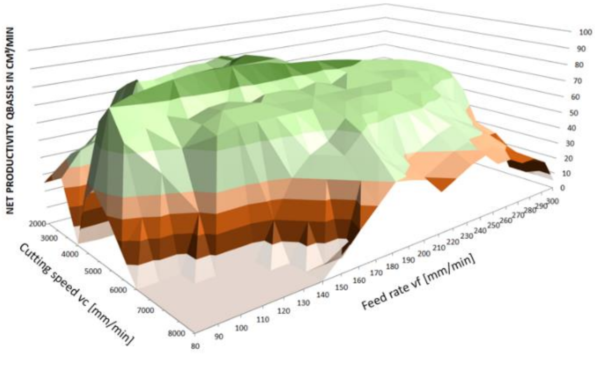


*Fig. 11: Visualization of the net chip rate depending on cutting speed and feed rate*

This leads to the question where gamification has a major impact on productivity. A simulation with a multidimensional approach as starting point might be also suitable for a combination with a gamification approach. The complexity can be reduced afterwards by transferring the multidimensional problem into a one-dimensional virtual time problem where the parameters feed and cutting rate are the control elements.

This approach allows using the machine data in different workflows to scale up the productivity impact. On the one hand to improve the NC program and on the other to improve the cutting process itself.

## 6 SUMMARY AND FUTURE RESEARCH

This paper summarizes ideas for using gamification in modern industry environments, gives instructions and guidelines for sophisticated development steps and shows a developed prototype application in a specific ETO production process. The presented work demonstrates the preparation for research about applicability and furthermore effectiveness of such complex supporting systems. Next step of this journey is to implement and evaluate the developed prototype in the demo environment compared to the current state of productivity and cost effectiveness. From an engineering perspective it will be difficult to divide between effects of the system itself and social and philosophical effects that come from the embedded need of human participation in this complex and expertise-based environment.

## 7 REFERENCES

[Alla 2019] Alla, A., Nafil, K. Gamification in IoT application: a systematic mapping study. Procedia Computer Science, 2019, 151, pp. 455-462.

[Deterding 2011] Deterding, S., Dixon, D., Khaled, R., Nacke, L. From game design elements to gamefulness: defining "gamification". In Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments, 2011, pp. 9-15.

[Hambach 2017] Hambach, J., Kuemmel, K., Metternich. Development of a digital continuous improvement system for production. Poeocedia CIRP, 2017, 63, pp. 330-335.

[Klocke 2008] König, W. Fertigungsverfahren 1: Drehen, Fräsen, Bohren. Springer-Verlag, 2008.

[Scheiner 2013] Scheiner, C. W., Witt, M. The backbone of gamification-a theoretical consideration of play and game mechanics. INFORMATIK 2013–Informatik angepasst an Mensch, Organisation und Umwelt, 2013.

[Ulmer 2019] Ulmer, J., Braun, S., Cheng, C. T., Dowey, S., Wollert, J. Human-centered Gamification framework for manufacturing systems. Procedia CIRP, 2020, 93, pp. 670-675.

[Wellmann 2019] Wellmann, F. Datengetriebene, kontextadaptive Produktivitaetssteigerung von NC-Zerspanprozessen. Aachen : Apprimus Wissenschaftsverlag, 2019.