Hochschule Ostwestfalen-Lippe
University of Applied Sciences

UNIVERSITÀ
DEGLI STUDI DI TRIESTE

Production Engineering and Management

7th International Conference
September 28 and 29, 2017 in Pordenone, Italy

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Production Engineering and Management

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PREFACE

It is our pleasure to introduce the seventh edition of the International Conference on Production Engineering and Management (PEM), an event that is the result of the joint effort of the University of Trieste and the Ostwestfalen-Lippe University of Applied Sciences. The conference has been established as an annual meeting under the Double Degree Master Program “Production Engineering and Management” by the two partner universities. This year the conference is hosted at the university campus in Pordenone.

The main goal of the conference is to offer students, researchers and professionals in Germany, Italy and abroad, an opportunity to meet and exchange information, discuss experience, specific practices and technical solutions for planning, design and management of manufacturing and service systems and processes. As always, the conference is a platform aimed at presenting research projects, introducing young academics to the tradition of symposiums and promoting the exchange of ideas between the industry and the academy.

This year’s special focus is on industry sustainability, which is currently a major topic of discussion among experts and professionals. Sustainability can be considered as a requirement for any modern production processes and systems, and also has to be embedded in the context of Industry 4.0. In fact, the features and problems of Industry 4.0 have been widely discussed in the last editions of the PEM conference, in which efficiency and waste reduction emerged as key factors. The study and development of the connections between future industry and sustainability is therefore critical, as highlighted in the recent “German Sustainable Development Strategy and the 2030 Agenda”. Accordingly, the seventh edition of the PEM conference aims to offer a contribution to the debate.

The conference program includes 25 speeches organized in six sessions. Three are specifically dedicated to “Direct Digital Manufacturing in the context of Industry 4.0” and “Technology and Business for Circular Economy and Sustainable Production”. The other sessions are covering areas of great interest and importance to the participants of the conference, which are related to the main focus: “Innovative Management Techniques and Methodologies”, “Industrial Engineering and Lean Management” and “Wood Processing Technologies and Furniture Production”. The proceedings of the conference include the articles submitted and accepted after a careful double-blind refereeing process.

Elio Padoano *Franz-Josef Villmer*

CONTENT

SESSION C
Direct Digital Manufacturing in the Context of Industry 4.0

SESSION D
Industrial Engineering and Lean Management

SESSION E
Technology and Business for Circular Economy and Sustainable Production

SESSION F
Wood Processing Technologies and Furniture Production

SESSION A
Direct Digital Manufacturing in the Context of Industry 4.0

QUALITY CONTROL OF ADDITIVE MANUFACTURING USING STATISTICAL PREDICTION METHODS

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Abstract
Additive Manufacturing (AM) is increasingly used to design new products. This is possible due to the further development of the AM-processes and materials. The lack of quality assurance of AM built parts is a key technological barrier that prevents manufacturers from adopting. The quality of an additive manufactured part is influenced by more than 50 parameters, which make process control difficult. Current research deals with using real time monitoring of the melt pool as feedback control for laser power. This paper illustrates challenges and opportunities of applying statistical predictive modeling and unsupervised learning to control additive manufacturing. In particular, an approach how to build a feedforward controller will be discussed.

Keywords:
Additive manufacturing, Process control, Predictive modeling, Predictive control

1 INTRODUCTION

Additive Manufacturing (AM) is increasingly used to design new products. This is possible due to the further development of the AM-Processes and materials. The less of assurance of quality of AM built part is a key technological barrier that prevents manufacturers from adopting Am technologies especially for high-value applications where component failure cannot be tolerated [1]. The lack of quality implies inadequate dimensional tolerances, surface roughness, embedded material discontinuities, and defects. Part quality issues may be attributed to AM process parameter settings. The settings are typically chosen by a trial and error process, which is time-consuming. More and more modeling is used to get a deeper understanding of the physics of AM process. Significant effort has been dedicated to the search of predetermined optimal processing conditions which result in desired mechanical properties for a given part. This optimization can be done with commercial modeling packages, mostly based on finite element methods. However, this approach is not economical nor robust enough to deal with perturbations. Uncertainty in the simulation inputs

and simplification of physical phenomena lead to uncertainty in the process parameters and thus the optimization is less beneficial. [2] [3]
Process control in general can limit the lack of quality assurance of AM built parts and the lack of the known variance of optimized process parameter from physical models.

This paper will discuss a new approach to using metamodel technologies to enable process optimization, to improve the AM part quality and to reduce the number of insufficient AM parts. The main goal is to reduce the waste of time and money by either detecting major errors of the AM part in a very early stage and stop the building job or fixing an expected defect during the build process by changing process parameters.

2 STATE OF THE ART

Using additive manufacturing to build a part with certain desired properties such as dimensional accuracy, part density, mechanical properties or microstructures can be challenging for several reasons. First, the number of parameters that have to be determined in an AM process is large. Second, some parameter can vary during the build process. For example, the porosity of powder bed may change depending on the distribution of the powder size particles in a layer. Third, some parameter could vary across builds, for example, if the lens focusing the laser beam gets polluted. Finally some material properties such as the absorptivity cannot be known precisely. In conclusion, these factors introduce uncertainties that influence the repeatability of the process and create uncertainties in the properties of the AM parts [4].

2.1 Process parameters correlation

The view on process parameter correlation follows the ideas of Mani et al. [5]. In an AM process there exist correlations between the process parameters, process signatures and product qualities. The AM process parameters are the inputs, which sometimes determine with uncertainties. The process parameters can be categorized either in controllable such as laser power and scan speed or predefined parameters. For example, material properties are predefined for every build job. The process signatures are dynamic characteristics of the powder heating, melting and solidification processes as they occur during the AM process. They are categorized into either observable that means measurable signatures or derived and determined from analytical modeling or simulation. The product qualities are also grouped in geometric, mechanical and physical qualities. Figure 1 identifies the correlation between the three categories which should facilitate the development of in process sensing and real-time control of AM process.

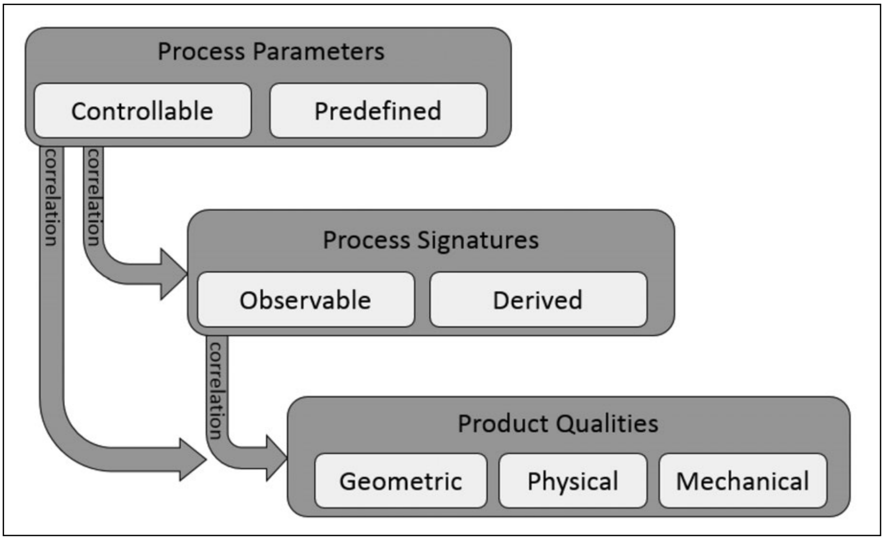

Figure 1: Correlation between process parameters, process signatures and product qualities [5].

Mani et al. identified a large number of process signatures which may potentially be monitored to identify irregularities that might result in poor product quality [5].
The basic idea as given in Figure 1 is categorizing the parameters and identification of their general relationship. This is used as foundation for the described models in chapter 3.

2.2 Computational models

Process signatures that cannot be measured during production, need simulation models for derived parameters like melt pool deep or residual stress. A number of scientific investigations were devoted to the numerical analysis of the thermal processes during laser beam melting. One of the studies was conducted by Ilin et al. [6]. This study focuses on the numerical analysis of the temperature distribution in the vicinity of the melt pool during laser beam melting process depending on the local geometry of the generated part. They use a simulation model to optimize the laser beam melting technique towards a stable formation of the melt pool during the entire generating process.

Commercial simulation tools allow predictions of the temperature during the build process and can therefore be used to forecast the distortion and residual stresses in the AM part. Normally these predictions take not into account the uncertainty of the input parameters or the variability in the process itself.

Running these simulation tools is a preliminary work for the optimization of process parameters like laser power or laser scan speed. It is possible to calculate with these simulations tools several controllable process parameters like the needed laser power, laser scan speed etc. These values can be calculated for every position on every layer. Because of the long computing times, it is not possible to use this kind of technology during the build process to control the process parameter.

2.3 Current control schemes in AM

Process control has been identified as an important tool to overcome the lack of quality and reliability in AM processes. Feedback control allows the intelligent modulation of process parameters following measurements of process signatures. Feedback control approaches for AM are often utilized in directed energy deposition processes. Most approaches are based on thermal signals gathered with cameras and photodetectors. The typically used algorithms are based on proportional-integral derivative (PID) controllers [3] [7]. Sometimes more advanced approaches, like model predictive control (MPC), are used. The feedback control is used with process signatures which are measurable or with derived signatures. A feedforward control is used for tuning the laser cladding melt pool shape online [8].

Adopting feedback control methods in AM is constrained by significant barriers. One is the lack of appropriate models for online estimation and control as well as the high sampling rates required to capture fast solidification dynamics in metal based AM.

3 RESEARCH APPROACH

The use of statistical methods will be useful to handle the process control in AM systems. Normally an AM process, for example, the selective laser melting (SLM) process, depends on about 50 parameters [9]. Some parameters are precisely known, other parameters have a higher variance. To manage the process control with predictive modeling two hypotheses must be valid. First, an effective direction must be existent in the process. This means small defects in layer n lead to errors in future layers n+y. Every AM part is sliced in layers. y is the number of layers that have been built until the known defect at layer n becomes a crucial defect at layer n+y, which in turn damages the AM part (see Figure 2). The second hypothesis implies a different significance of the layers. Not every layer has the same importance for future layers. The previous layer is most important for the following one. Former layers are less important.

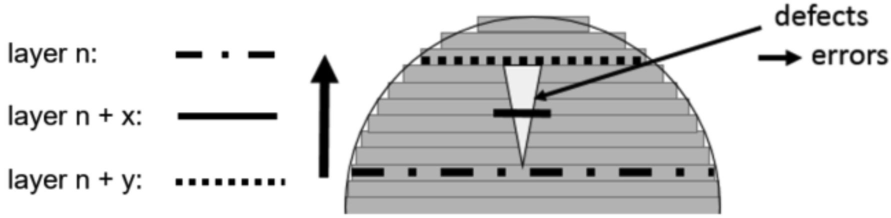

Figure 2: Hypothesis error spread.

A single layer is generated during one laser scan. A layer itself is divided in cubes. Every cube has the height of the layer thickness and the area is the square of the track distance + variance. A cube as defined here may contain more than one voxel. It is important that all dimensions of the cube relate directly to process parameters as illustrated in Figure 3.

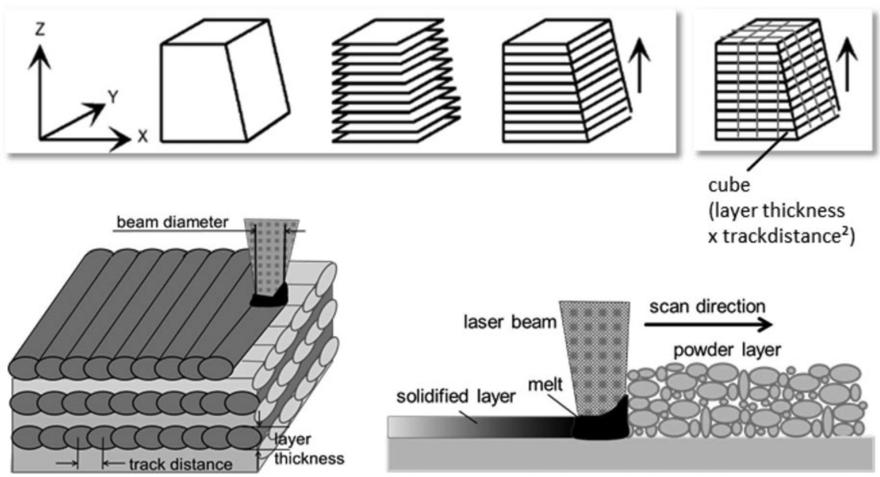

Figure 3: Geometry with cubes, voxel and laser beam.

The basic idea is to detect a situation that will lead to a potential low-quality piece, before the situation itself happens. Practically this means small deviations in layer n lead in summary to a relevant error in layer n+y. After detection of small defects, the parameters might be adjusted in layer n+x to avoid the error in n+y, assuming x is smaller than y. Therefore it is important that calculation time for forecasting errors from the data volume must be shorter than the time for production from layer n until layer n+x.

3.1 Predictive models in general

Predictive modeling is used to estimate an unknown dependency from known input-output data. Input variables might include quantities of different process parameters by a cube. Output variables might include an indication of the level of a cube of whether a defect happens or not. Output variables are also known as targets in predictive modeling.
In deployment, there is likely to be a time gap between using the model that has been developed and carrying out the activity. The analysis period consists of the base period (for the input variables) and the aim or target period (for the target or output variables). The base period always comes before the target period and reflects the time gap between running a model and using the results of the model (Figure 4) [10].

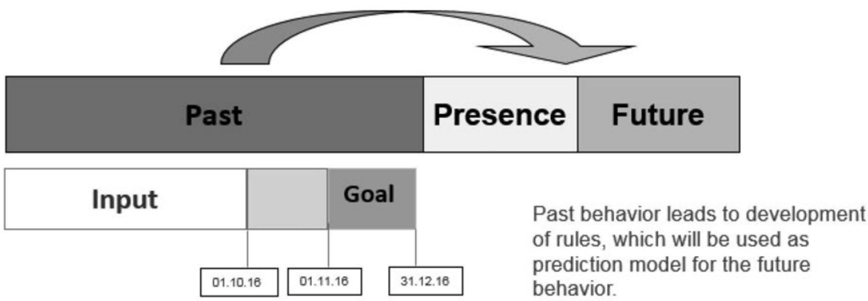

Figure 4: Development of models learning phase.

To visualize how the general set up can be used for AM processes the model learnings phases are added to the research approach.

Depending on former activities, an anticipation of the deployment time gap (y) can be made. Then a temporal mismatch can be added into the modeling data. This is crucial, because input variables such as geometry, laser power or melt pool temperature are generated for every layer until layer n and target variables generated e.g. out of the melt pool temperature are from a later period, say layer n+y. Note that the time period (y) may differ depending on the type of the AM process, AM machine or material.
This temporal mismatch of variables is a major difference to other statistical models and to the above-described state of the art solutions. It is possible that the measurement of some parameter until layer n is used as input

variables and adding the measurements at layer n+y to define the target variable. Besides the temporal shift in the data, the availability of the data also needs to be considered.

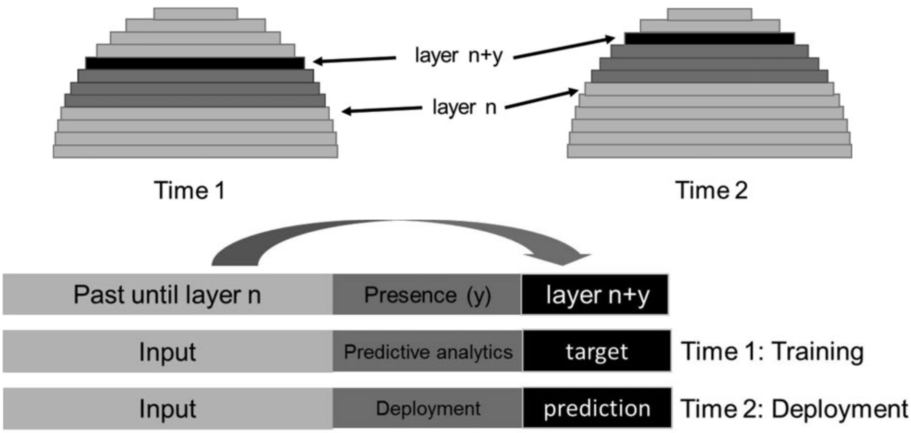

Figure 5: Phases in AM process.

It is to consider that at one point in time (Time 1) the model has to be built, at that time the target must be known. The whole input and target data are given from the past. After the model is validated it will be deployed at time 2 when only input variables are assessable. Within this deployment, a prediction of the target is generated. The prediction in turn gives an answer on the question whether the target is leading to a potential defect or the quality of the AM part is fine. Once the model is validated and established it can be also used for time 3, time 4 and so on.

4 PRAGMATIC WORKFLOW

To incorporate this knowledge and technology to a solution, which provides the opportunity to control and react on upcoming defects in any AM-process, the following workflow is defined. In general the Finite Element Modeling (FEM) and two metamodels (I and II) will be employed. The Finite Element Modeling is used to generate data for an ideal situation. This data will be used to build a simplified metamodel (I) that can be used to regulate the process to avoid potential future defects. Afterwards the likelihood of having a potential future defect is calculated by metamodel (I).

For phase time 1 following pre work has to be done.

- Define measurable outcome parameters, which show the optimum scope for results.
- Development and usage of relevant design of experiments (DOE).
- Data generation by DOE. Data that leads to good AM parts and data represent bad or defected parts are generated.
- Identification of potential standard parameters for a simplified metamodel (II) for deviation correction.
- Computer simulation (FEM) to identify the ideal outcome parameter per cube/per layer.
- Build a second metamodel (I) based on the data generated in the simulation. The aim of the model is to find a simplified and fast equation to estimate the outcome parameters as good as possible.
- As input parameters only machine parameters and known physical equations are accepted.

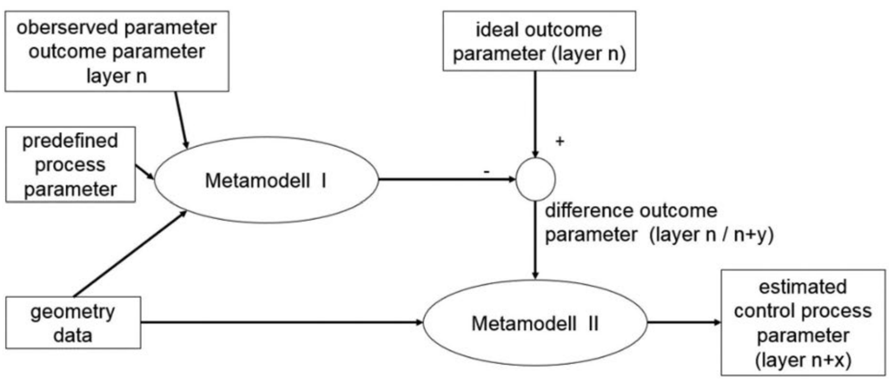

Figure 6: Deployment predictive control process.

Based on the workflow the following predictive control process can be developed.

Figure 6 shows the control process:

- Step 1: Start with calculating the ideal outcome parameter (p_{ideal}) for every layer and cube with use of metamodel (I). Can be done before starting the building process itself in the preparation phase.
- Step 2: With metamodel (I) outcome parameters ($p_{(n+y)}$) of layer n+y based on the actual measured data until layer n are estimated.

- Step 3: Compare the ideal outcome parameter (p_{ideal}) with estimated outcome parameter ($p_{(n+y)}$).
- Step 4: Calculate differences and correct some process parameter at layer n+x with the help of metamodel (II).
- Step 5: Use the corrected process parameter at layer n+x

The amount of layer x depends on the time for calculation and adjustment of the process parameter. This time must be less or equal compared to the time needed for production from layer n to n+x.

5 CONCLUSION AND OUTLOOK

The development of metamodels can be used to implement simple calculation rules for AM-process. Ideal outcome parameters $p_{(n+y)}$ for every cube in a layer can be estimated easily for different forms and geometries. The measured data until layer n and estimation of outcome parameters $p_{(n+y)}$ lead to a change in process parameter at layer n+x. This in turn leads to a better part quality and therefore to enormous time savings.
Based on this approach a controlling of the production process will be possible. A next step will be to evaluate the applicability of the theoretical concept described in this paper. The concept must be proven in an industry environment together with industrial partners.

REFERENCES

[1] Everton, S. K., Hirsch, M., Stravroulakis, P., Leach, R. K., & Clare, A. T. (2016) Review of in-situ process monitoring and in-situ methodology for metal additive manufacturing. Materials & Design, 95, 431-445.

[2] Lopez, F., Witherell, P., & Lane, B. (2016) Identifying uncertainty in laser powder bed fusion additive manufacturing models. Journal of Mechanical Design, 138(11), 114502.

[3] Fox, J., Lopez, F., Lane, B., Yeung, H., & Grantham, S. (2016) On the requirements for model-based thermal control of melt pool geometry in laser powder bed fusion additive manufacturing.

[4] Kamath, C. (2016) Data mining and statistical inference in selective laser melting. The International Journal of Advanced Manufacturing Technology, 86(5-8), 1659-1677.

[5] Mani, M., Lane, B., Donmez, A., Feng, S., Moylan, S., & Fesperman, R. (2015) Measurement science needs for real-time control of additive manufacturing powder bed fusion processes. National Institute of Standards and Technology, Gaithersburg, MD, Standard No. NISTIR, 8036.

[6] Ilin, A., Logvinov, R., Kulikov, A., Prihodovsky, A., Xu, H., Ploshikhin, V., Bechmann, F. (2014) Computer aided optimization of the thermal

management during laser beam melting process. Physics Procedia, 56, 390-399.
[7] Kruth, J. P., Mercelis, P., Van Vaerenbergh, J., & Craeghs, T. (2007) Feedback control of selective laser melting. In Proceedings of the 3rd international conference on advanced research in virtual and rapid prototyping (pp. 521-527).
[8] Moralejo, S., Penaranda, X., Nieto, S., Barrios, A., Arrizubieta, I., Tabernero, I., & Figueras, J. (2016) A feedforward controller for tuning laser cladding melt pool geometry in real time. The International Journal of Advanced Manufacturing Technology, 1-11.
[9] Van Elsen, M. (2007) Complexity of Selective Laser Melting: a new optimisation approach.
[10] Ahlemeyer-Stubbe, A., Coleman, S. (2014) A practical guide to data mining for business and industry. John Wiley & Sons.

INFLUENCING FACTORS ON PART QUALITY IN SELECTIVE LASER MELTING

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Abstract
Selective Laser Melting (SLM) is a powder bed fusion process to produce additively metal parts. From the current point of view, it seems to be one of the most promising additive manufacturing technologies for the production of end use parts. An increasing number of examples prove the successful application of SLM for technical part production. Nevertheless, they also show the enormous effort that is still required to qualify the production process of every single part individually.
The present paper gives an overview of the major influencing factors of the SLM process. To get a comprehensive research approach, existing publications on the topic are taken into account as well as own experimental work, evaluating the effects of the process parameters on the relative density of samples made from tool steel. The experimental setup and the results are described and opportunities for the further research work are discussed.

Keywords:
Selective laser melting, Additive manufacturing, Process parameters, Process optimization

1 INTRODUCTION

Additive manufacturing (AM) describes a number of technologies that create parts directly from three-dimensional CAD data, by additive joining of volume elements, usually in layers [1]. Since the advent of the first AM machines in the late 1980s, developments in this field have generated a large variety of technologies. Today, a number of AM technologies show a degree of maturity that allows their application for final part production. One of the most important AM technologies for final part production is Selective Laser Melting (SLM), which is a powder bed technology that fuses metal materials by use of a laser.
Compared to traditional technologies such as milling, forging or casting, AM technologies provide a number of advantages [2]: As no molds or tools are needed, AM processes are suitable for the production of small lots and even single parts. Furthermore, they allow producing structures that are impossible or very difficult to realize with traditional technologies. Products with internal cavities, strictly defined porosity or surface structures are opening up a wide

area of applications. Currently, end-use applications can be found e.g. in aerospace [3] or in the dental industry [4].
Besides the many advantages of AM, there are also a number of shortcomings to be mentioned: The staircase effect results from the layer wise build-up of the parts and influences the geometrical accuracy of the produced parts. Additionally, dimensional accuracy and surface quality do sometimes not achieve the benchmark set by conventional manufacturing processes, especially such of subtractive technologies [5].

2 SELECTIVE LASER MELTING PROCESS

2.1 Process description

Selective Laser Melting is a powder bed fusion process for metal materials. The basic principle of this method is to spread a layer of powder on a build platform, which is then selectively fused by use of a laser beam in the area where the part is to be generated. After that, the platform is lowered, a new layer is spread and fused again. This procedure is repeated until the final height of the product is reached and thus the product is generated layer by layer, surrounded by the residual powder. The laser beam completely melts the powder, so that the fusion is based on a liquid phase sintering. In this way, almost completely dense products can be generated.
The complete AM process does not only include the build process itself, but also pre- and post-processing. The first step is Computer Aided Design (CAD) that delivers a three-dimensional model of the product. This is converted into an STL file, which is still the common exchange format for AM. This data has to be transferred to the machine, where the machine setup is done including the parameter definition. Then the build process itself is carried out. After removing the parts from the machine and cleaning, the post-processing is done. This includes e.g. removing of support structures, heat treatment and machining of surfaces or fits. After post-processing, the products are ready for application. [6] The process chain is shown in Fig. 1.

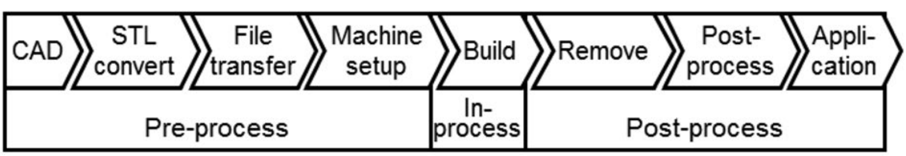

Figure 1: AM process chain.

Depending on the specifics of the setup that is used for the process, the sequence can vary slightly, e.g. the parameter definition might be done with a separate software before the data is transferred to the machine.

2.2 Process parameters

The SLM process is subject to a large number of influencing factors. Besides the process parameters of the in-process, also many factors of the pre- and post-process stages have a strong impact on the process result. For example, in the pre-process the orientation of the part in the build chamber is defined. This influences the surface quality and, due to a typically anisotropic behavior, the mechanical properties.

For the in-process, a large number of parameters need to be defined. They include the definition of the exposure strategy, e.g. hatch definition, laser energy, and scan speed, but also the environmental control of the build chamber, including gas flow, atmosphere, and temperature. Possible influencing factors in the post-process stages are temperature and time for heat treatments, parameters for milling or grinding, etc. An extensive overview of a number of influencing parameters in each stage is given in Tab. 1.

Table 1: Influencing parameters in AM process stages.

Process stage	**Influencing factors**
CAD	AM suitable design, build orientation support structures
STL convert	Level of detail, number of triangles
File transfer	Software, file format
Machine setup	Laser parameters: type of laser source, laser energy, scan speed, spot diameter, focus position Scan strategy: hatch pattern and rotation, beam compensation, sequence of hatch/contour scan
Build	Condition of laser source, optical system Atmosphere: oxygen content, pressure, gas flow speed and direction Ambient factors: temperature, humidity Material: grain size distribution, grain shape, chemical composition Powder bed: layer thickness, build platform temperature, coating system
Remove	Powder removal, cleaning process
Post-process	Manual operations Machining: cutting speed, feed rate, tool contour Heat treatment: temperature, heat-up/cooling rate, dwell time

The extensive number of influencing parameters hinders the development of suitable methods for process control and quality assurance, especially as the quantitative correlation between the parameters and the process results are mostly unknown.

2.3 State of technology

The application of the SLM technology offers new opportunities in design and manufacturing, as it provides an increased freedom of geometrical design and an economical production of single parts. Case studies show the general applicability of SLM to produce topology-optimized structures [7]. The widespread application of SLM in the dental industry is an example of the use of an AM technology for mass production of highly individual parts, considering the specific requirements [8].
Nevertheless, the technology also shows some limitations, especially regarding maximum part size and accuracy. Current SLM machines have build platform sizes of 100 x 100 to 400 x 400 mm² with about equal build height. The largest currently available machine has a build chamber volume of 800 x 400 x 500 mm³ [9] [10] [11] [12]. The achievable precision is different for x-y- and z-direction, commonly a geometrical accuracy between 0.05 and 0.2 mm is considered as state of technology. The precision depends on the diameter of the laser beam and the layer thickness. Due to the welding process and the structure of the powder material, the surface is rough compared to common subtractive machining, with average roughness values of 20 µm [13].
Quality control measures are largely limited to quality inspection, due to a lack of empirical data regarding the quantitative correlation between the process parameters and results. The assessment is either carried out as a final part inspection after the build process is completed or integrated into the build process, e.g. in form of a layer or melt pool monitoring [9] [10] [11] [12]. The available monitoring systems aim at detecting possible mistakes during the build process already.
As an additional quality management measure, the SLM machines record a large number of process parameters during the build process. Approaches for the analysis of these data exist mostly within research but require detailed knowledge of the interrelations between the parameters and the resulting part quality. These shortcomings are reflected by the fact that the improvement of the reproducibility and the development of suitable quality management methods are among the crucial success factors that are identified for the further advancement of AM [14].

3 DESIGN OF EXPERIMENTS

The analysis of complex processes like AM requires the identification of target quality attributes that characterize the output of the process and of factors possibly related to those attributes. Once a list of potential factors is identified from pre-testing and literature review, the strengths of the interdependency between those factors and the target attributes need to be quantified.

A plain one-factor-at-a-time analysis would require an extremely large number of tests. Furthermore, this is not suitable to identify existing interactions between input parameters, which may influence the correlation between the single input parameters and the target value. Using the statistical methods for Design of Experiments [15] is more efficient in this case. Due to a large number of process parameters in AM, a screening of the influencing factors is advisable as a first step. Screening experiments tend to be small and are aimed at identifying the factors that affect the target value most. As identification is the goal rather than sophisticated modeling, continuous factors in a screening design are typically set at only two levels. Thus, two-factor interactions are not discernible with this design. Therefore, definitive screening design [16] can be applied. This design is able to identify causes of nonlinear effects by investigating each continuous factor at three different levels. Definitive screening design will also require a small number of experiments, e.g. for six or more factors only about twice as many tests as factors are needed. The main advantages of definitive screening design are:

- Main effects are orthogonal to two-factor interactions.
- No two-factor interaction is completely confounded with any other two-factor interaction.
- All quadratic effects are determinable in models containing only main and quadratic effects.

4 RESEARCH SUMMARY

A lot of research work is carried out on the topic of the SLM process by different research institutes and companies. Only literature dealing with the evaluation of the influence of process parameters on the process results is included in this review. As no standards for the experimental setup exist, the results of the studies are difficult to compare. While in general, more than 50 influencing parameters in the SLM process can be identified [17], most research work focuses on the influence of the laser exposure parameters [18] [19] [20]. The exposure parameters can be put together to calculate the energy input or energy density of the SLM process, which is considered as the dominant influencing factor on the porosity and other quality characteristics by several researchers [18] [20]. Nevertheless, other publications show, that the energy density is not the only influencing parameter, as the same value for the energy density, achieved by different combinations of scan speed and laser energy, result in different porosities of samples [21].

Furthermore, it must be stated that there is no common understanding of energy density as a physical variable. While some work considers the two-dimensional energy density, that calculates the energy input per surface area, others use a three-dimensional approach that also includes the layer thickness to calculate the energy input per material volume.

A comparison of different research carried out on the process parameters for SLM does not deliver an explicit result for identifying the most important influencing factors and it becomes obvious that experiments have to be carried out for each material individually.

5 PROBLEM DEFINITION

Existing research work identifies a number of different influencing process parameters. The results are ambiguous and strongly depend on the material as well as on the specific machine used for the evaluation. Thus, it is not possible to deduce quantitative correlations or mathematical relationships from the existing work to apply this for identifying the most important influencing factors. To achieve this, tests have to be carried out with predefined machines and materials. The aim of this research work is to identify the most important influencing factors within the SLM process by applying statistical methods for experimental design.

6 METHODOLOGY

The porosity of the produced parts is chosen as the value to be measured for evaluating the part quality, as this is influenced by the process parameters and has a strong impact on the mechanical properties of the final part. All tests are carried out on a Realizer SLM 125 machine. The material used for these experiments is tool steel 1.2709 (material number according to DIN EN 10027-2:2015 [22]).
Pre-tests are carried out for a first evaluation of the repeatability: Eight cubes 8 x 8 x 8 mm^3 are built. The build job is repeated three times with identical process parameters.
The porosity of the sample parts is evaluated by metallographic analysis. For this, a vertical cross section of the samples is grinded, polished and etched with a solution for macroscopic etching to remove material residue from the open pores. Microscopic images are taken in five different areas of the cross section. The location of the samples on the build platform and the position of the cross section and the microscopic images are displayed in Fig. 2.

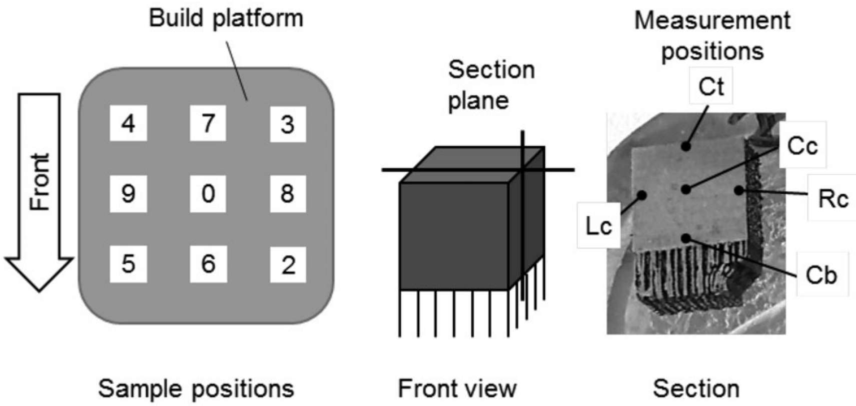

Figure 2: Sample and measurement positions for pre-tests.

The microscopic images are taken with an incident light microscope with an optical enlargement of 100x and analyzed by an image processing system, that calculates area segments based on a threshold value for gray scales. As the pores are visible as black spots on the microscopic images, it is possible to evaluate the porosity within the cross section.
In a next step, an experimental design is carried out to evaluate the influence of different process parameters on the porosity of the parts. The definitive screening design is chosen to identify the strongest influencing factors. Based on the results of the literature research, the parameters for the laser power and movement and the hatch strategy are varied in the experiments, as they are expected to have the strongest influence on the porosity. The experimental setup for the first block is given in Tab. 2.

Table 2: Experimental setup for the definitive screening.

Block	Sample	Exposure time [µs]	Point distance [µm]	Laser current [mA]	Lens position [mm/100]	Hatch distance [mm]	Position	Hatch rotation
1	1_0	25	50	3300	300	0,08	Middle	45°
1	1_2	40	30	2700	220	0,08	Front	10°
1	1_3	40	50	3300	300	0,12	Back	90°
1	1_4	25	30	3300	260	0,08	Back	10°
1	1_5	55	50	3300	300	0,08	Front	10°
1	1_6	55	50	2700	260	0,12	Front	90°
1	1_7	25	30	2700	220	0,12	Back	90°
1	1_8	55	30	2700	220	0,12	Middle	45°
1	1_9	40	40	3000	260	0,1	Middle	45°

The exposure parameters in the table refer to the hatch exposure, the parameters for the boundary are kept constant during the whole experiment. The experiments were grouped into three blocks, each block representing one build job. The sample geometry and positions are equal to those of the pre-tests. During the tests, it became obvious that the chosen parameter variations lead to a very unstable production process, which ended in a process break during the second block. Due to this, the third block was not built in this experiment. Nevertheless, the parts built within the first two blocks are analyzed in the same procedure as described for the pre-test. To exclude the influence of the boundary exposure only the center position (Cc) is analyzed for these samples.

7 RESULTS

The evaluation of the samples from the pre-test show large variations in the porosity between the single parts as well as within the parts. Tab. 3 and Fig. 3 show the results for the porosity calculated as mean and standard deviation from the five measurement areas, shown in Fig. 2.
The high mean value and standard deviation for the porosity of the sample 0 of test series 1 results from a large void that is formed in the center top of the sample and leads to a porosity of 17.02% in that measurement area. The formation of single large pores can weaken the material and result in a decrease of mechanical properties. Thus, it is important to consider these results in a further analysis.

Table 3: Results for porosity of the pre-test.

Test series 1	Sample:	0	2	3	4	5	6	7	8	9
		Porosity [%]								
	Mean:	4,22	0,42	0,21	0,42	0,45	0,44	0,44	0,65	0,56
	SD:	6,42	0,33	0,09	0,11	0,23	0,18	0,23	0,51	0,33
Test series 2	Sample:	0	2	3	4	5	6	7	8	9
		Porosity [%]								
	Mean:	0,46	1,55	0,31	0,27	0,25	0,52	0,24	0,34	0,34
	SD:	0,29	1,42	0,19	0,16	0,13	0,54	0,12	0,17	0,13
Test series 3	Sample:	0	2	3	4	5	6	7	8	9
		Porosity [%]								
	Mean:	0,36	0,09	0,31	0,65	0,03	0,04	0,25	0,17	0,09
	SD:	0,20	0,05	0,10	0,49	0,02	0,02	0,16	0,13	0,05

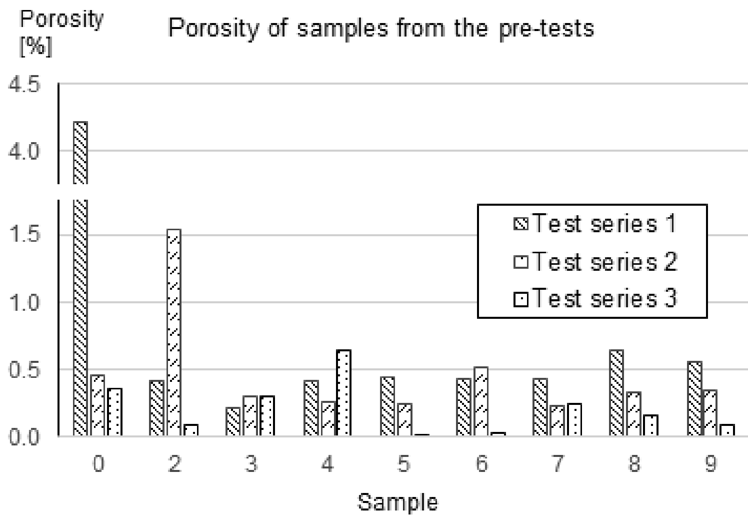

Figure 3: Mean values for porosity of the pre-test.

It is not possible to do the complete definitive screening, due to the missing third block of the screening experiments. For an evaluation of the present data, the two blocks of the screening experiment are combined with the results from the pre-tests. A screening analysis is applied to these data. The results are shown in the half normal plot, Fig. 4.

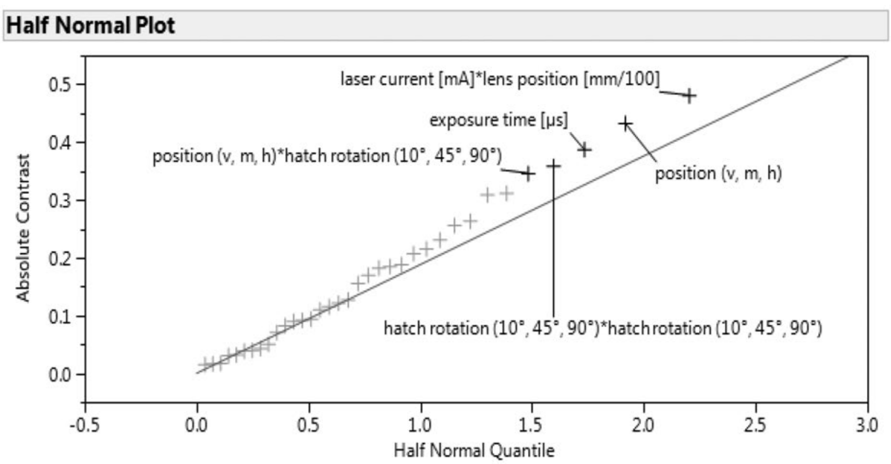

Figure 4: Half normal plot of the screening.

The distance of the data points of the straight is an indicator for the degree of influence of the parameter. The plot shows, that in this case the parameters with the strongest influence are: laser current*lens position, position, exposure time, hatch rotation*hatch rotation and position*hatch rotation. These parameters have a stronger influence on the porosity than the others, that are included in the screening. Nevertheless, for none of them, the result is clearly differentiating from the others.
Besides the quantitative results from the porosity analysis, the metallography delivers further information on the shape of the pores. The voids are either of an elliptical form or of irregular shape (Fig. 5).

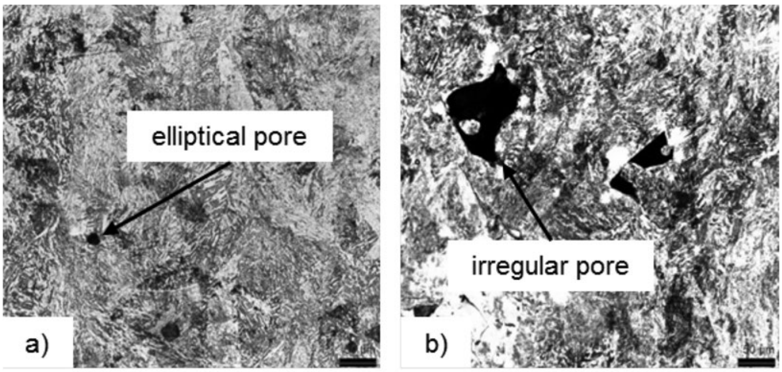

Figure 5: Microscopic images of voids in SLM samples, 200x.
a) Sample with elliptical pores, b) Sample with irregular voids.

The shape of the voids gives an indication of the formation mechanism. A more spherical or elliptical shape indicates the formation of the pore due to a gas bubble, that was enclosed in the melt pool during the solidification. These gas bubbles either can exist inside the powder particles of the raw material or be formed by evaporation of material during the melting process, as a result of a too high energy input. The irregularly shaped cavities can either be formed by material contraction during the cooling or be caused by an incomplete melting process, resulting from a too low energy input. The concrete form of the present cavities indicates, that the latter is more plausible in this case.

8 DISCUSSIONS

Together with the fact that certain combinations of parameters in the definitive screening design lead to a process break during the build, the results from the pre-test indicate that a closer evaluation of the other influencing factors is

required. The causes for the high variations within the pre-tests need to be identified and eliminated, if possible, as they will overlay the influence of the parameter variation. Careful analysis and optimization is required to reach a process state that enables the further evaluation of the influences of the different parameters.
As the screening analysis does not lead to an explicit result for the strongest influencing factors, further experiments are required. These should include a larger number of tests as well as consider more different process parameters. One possible approach can be the utilization of the process log files of the SLM machine as here all surrounding parameters are filed. Furthermore, the evaluation of the areal percentage of porosity is not sufficient. As the different formation mechanisms of the pores indicate a too high or too low level of energy input, this should be taken into account as well.
Further experiments with an optimized setup are required, as the current results are not sufficient for a conclusive evaluation.

REFERENCES

[1] Verein Deutscher Ingenieure (2014) VDI 3405 Additive manufacturing processes, rapid manufacturing – Basics, definitions, processes, Beuth Verlag, Berlin.

[2] Gebhardt, A. (2005) Rapid Prototyping für metallische Werkstücke: Direkte und indirekte Verfahren. RTejournal - Forum für Rapid Technologie, Vol. 2, online available: http://www.rtejournal.de/ausgabe-2-2005/233, 21.07.2014.

[3] GE additive (2017) online available: http://www.geadditive.com/#experience, 31.05.2017.

[4] Methner, M. (2007) Rapid Manufacturing: Dentaltechnik arbeitet effizienter mit Schichtbauverfahren - Schluss mit Guss, in: Medizin und Technik, Konradin-Verlag, Leinfelden-Echterdingen, online available: http://www.medizin-und-technik.de/home/-/article/33568401/35327192?returnToFullPageURL=back, 15.02.2016.

[5] Gebhardt, A. (2007) Generative Fertigungsverfahren, Hanser, München.

[6] Gibson, I., Rosen, D. W., Stucker, B. (2010) Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing, Springer Science and Business Media, New York.

[7] Scheideler, E. M., Villmer, F.-J., Adam, G., Timmer, M. (2016) Topology Optimization and Additive Manufacturing – A Perfect Sybiosis? in: Villmer, F.-J., Padoano, E.: Proceedings 6th International Conference Production Engineering and Management, Lemgo, pp. 39-50.

[8] Huxol, A., Villmer, F.-J. (2016) Special Requirements for Additive Manufacturing of Dental Frameworks in: Villmer, F.-J., Padoano, E.: Proceedings 6th International Conference Production Engineering and Management, Lemgo, pp. 15-26.

[9] SLM Solutions (2017) online available https://slm-solutions.de/maschinen, 21.06.2017.

[10] Concept laser (2017) online available https://www.concept-laser.de/produkte/maschinen.html, 21.06.2017.

[11] EOS (2017) online available https://www.eos.info/systeme_loesungen/metall/systeme_und_zubehoer, 21.06.2017.

[12] Realizer (2017) online available http://www.realizer.com, 21.06.2017, 14:40.

[13] Berger, U., Hartmann, A., Schmid, D. (2013) Additive Fertigungsverfahren, Europa Lehrmittel Verlag, Haan-Gruiten.

[14] Acatech – Deutsche Akademie der Technikwissenschaften, Nationale Akademie der Wissenschaften Leopoldina, Union der deutschen Akademien der Wissenschaften (Eds.) (2016) Additive Fertigung, München.

[15] Rushing, H., Karl, A., Wisnowski, J. (2013) Design and Analysis of Experiments by Douglas Montgomery: A Supplement for Using JMP, SAS.

[16] Jones, B., Nachtsheim, C. J. (2011) A class of three-level designs for definitive screening in the presence of second-order effects. Journal of Quality Technology, 43(1), 1.

[17] Spears, T. G., Gold, S. A. (2016) In-process sensing in selective laser melting (SLM) additive manufacturing, in Integrating Materials and Manufacturing Innovation, 5:2, online available https://link.springer.com/article/10.1186%2Fs40192-016-0045-4, 22.06.2017.

[18] Cherry, J. A. et al. (2015) Investigation into the effect of process parameters on microstructural and physical properties of 316L stainless steel parts by selective laser melting, in The International Journal of Advanced Manufacturing Technology, Volume 76, Issue 5-8, pp. 869-879.

[19] Yadroitsev, I., Yadroitsava, I., Bertrand, P., Smurov, I. (2012) Factor analysis of selective laser melting process parameters and geometrical characteristics of sythesized single tracks, Rapid Prototyping Journal, Vol. 18, Issue 3, pp. 201-208.

[20] O´Regan, P. et al. (2016) Metal based additive layer manufacturing: variations, correlations and process control, in Procedia Computer Science, 96, pp. 216-224.

[21] Prashanth, K. G. et al. (2017) Is the energy density a reliable parameter for material sythesis by selective laser melting?, Materials Research Letters, online available http://dx.doi.org/10.1080/21663831.2017.1299808, 22.06.2017.

[22] DIN EN 10027-2 (2015) Bezeichnungssysteme für Stähle – Teil 2: Nummernsystem; Deutsche Fassung EN 10027-2:2015, Beuth, Berlin.

PARTICIPATIVE DEVELOPMENT OF AN IMPLEMENTATION PROCESS FOR WORKER ASSISTANCE SYSTEMS

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Abstract
Challenges of companies are presented by an increasing number of product variants or a growing product complexity in combination with a reduction of lot size. Therefore the scope of the work in the field of manual assembly will be more complex. This situation leads to a need of assistance systems. With these systems, the assembly workers will be qualified to execute their work tasks within the requirements. This approach set up on a further implementation of an assistance system at a great device manufacturer. The main focus of this implementation was the technical and functional design of the assistance system, but a successful implementation requires also an active handling of the change process. The purpose of this paper is the presentation of design principles in form of a process model for the implementation of digital assistance systems. The development of the design principles takes place in a participative approach. Executives, work councils and workers develop the project results together with external project members. Project managers will be able to manage implementation processes with the results and take all the success factors into account.

Keywords:
Assistance systems, Change management, Success factors, Process model

1 INTRODUCTION

Manufacturing companies with assembly areas are presented with challenges, such as an increasing number of product variants, increasing product complexity, and shrinking lot sizes. These challenges change the demands on assembly systems and those working on them. The scope of the work is becoming more complex, more varied and undergoes more frequent changes due to shorter product life cycles. The short change cycles of various manufacturing orders in assembly can lead to early interruption of the learning curve of those involved [1] and to lower work productivity and a high error rate. This situation leads to a need for assistance systems, which support employees in carrying out their work duties in a cooperative manner [2] [3] [4]. At a large device manufacturer, an assembly assistance system consisting of three different applications was developed and introduced on a trial basis [5]. The developed applications support different professional groups with information based on needs. So, for example, employees are provided with information on the work steps, visualized through images, videos or texts [5] [6]. During this implementation process, the focus was on the technical and functional design of the applications. However, the successful introduction of such applications also requires, in addition to the functioning technology, an organization and workforce prepared for the technological change, as the workforce is required to undergo a not inconsiderable change process [4]. Only when the affected workforce views the assistance system as an asset and actively uses it, the introduction can be regarded as successful. Therefore there is a requirement for the development of user-centered design and implementation processes [7]. If this defined implementation process is lacking, this represents a major hurdle for the introduction of assistance systems [8].

2 OBJECTIVES AND APPROACH

The objective of the project described below is the development of a target process for the implementation of digital assistance systems. In addition to design tasks, this should also include success factors for change management and best practice examples. The results can be used by project managers in the future as a tool for the effective and efficient planning and implementation of the introduction process. In this project, the employees, work councils, and management of the device manufacturer with their different perspectives are explicitly included. The empirical basis for this project is formed essentially by the implementation of an assistance system by a device manufacturer mentioned above.

The selected procedure is set out in Figure 1 and consists of three phases: (1) Identification of success factors, (2) selection of the procedure model (3) combination of success factors and process model into a target implementation process. The results of these phases are described in sections 3.1 to 3.3.

The first phase is broken down into three parts. The first part consists of literature research on success factors for introduction and change processes in general and a subsequent inductive category formation in accordance with Mayring [9]. For this, prominent specialist texts and studies on change management [10] [11] [12] [13] [14] [15] [16] [17] are searched through for success factors for change processes. Using inductive category formation, the success factor categories are derived from the sources mentioned. To this end, the core statements from the respective sources on the success factors are filtered out and noted. If an aspect arises that is not dealt with in the previous sources, the category is expanded or a new one formed. At the end of the review, the categories are again reviewed for overlaps and adjusted so that they are better delineated.

Section	Content	Method	Result
3.1	Phase 1		
	Identification of success factors	Literature research and inductive category formation	Success factors of change management
	Identification of critical incidents	Workshop and critical incidents technique	Evaluated, critical incidents
	Combination of critical incidents and success factors	Deductive category formation	Summarized and specified success factors
3.2	Phase 2		
	Selection of a procedure model	Literature research and evaluation	Selected procedure model
3.3	Phase 3		
	Combination of procedure model and success factors	Allocation in expert workshop	Target model for the implementation process

Figure 1: Phases of the approach.

In the second part, critical incidents for the completed introduction process at the device manufacturer are identified, using the Critical Incident Technique of Flanagan [18]. Following Koch [19], the procedure for data collection consists of three steps: (1) recording critical incidents, (2) evaluating the relevance of the critical incidents and (3) dividing the critical incidents into categories. This method is based on experience, yields practical results and can be adapted relatively flexible to the question being posed [20]. Therefore the application of this method in this case is useful. The critical incidents recorded are based on activities from the introduction process that was undergone, e.g. in workshops or during the test phase. In the third part, these will be assigned to the success factor categories from part 1 in a workshop. The procedure here will be in accordance with deductive category assignment [9]. The results of this phase are success factor categories specially adapted to the implementation of assistance systems (cf. section 3.1).

In phase 2 there is a comparison and the selection of a procedure model for the implementation process. In doing so, various different procedure models are considered [10] [11] [12] [16] [21] [22] [23] [24] [25] [26] [27] [28]. The selected procedure model is adapted to the requirements of the assistance system design and represents the result of the second phase (cf. section 3.2). The third phase consists of the combination of the success factor categories and the procedure model. For this, an expert workshop is held. Here the success factor categories are each assigned to the individual stages of the procedure model. Subsequently, specific success factors are developed for each success factor category of a stage. The procedure developed in this manner is the result of the third phase (cf. section 3.3).

3 RESULTS

3.1 Success factors

By means of an evaluation of the literature on the subject of change processes, a total of ten success factor categories were identified. These were refined on the basis of 23 recorded critical incidents and the expert opinions in the workshop. The final ten success factor categories are shown in an overview in Figure 2. By evaluating the critical incidents, it was possible to identify the relevance of individual success factor categories. Thus in the category of communication, 14 critical incidents were considered. This means that the greatest number of incidents fed into this category. The conclusion can be drawn that this category has particular significance for the success of the project. In nine of the 14 cases, however, communication is not the only category to which these critical incidents were assigned. This demonstrates that communication is closely connected to other success factors - such participation, for example. This result is confirmed by Lauer [11]. He describes communication as the central success factor and as a catalyst for change.

Leadership & key personnel	Vision
Leadership driving the change process. **Important:** Pay special attention to trustworthy key personnel.	Deriving the vision from the company vision. Formulation of a clear and realistic vision from which the strategy and goal can be derived.
Communication	**Team-building**
Use open and clear communication internally and externally. **Important:** vision, successes and regular communication (including feedback)	Integrate all participants in the project. **Important:** Pay attention to and use the strengths, networking and motivation of participants.
Analysis	**Participation**
Systematic analysis of the starting situation and goal attainment.	Turn those affected into participants. **Important:** Involve all stakeholders in accordance with needs.
Qualification	**Sustainability**
Train all participants using appropriate methods and in accordance with requirements.	Embed the change and change process sustainably in the company. **Important:** Establish a willingness to change in the culture.
Project organization	**Process-oriented management**
Create a structure for the systematic completion of projects. **Important:** Prioritize tasks, pay attention to timing.	For each stage of the project, use appropriate methods, techniques and tools. **Important:** Plan conflict management, controlling, external consultants and rapid results.

Figure 2: Overview of change management success factors categories of an assistance system implementation.

3.2 Process model

In order to attain the goal of this project of designing a target process for the implementation of digital assistance systems, existing procedure models for organizational or technical change processes were analyzed. The criteria for the selection of the procedure model largely consisted of the project stage completeness, the level of detail and the suitability for software, hardware and work organizational changes. After several side-by-side comparisons, the REFA Standard Programs Work System Design [28] and Assembly System

Design [29] emerged as particularly suitable. The REFA procedure models were adapted in terms of content to the requirements for the implementation of an assistance system. Figure 3 shows the procedure model in a summary overview. So for example the iterative nature of the procedure is emphasized in some stages, as these are needed in the development of software in particular. The procedure model consists of a total of six stages.

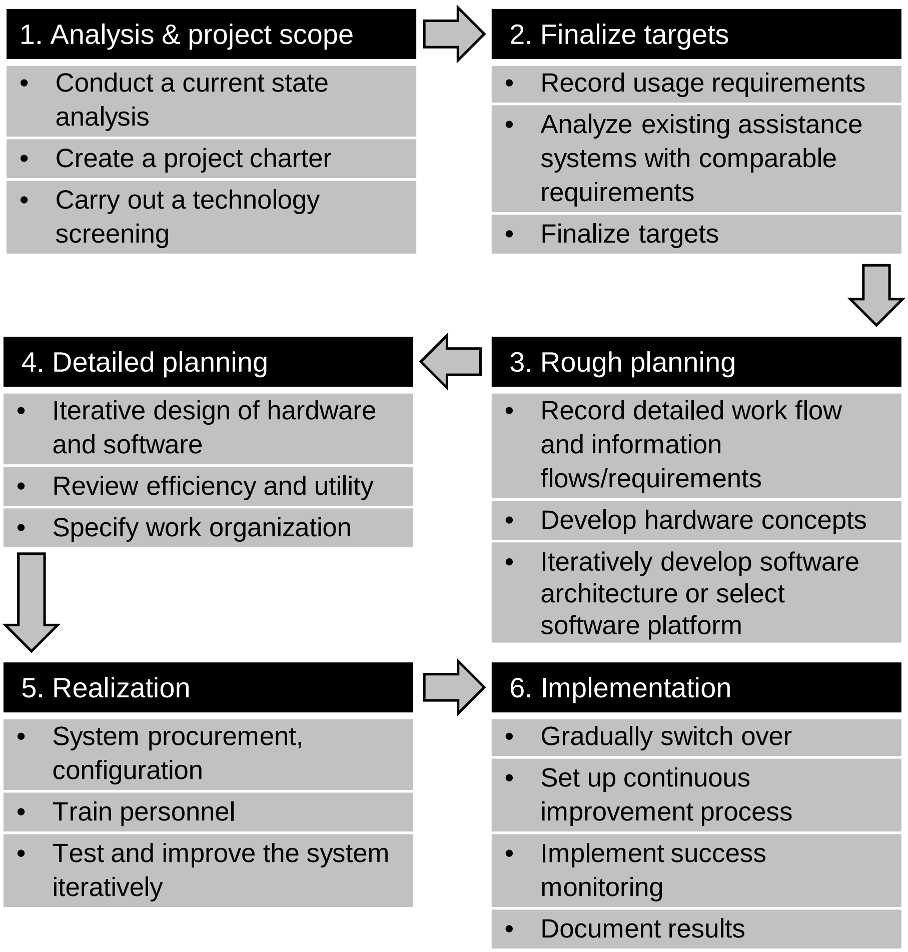

Figure 3: Procedure model for the design and change process (REFA 2016, modified).

In the **first stage** of the model, the starting situation is analyzed and project framework conditions are derived. Problem statement, goal setting, system delimitation, milestones and the project team are defined here. In the **second stage**, additional data is gathered, in order to specify in further detail the basis of these goals. Based on this, requirements are defined. These are refined in collaboration with possible software and hardware providers and if necessary verified in a mock-up. Then in the **third stage**, the hardware concept is developed and a software platform selected, and/or the software architecture is iteratively developed. In the **fourth stage**, the final hardware is selected and the software is developed or procured on a prototype basis. The process of development generally proceeds in short-cycle loops, so that quality can be assured through continuous feedback. The work organization is finalized in this stage. In the **fifth stage,** the system is implemented in a test environment. Through multiple testing (iterative), problems are identified and subsequently eliminated, so that production readiness is achieved. In the **sixth stage**, there is a gradual introduction in the selected area. Any errors are continuously eliminated in real-time operation. The sustainability of the system is ensured by selecting a person with responsibility for this task.

3.3 Target process

The target process was developed on the basis of the success factor categories identified, the critical incidents and the selected procedure model. A list of success factors was assigned to each stage of the procedure model. In Figure 4, the success factors of the first stage, "Analysis & project scope", are shown according to success factor category. Consideration of the factors supports the successful implementation of the change process. In Figure 5, the design tasks from the procedure model and the assigned success factors for stage 4 "Detailed planning" are shown exemplarily. There are interactions between these. So, for example, there is a connection between the iterative design of hardware and software and the success factor "Design and test functions and user interfaces with users". In this success factor, the change process with the participation of users is to the fore. The design tasks primarily relate to technical or functional aspects and directly to the hardware and software.

Success factors of change management: Stage 1
Vision:
• Emphasize the relevance of the vision
• Include company vision and location vision
Analysis:
• Understand the starting situation (current state analysis)
Communication:
• Communicate vision (at a factual and process level)
• Communicate in accordance with target group (overall project)
Lead & key personnel
• Visionary / promoter (initiator) is present
• Identify key persons for the project (team)
Process-oriented management:
• Monitoring of relevant key persons

Figure 4: Change management success factors of stage 1 of the process model.

A comprehensive inventory of 28 tasks and 72 success factors over 6 stages for the implementation of assistance systems was developed. In Figure 5, the amount of tasks and success factors per stage are shown. Overall, stage 6 includes the greatest number of success factors, with 16 in number. Relating to the success factor categories, the communication category includes 21 success factors. No other category has a greater number of factors. Using this inventory, executives and employees in companies can plan and implement the introduction process holistically, having regard to people, the organization, and technology.

	Stages					
	1	**2**	**3**	**4**	**5**	**6**
Amount of design tasks	3	4	4	5	7	5
Amount of success factors	8	11	11	13	13	16

Figure 5: Number of design tasks and success factors per stage.

Stage 4: Detailed planning

Design tasks

- Iterative design of hardware and software (including presentation, functionality, system performance, interactive behavior and supporting resources)
- Evaluation of design solutions based on requirements and selection of a solution
- Specify work organization
- Review efficiency of the investment(s)
- Prepare realization

Results of the stage

- Selected design solution for the assistance system

Success factors of change management

Project organization:

- Plan short project meeting cycles
- Plan detailed timelines for implementation

Participation:

- Design and test functions / user interfaces with users
- Gather feedback on design
- Determine the degree to which the functions can be affected during use with users

Communication:

- Regularly communicate the project status
- Communicate feedback results, including procedures
- Communicate in accordance with target group (overall project)

Qualification:

- Identify qualification needs
- Develop further training plan

Analysis:

- Review of project plan (utility analysis, efficiency analysis)

Process-oriented management:

- Monitoring of relevant key persons

Lead and key person:

- Identify and involve a key person from the area of HR / further training

Figure 6: Design tasks and success factors of stage 4 of the process model.

4 CRITICAL APPRAISAL AND OUTLOOK

The developed target process came about firstly from an evaluation of literature and secondly from interviews and workshops. As described in the introduction, a user-centered implementation process is required for a successful introduction of an assistance system. Therefore this approach covers the lack of such an implementation process that regards also human and organizational aspects. The target process is an enhancement to previous approaches as the morphology of assistance systems in manual assembly or the design process model [7]. The benefit is in the holistic approach to the implementation process. This makes a proactive design of the individual stages possible. In addition, the process allows the development of active, partnership-based cooperation between users, management and works councils in projects of this nature. For a similar evaluation of the implementation process, an additional project must be carried out in which this is used. Only then reliable statements on the effectiveness of the procedure model and the success factors assigned can be made. Nevertheless, there can be made an initial assessment of managerial implications. Using this target process, there will be a risk to require more resources in the development and implementation, but a standardization of the process will reduce the amount of required resources. Further, there will be indirect costs benefits, because implemented assistance systems will be accepted by the users and there will be less system changes or improvements. The results shown feed into guidelines for the implementation of assistance systems in manufacturing and assembly. The process is complemented by best practice examples and methods for individual stages of the process.

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REFERENCES

[1] Hunter, J. E., Schmidt, F. L., Judisch, M. K. (1990) Individual differenced in output variability as a function of job complexity. Journal of Applied Psychology, 75 (1), S. 28-42.

[2] Gerke, W. (2014) Technische Assistenzsysteme – Vom Industrieroboter zum Roboterassistenten. De Gruyter Oldenbourg.

[3] Unrau, A., Hinrichsen, S., Riediger, D. (2016) Development of Projection Based Assistance System for Manual Assembly. In: ERGONOMICS 2016 - Focus on Synergy of the 6th International Ergonomics Conference (2016), pp. 365 - 370.

[4] Bischoff, J. (2015) Erschließung der Potenziale der Anwendung von Industrie ‚4.0' im Mittelstand.
[5] Hartbrich, I. (2016) Lernen in der Endlosschleife. In: VDI Nachrichten. http://www.vdi-nachrichten.com/Technik-Gesellschaft/Lernen-in-Endlosschleife (13.06.2017).
[6] Stockinger, C., Verma, R., Konig, C. (2017) Konzipierung einer Cockpit-Applikation für smarte Fabriken zum Abbau von Komplexität. In: GfA (Hg.): Soziotechnische Gestaltung des digitalen Wandels – kreativ, innovativ, sinnhaft. 63. Kongress der Gesellschaft für Arbeitswissenschaften. Brugg-Windisch, Schweiz, 17.02.2017.
[7] Hinrichsen, S., Riediger, D., Unrau, A. (2016) Assistance systems in manual assembly. In: Villmer F.J. (Hg.): Production engineering and management. Proceedings 6th international conference, September 29 and 30, 2016, Lemgo, Germany: S. 3–13.
[8] Willeke, S., Kasselmann, S. (2016) Einführung interaktiver Assistenzsysteme über Reifegradmodelle. In: *ZWF* 111 (11). S. 691–695.
[9] Mayring, P. (2015) Qualitative Inhaltsanalyse. Grundlagen und Techniken. 12. Auflage. Beltz.
[10] Kotter, J.P. (2013) Leading Change: Wie Sie Ihr Unternehmen in acht Schritten erfolgreich verändern. Vahlen.
[11] Lauer, T. (2014) Change Management - Grundlagen und Erfolgsfaktoren. 2. Aufl., Berlin, Heidelberg: Springer.
[12] Doppler, K., Lauterburg, A.E. (1998) Change Management – Den Unternehmenswandel gestalten. Frankfurt, New York: Campus.
[13] Keicher, I., Bohn, U., Anke, T., Crummener, C., Mergenthal, N., Gerhard, B. (2012) Digitale Revolution – Ist Change Management mutig genug für die Zukunft? In: 10 Jahre Capgemini Consulting Change Studie. München: Capgemini Consulting.
[14] Ernst&Young C. G. (2008) Change Management 2003/2008 - Veränderungen erfolgreich gestalten. http://www.unternehmenskultur entwicklung.de/fileadmin/pdf/ukult/capgemini_changemanagement.pdf (13.06.2017).
[15] Ackermann, M., Dimmeler, D., Iten, P., Meister, D., Wehner, T. (2000) Wissensmanagement in der Praxis - Umfrageergebnisse und Trends.
[16] Schuh, G. (2006) Change Management - Prozesse strategiekonform gestalten. Berlin, Heidelberg: Springer.
[17] Hutmacher, D. (2004) Einflussfaktoren auf Veränderungsprozesse: Change Management, Innovationsmanagement, Projektmanagement: eine Literaturstudie.
[18] Flanagan, J. C. (1954) The critical incident technique. Psychological Bulletin 51 (4). S. 327-358. http://www.apa.org-/pubs/databases/psycinfo/cit-article.pdf.3 (13.06.2017).
[19] Koch, A., Strobel, A., Kici, G., Westhoff, K. (2009) Quality of the Critical Incident Technique in practice: Interrater reliability and users acceptance

under real conditions. In: Psychology Science Quarterly, Volume 51 (2009) (1). pp. 3-15.
[20] Lipu, S., Williamson, K., Lloyd, A., Ferguson, S., Crease, R. (2007) Exploring Methods in Information Literacy Research. Wagga Wagga.
[21] Hui, A. (2013) Lean Change: Enabling Agile Transformation through Lean Startup, Kanban and Kotter: An experience report. In: Agile Conference (AGILE) (2013). Nashville, TN, USA, pp.169-174.
[22] Anderl, R. (2015) Leitfaden Industrie 4.0. - Orientierungshilfe zur Einführung in den Mittelstand. Frankfurt a. M.: VDMA.
[23] Roth, A. (2016) Einführung und Umsetzung von Industrie 4.0. Grundlagen, Vorgehensmodell und Use Cases aus der Praxis. Berlin: Springer.
[24] Little, J. (2014) Lean Change Management: Innovative Practices for Managing Organizational Change. Happy Melly Express.
[25] Deming, W. E. (1986) Out of the crisis. Cambridge: Massachusetts Institute of Technology.
[26] Krüger, W. (2006) Excellence in Change: Wege zur strategischen Erneuerung (3. Ausg.). Wiesbaden: Gabler.
[27] Palmer, I., Dunford, R., Akin, G. (2008) Managing organizational change: A multiple perspectives approach. New York: McGraw - Hill Irwin.
[28] REFA-Bundesverband e.V. (2012) REFA-Grundausbildung 2.0 – Lehrunterlage zu Teil 2A: Ermittlung und Anwendung von Prozessdaten. Modul 2: Arbeitssystemgestaltung. Darmstadt.
[29] Hinrichsen, S., Riediger, D. (2016) REFA-Standardprogramm Montagesystemgestaltung. In: Industrial Engineering – Beiträge für die „Arbeit an der Arbeit". REFA, http://refa-blog.de/refa-standardprogramm-montagesystemgestaltung (13.06.2017).

SESSION B
Innovative Management Techniques and Methodologies

TOTAL PRODUCTIVE MANUFACTURING APPROACH FOR QUALITY MANAGEMENT IN THE WOOD AND FURNITURE INDUSTRY IN GHANA

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Abstract
This paper gives an overview of the state of quality management system in the wood and furniture industry in Ghana and assesses the influence of gender in enhancing quality management in developing countries like Ghana using the adaptive total production management approach. It specifically encompasses some investigations about the actual role of women in the Ghanaian society and possible developments according to the gender mainstreaming. Results indicate that there is a low level of women participation in the wood and furniture industry in Ghana. Therefore there is the need to entice, train and retain women to play a very active role in the maintenance department of furniture industry in Ghana and other developing countries. This approach will improve the quality of products, maintenance of tools and equipment for enhanced productivity. Sufficient funding and periodic training workshops will be required to achieve this important goal in the wood and furniture industry in Ghana where quality management and assurance is low.

Keywords:
Kaizen, Total productive maintenance, Total productive manufacturing, women, Gender diversity productivity, Wood and furniture industry, Ghana

1 INTRODUCTION

Collaborative aid between developed countries and developing countries has been in existence for many years with some degree of success in many countries. The Industrialized countries, on one hand, often use and trade the collaborative aid as an instrument to support their own economy in terms of promoting export. The developing countries, on the other hand, often receive such support to support their fragile economy with some uncertainties about appropriateness and sustainability, because often the ideas are foreign and really fit into culture of the countries. It is clear that the majority of the population will not really follow these developments and will continue to seek answers on materialism and capitalism. The Economic Partnership Agreements (EPA) with some countries in Africa and overseas may not

improve the situation. In consequence of the omitted import taxes maybe there will be more direct investments by bigger companies. But the ‘big players’ avoid taxes there ever they can [1], so they do in the industrialized countries there the SME play a great role for the revenues of the state. For sustainable development, strong domestic SME’s are needed.
The challenges encountered to ensure quality assurance and quality management in SME’s in the wood and furniture sector in Ghana like other developing economies are primarily lack of adequate technical know-how in terms of technical staffs, poor maintenance culture and lack of attention by government agencies and policy deficiency. Most of the innovations in maintenance and quality assurance are taught theoretically in the few training institutions in developing countries with little practical orientation and sustained training programs for few technical staffs for the wood industry in Ghana.

2 AIM OF THE PAPER

This paper reviews the TPM approach in quality management in the wood sector in Ghana - a developing country - with special emphasis on maintenance culture in the Ghanaian society and how it permeates the wood and furniture industry.
Besides the grade of industrialization, a method is needed to enhance the productivity and quality in the developing countries. It should fit the mentality but also allow a moderate development towards industrialization. The EPA’s are signed so the competition of markets is sustained. The developing countries must simply compete rather than operate as a workbench of the industrialized countries or to be a material sub supplier and selling market. The method will use parts of the Total Productive Manufacturing (TPM) and adapt them to the needs of developing countries. As an example Ghana with its wood sector is taken with special emphasis on the untold role of women in quality management.

3 GHANA’S WOOD SECTOR

Like other aspects of Ghana’s economy and other tropical developing countries, the wood and furniture industry is a very important sector of Ghana‘s economy. It employs millions of Ghanaians and supplies tropical hardwood species to many European and Asian markets for significant foreign earnings. In recent times, a number of challenges have been identified in this sector leading to a decline in foreign exchange earnings over the years. For instance, in terms of value, wood export decreased from US$ 34,846,969 in 2004 to US$ 12,631,065 in 2009 [2]. In 2014, however, a significant rise in export was achieved mainly due to exploitation of some timber species [3] rather than quality management issues. Moreover, Ghana’s timber industry is currently challenged with dwindling wood supplies and hence the need to redirect industry focus for higher value processing. Aside, obsolete equipment, low skill of workers, poor quality of finished products, low product diversity, quality assurance and management is almost non-existing. Limited research has been done on the assessment and improvement of quality in the timber and furniture industry in Ghana and most developing countries [4] [5]. This indirectly affects the competitiveness on the international markets.

Figure 1: Furniture industry Ghana (Ghana News Agency 2015).

Stakeholders in the wood and furniture industry (Fig. 1) in Ghana accepted that there is still poor skill of the machine operators, poor maintenance culture and poor product quality among the wood and furniture companies in Ghana. It was further recommended that more research work should be geared towards improving quality assurances and management in the wood and furniture industries in Ghana. In fact, the timber industry in Ghana has very little opportunity to improve quality assurance without thorough research and development. There is little evidence of quality management especially in the small and medium scale furniture and wood industry in Ghana. Maintenance and sustainability of process are also major concerns in the industry which has resulted in low-quality products and hence low productivity and profitability and poor efficiency in timber resources utilization.

4 TOTAL PRODUCTIVE MANUFACTURING

The origin of Total Productive Maintenance is the Japanese Kaizen, a continuous improvement process which is based on the creativity of the ordinary workers to solve the daily problems in production. It was found out that many problems were caused by bad maintenance. So out of the Kaizen method, the new method of Total Productive Maintenance was created by focusing on maintenance issues and systematically adding the 5S – Cleanliness and Discipline. The method Total Productive Maintenance consists today out of the modules (pillars) shown in Fig. 2. When Total Productive Maintenance is introduced in a company by a project it is only a small step forward to improve Health and Safety, Quality Assurance and Shop Floor Management Processes. By adding again these pillars Total Productive Maintenance was transformed to Total Productive Manufacturing (TPM) (Fig. 3) which is the base of the new method.

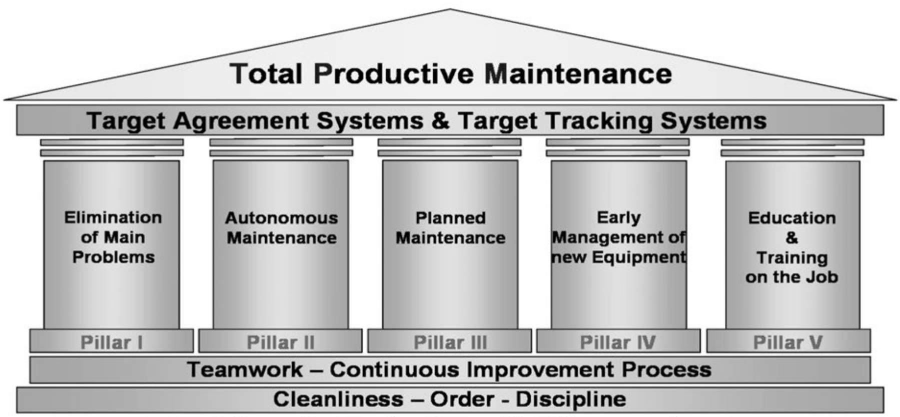

Figure 2: The 5 pillars of TPM-concept.

5 NEED FOR ADAPTATION

Generally speaking, all pillars of TPM are poorly developed in most sawmills and traditional companies in the wood sector in Ghana. The educational system is based on the British system, so even skilled and educated craftsmen are hard to find. The Ghanaian pupils must go to primary and secondary school but the learning content is of poor use in the later professional life. The profession is more a family heritage. Intuitive use of the TPM pillars by a skilled craftsman is not common. The traditional skills are of poor use for the production of furniture which can compete in an international market or with imported furniture.

Not all pillars have the same impact to increase the productivity of Ghana's wood and furniture production. The pillars are listed and the needed changes are explained.

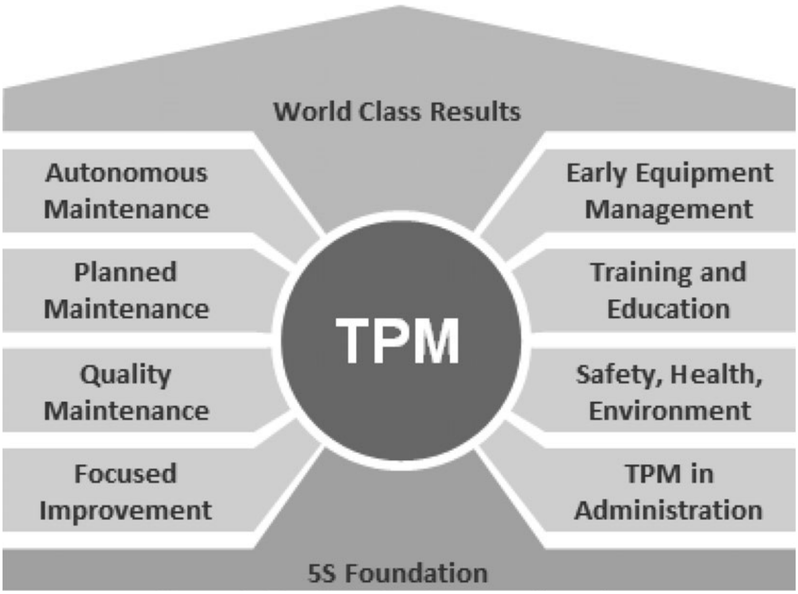

Figure 3: Total productive manufacturing.

5.1 5S

The so called 5S program, which focuses on cleanliness, orderliness, and discipline is the base of all TPM approaches. By the subtopics

- Sort: Keep only that is absolutely essential;
- Systemize: Store every item at its right place;
- Shine: Keep your workplace clear;
- Sustain: Make a habit out of it: tidiness and cleanliness;
- Standardize: Observe rules and standards.

The shop floor is cleaned up and kept in order. The developed proceedings should fit also in developing countries, but the module sustainability should be especially taken into consideration. Due to the lack of skilled operators and the education system which favors the training on the job where is almost no attitude or pride on an own clean workplace. But this seems to be a known phenomenon [6] that workers stop after a successful implementation celebrate and the involved managers move apart instead of standardizing the successful path. A control group is needed to implement it as an everyday routine. There is really no big difference to industrialized countries and other branches.

5.2 Quality

Quality management is poorly developed in sub developed countries [7]. In the wood sector it is even worse. Also in industrialized countries in best in class companies, the products are rarely exact defined by complete and clear drafts. Trade practices and physical thresholds are state of the art, verbal or written description are sometimes given. To compete in international markets SME's in sub developed countries need a clearly communicated quality understanding. Here in this pillar all shop floor activities are meant even if there is more backlog demand. Positive thresholds are fine to define the expectations of the customer and easy in use at the shop floor. But also samples showing failures which the customer will not accept are very helpful to educate a clear understanding about the product quality. Measuring devices are almost not available except for lengths. Therefore the control of inspection, measuring, and test equipment is needed. In most cases visual and haptic inspection is needed to evaluate the workpiece quality, sufficient illumination and trained assessors is a must for sensory assessment [8].

5.3 Elimination of main problems

The TPM-method is based on the continuous improvement process, better known as Kaizen. The pillar elimination of main problems still refers to that origin and is therefore important to raise a better understanding of quality and in case of TPM also of efficiency [9]. Kaizen could be a door opener for other quality management tools and a better understanding of quality, but not organized in quality circles.

5.4 Autonomous maintenance

That the operator is responsible for many maintenance procedures related to "his" machine is indeed a kernel of TPM. This is not uncontroversial, to fulfill this the worker must in normal circumstances educated for this additional operations and might ask in consequence for higher fees. Ford Motor Company e.g. was running a similar program like TPM the Reliability and Maintainability Program (R&M) to avoid some of these disadvantages. But to put the operator in the middle and enable him for maintenance is right. He knows the best and should take care of "his" machine. But due to a normal lack of discipline in SME's in the shop floor autonomous maintenance means at the same time a certain work specialization. Micro companies with four employees are often very unproductive [10]. Companies with 50 employees are ten times more efficient and there the question for autonomous maintenance arises.

5.5 Education and training

Ghana's educational system is developed (literacy rate 71.5% in 2014) but most of the contents seem to be far away from practical work/professional life. Formal apprenticeships – basis of the German success – are not fully developed or unknown. During projects with new investments in most cases training related to operation and maintenance is also ordered from the machine supplier. In SME's in Ghana mostly used machines are installed. Workers Unions provide education [11] like in the UK but this and the offers of private schools seem to be not enough. Education and training in SME's is equal with training on the job mostly without basic professional education. A formal initiative driven by federal institutions is needed (compare Compass-Transfer-Workshops provided by the OWL University of Applied Sciences in the years 2005- 2008).

5.6 Planned maintenance

A maintenance and repair handbook is a necessary equipment for new machines. At the moment there is no standardization in this field. The end user must shuffle together all information needed for his used tailor-made maintenance system. A modular technical documentation [12] is helpful to collect all data which is needed for a planned and scheduled maintenance carried out by an own maintenance department. It is an open question whether an own maintenance department is existing in SME's in Ghana. Where is a strong need for this, service contracts as used in industrialized countries seem to be not common. The representatives of the machine manufacturer are often too far away. Only own specialists guarantee low down time in case of a breakdown.

5.7 Early management of new equipment

Besides that in SME's in Ghana at the moment almost no new machines are installed this pillar is crucial. The end user of the machine should have a deep understanding of TPM and preventive quality management tools to conduct a discussion about possible failures and problems of the new equipment. Both is not given in Ghana's SME's. It makes sense that the machine producer leads the communication and the customer might be supported by an independent consultant or federal institution or association working on this field.

5.8 Health and safety

This is at the moment not really a topic for sub developed countries. Health and safety are poorly developed. It makes sense to introduce a certain standard and improve it continuously with TPM. Also here consulting federal institutions or associations should support the SME's.

5.9 Shopfloor management

This pillar is also included in TPM but it leads here too far to discuss here all necessary actions. For all activities, a clear commitment and the responsibility of the management are needed.

6 ADAPTION OF TPM USING WOMEN AS AGENTS OF CHANGE

The empowerment of women is in the focus of the United Nations and other institutions [13] [14]. It might be also here a key for success but TPM has to be modified/rearranged to ATPM. There is no proof that women have a worse understanding of technology than men. During the Second World War due to the absence of men women successfully occupied almost all working places (Fig. 4) in industry [15]. But women have some abilities men do not have which are necessary in the context of ATPM. Maybe it is a stereotype and besides recent investigations [16] but women are more caring than men [17]. Due to a minor rate of testosterone they are better in mathematical calculations and a faster and more precise perception and cognition of the close surrounding [18].

Figure 4: Poster US war production coordinating committee.

They are faster in recognition and better in remembering things and have a finer motor function [19]. In industrialized countries they often are employed in quality assurance and for checking operations.

Because of the aforementioned women are predestinated to take care of the pillars autonomous maintenance, quality management and 5S (Fig. 5). Not in a sense of a chairwoman but as an emancipated backup force for a male or female machine operator. The machine operator shall stay in charge of maintenance but share the job. And there is a place for a second worker at the machine, due to the low automatization in most cases workers for feeding operations are needed.

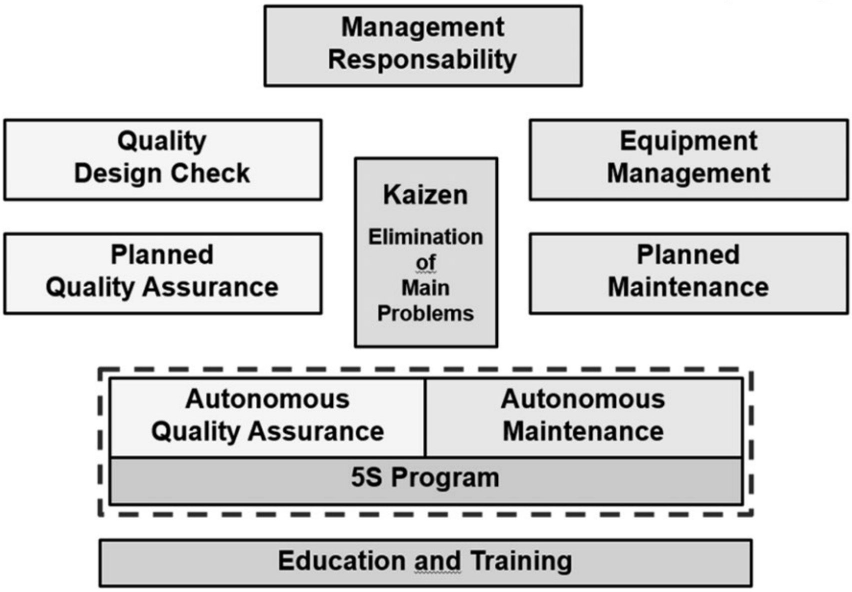

Figure 5: Block chart ATPM.

To enhance the focus on quality management two other activities are recommended. On one hand, a quality understanding first for the products is needed. Not to overburden the design department in SME's a simple check should be made like:

- Is a clear and complete definition of the product given by a physical example or drafts?
- The customer has defined quality characteristics or has the marketing a clear understanding what the customers want?
- Are there failures the customer do not want to see?
- Is a method described how to evaluate the quality characteristics and the failures?
- Are tolerances or thresholds defined?
- Is a method in use to forward all information to the production?

If this information is given the production can start planning regular quality assurance at quality gates e.g. before coating, shipping and the autonomous quality at the machine.

7 CONCLUSION

There is indeed a need in Ghana for an independent institution supporting the SME in the introduction of ATPM and doing research in this field. Maintenance and quality insurance in most of the furniture and wood firms in Ghana and in fact many developing African countries is relatively low compared to their developed industrial counterparts. As collaborative supports through financial and technical aid are being provided, there is the need to ensure that quality benchmarks are strictly met to ensure sustainability and enhanced profitability. Gender issues will obviously play an important role in adapting a suitable ATPM because of the possibility of better performance and accuracy. There is a need for an independent body responsible for quality management and promotion of quality assurance among SME in Ghana and other developing countries.

REFERENCES

[1] Fuest, C., Riedel, N. (2009) Tax evasion, tax avoidance and tax expenditures in developing countries: A review of the literature Oxford: Oxford University Centre for Business Taxation.

[2] Timber Industry Development Division Annual timber Export report 2011

[3] Timber Industry Development Division Annual timber Export report 2015

[4] Tekpetey, S. L., Ofosu, M., Appiah-Kubi, E. (2011) Quality Control and Grading of Sawn Timber from Mills in Southern Ghana: Constraints and Opportunities. In: Gronlund and Cristovao (eds) Proceedings of the 20th International Wood Machining Seminar (IWMS-20), June 7-10, 2011 Skelleftea, Sweden. pp 514-519.

[5] Tekpetey, S. L., Riegel, A., Kerstin, D. (2015) Investigating Surface Quality of African Mahogany (Khaya ivorensis) from Ghana using Stylus and Deflectometry Techniques. Wood and Fiber Science Vol. 47(2) pp 190-198.

[6] Oswald, C., Reynolds, D., Casey, J.J. (2013) The Secret for sustaining 5S. QualityDigest 4.2.2013. https://www.qualitydigest.com/inside/metrology-article/secret-sustaining-5s.html.

[7] Gosen, J. (2005) Quality and Developing Countries: The Role of international and organizational factors. International Journal of Quality & Reliability Management 2005 (22) p. 452-46.

[8] Baade, C., Dekomien, K., Riegel, A. (2011) Sensory Quality Assessment of Surfaces, Especially Wooden Surfaces. In: Proceedings of the 20th International Wood Machining Seminar. ed. Grönlund, A., Cristóvão, L. (2011), pp 141-148.

[9] Khamba, I.A. (2008) Total Productive Maintenance: Literature Review and Directions. International Journal of Quality & Reliability Management p. 712.

[10] Collier, P. (2016) Afrika kann nur sich selbst retten. Interview von Mark Schieritz: Die Zeit Nr. 43/2016.

[11] Hodges, J., Baah, A. (2006) National Labour Law Profile: Ghana. International Labor Organization. http://www.ilo.org/ifpdial/information-resources/national-labour-law-profiles/WCMS_158898/lang--en/index.htm.

[12] Docufy (2015) Variantenvielfalt im Maschinenbau erfordert modulare Produktdokumentation. Pressemitteilung Dokufy zur Tagung des VDMA in Bad Dürkheim 22.5.2015.

[13] Duflo, E. (2012) Women Empowerment and Economic Development. Journal of Economic Literature 2012, 50(4), 1051-1079.

[14] Trask, Bahira Sherif (2014) Women, Work, and Globalization: Challenges and Opportunities. New York: Routledge.

[15] Gazeley, I. (2008) Women's pay in British Industry during the Second World War Economic History Review. p. 651-671.

[16] Storey, A. E., Noseworthy, D. N., Delahunty, K. M., Halfyard, S. J., McKay, D. W. (2011) The effects of social context on the hormonal and behavioral responsiveness of human fathers. Hormones and Behavior, 60, 353-361.

[17] Lutz, H. (2011) The new maids: Transnational women and the care economy. London, UK: Zed Books, Ltd.

[18] Wickler, W., Seibt, U. (1998) Männlich - Weiblich. Ein Naturgesetz und seine Folgen. Heidelberg: Spektrum 1998.

[19] Hilbig, H. (2000) Geschlechtsunterschiede aus neurowissenschaftlicher Sicht. Lexikon der Neurowissenschaft 2000. http://www.spektrum.de/lexikon/neurowissenschaft/geschlechtsunterschiede-aus-neurowissenschaftlicher-sicht/4636

SUCCESSFUL APPLICATION OF AGILITY MANAGEMENT IN CONSULTING PRACTICE IN CHINA

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Abstract
The theoretical and methodical approaches to agile management are reflected in the practice and experience gained in Chinese companies from the commercial vehicle industry.
Agile management is not only a project management method, but also a guiding principle and expression of a form of organizational structure. Jens Bergstein defines agility as “the ability of an organization to react quickly to changes.” [1] Other definitions describe agility as the highest form of adaptability. HR Pioneers has developed a model that consists of 6 levels:
The agile target images:

- Customer-oriented organizational structure;
- Iterative process landscapes;
- Employee-centric management skills;
- Agile personnel and management instruments;
- The agile corporate culture [2].

Other criteria are: “The concept of agility involves short, straightforward planning and implementation cycles with “prototyping,” [2] so that immediate adaptation to the changing conditions is possible (“inspect and adapt”). Errors become visible at an early stage and can be corrected in the early stages, priorities are regularly queried and reoriented. Agility stands for iterative approach, lateral leadership, interdisciplinary and cross-functional teamwork as well as organized self-responsibility.
For the decision-making in organizations this means that decisions are made “where the knowledge and not the disciplinary power sits.” According to the authors, this means that customers are integrated into the product development right from the start, so that continuous feedback and immediate learning transfer are process-oriented. Processes are thought out of customers’ minds. “Agile organisations have also understood that radical customer orientation along with radical employee orientation: [3] “Agility is about people and the way they work together.” [4].

Keywords:
Agility management, China, Industry 4.0, Organizational flexibility, MSCDPS®

1 INTRODUCTION - AGILE ORGANIZATION

The first requirement for a company that sees itself as agile is anticipatory, forward-looking thinking, which goes for the entire staff, including for the management and executive board.
Orientation and perspectives work both retrospectively and prospectively, with the former pointing to a company's strong points. To determine in-house, experience-based strong points, the following factors must be taken into account:

- Innovation;
- Variety;
- Development capacity;
- Organization of knowledge flows.

A versatile workforce with its specific experience and potential, brought in by individual employees, is what drives a company's development capacity in the first place. With prospective activities, new designs for the future take center stage based on an anticipatory, forward-looking approach. In-house, implemented standards and routines are equally valid as a basis as is a lean, project-oriented organizational and operational structure. Externally, the company cooperates with and in networks [5].

1.1 Agility definition and scientific approach

Agility is nothing new. Nevertheless, in daily business, with its structural changes and company restructurings, it is gaining traction: "For around 20 years now, the agility concept in organization theory has come to denote a type of flexible, lean, customer-oriented organizational design that is associated with a fresh, modern form of organization and always enhanced with newly-developed technologies." [3].
Agility does not have a basis in practical operations but finds its origin in organization theory as a solution to economic stagnation. Talcott Parsons first came up with a model based on a systems-theoretical approach used in the social sciences (1953). Already in the 1940s, the US social psychologist Robert Bales analyzed group behavior and his findings later formed the basis for Parsons' agile scheme.

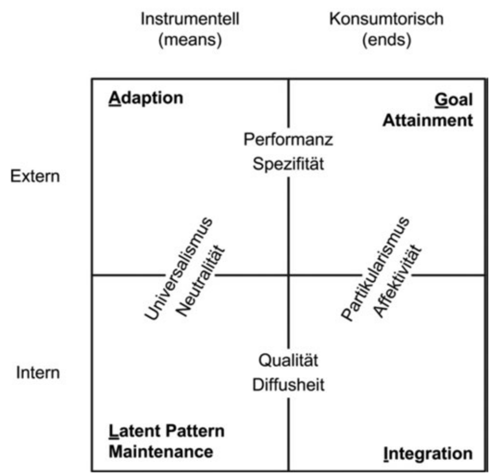

Figure 1: Phases and axes of T. Parsons' agile scheme [6, p. 3-4].

- Parsons sees Phase A (adaption) as the "systems adaption to changing conditions."
- The specific goals of actions designed to optimally meet requirements take center stage in Phase G (goal attainment).
- Phase I highlights integration, cohesion, and joint activity.
- Phase L stands for latency, compliance with values and standards including quality [3].

An early definition of agility from the 1980s states that Corporate agility is the capacity to react quickly to rapidly changing circumstances, requires a focus on clear system output goals and the capability to match human resources to the demands of changing circumstances [3].
With this definition, the special focus is already on

- Swift response to environmental changes;
- Requirement of clear targets;
- Evaluation of human resources.

Later on it reads: "Since the late 1990s, there is greater emphasis on individual customer value as well as on product development initiated by customer requirements." [3].
To a large extent, our approach is in line with a model from the turn of the century that was designed as an "agile-manufacturing model" in cooperation with various authors. The framework comprises the attributes strategy, technology, organization, and people, to which various concepts are applied. The attribute strategy includes the concepts reconfigurability, flexibility, virtual

organization, strategic alliances, integration, and parallel development. As concepts of the attribute technology, Gunasekaran mentions modular software components, real-time checks, information technologies, multimedia, graphic simulators, and more. The attribute people includes the concepts flexibility, IT, top-management support, and employee knowledge and under the attribute systems are grouped MRPII, Internet, WWW, electronic trade, CAD/CAE, ERP, JIT, etc. [3].
The characteristics quality, training, education, and incentives system are key components of this framework, also in terms of organization and people. In the end, Foerster und Wendler [3] describe agility from the angle of organization theory as a “conglomerate of elements from various theories and concepts, that […] are continually expanded with new approaches [...]. Its strength may be that the term agility continues to be adapted to current developments and can therefore be considered as ‘modern’ in spite of its 20-year history.”

1.2 Agility in companies

Employees with their skills and qualifications are unquestionably the key resources of companies. For example, another strand of agility theory - a psycho-social and systems-theoretical strand - includes team theory. “The self-organization theory (a variant of the systems theory) and team theory were selected [3], because the requirement of self-organized groups, who independently accomplish complex tasks as a team, constitutes a distinctive attribute of agility.” [3]
From the point of view of organizational theory, various approaches play a role herein. In the field of psycho-social organizational theories, they include the

- Human-relations approach, an alternative to Taylor’s principles of assembly-line work with fixed cycle times;
- Human-resources approach, a motivation-oriented model with focus on development opportunities for employees and self-control instead of external control: *“The idea is to shape the organisation so that through the achievement of individual targets organisational targets are achieved simultaneously. Work is no longer seen as ‘plight, but as ‘joy,’ as a source of needs fulfilment”* (Schreyoegg, 2003, p. 54). Parallels can be drawn to lean production and agile organization that pursue flat hierarchies, in which decision-making is transferred to lower hierarchical levels” [3].

Among other things, process orientation plays a central role in the self-organization theory (a variant of the systems theory). In the team theory, the team is seen as “a target-compliant group of actors whose members perform various tasks, which they may complete using non-identical information. The members pursue similar targets, so there are no conflicting goals [3]. So this is about job-sharing, communication of information exchange, and rules of conduct for team members.

"The teams work with various team models, although the concentration on self-organised teams in a decentralised organizational form is a key agility hallmark. The architects of the agility concept relied on insights of the team theory, established for several decades and already an integral component of various organizational models (including lean production), before it was incorporated into agile models." [3].

1.3 The flexible company - agile and lean

In times of change and restructuring, it becomes apparent whether companies manage to operate flexibly and make readjustments. Increasingly, companies must be able to adapt ever faster to environmental changes with regard to product variants, time, and costs, which makes their effectiveness measurable. Company flexibility is the requirement for an unequivocal focus on customer requirements.

Foerster und Wendler comment on flexible manufacture and lean organization: "The manufacturing concept known as lean production, as with flexible manufacturing, represents a direct answer to the mass-production system and already contains many agility characteristics" (p. 25). Although the practice originated in the 1950s in Japanese companies, the concept continues to be a familiar and current approach. Having said that, the Japanese model has met with increasing criticism in subsequent years: a study of the Massachusetts Institute of Technology (MIT) points to worker strain, high levels of fluctuation, and an inadequate environmental approach. [3].

Shah and Ward [3] count 10 characteristic dimensions for lean production:

With regard to the production system, it shows that a lean factory "(transferred) a maximum of tasks and responsibilities to those employees who actually added value to the car on the assembly line, and (has) installed a system of fault detection that quickly traces each identified problem to its final cause" [3]

In this concept, teamwork is of great importance, both in manufacturing and product development: "Lean product development/construction is largely a construct of four basic elements management, teamwork, communication, and simultaneous development." [3].

To be able to quickly respond to customer requirements, we develop close ties to customers. This makes it possible to quickly obtain feedback, for example on trends. A comparison of lean and agile principles is given in a study of Koblenz University [6].

1.4. Statement of a Chinese manager

OVERCOMING CHALLENGES WITH LEAN MANAGEMENT

Nowadays, state and private companies e.g. in China must face numerous challenges such as the global and domestic economic downturn, rising labor costs, unstable currencies, and stricter environmental and safety requirements.

Business leaders are compelled to find appropriate solutions. Using lean thinking, they may succeed in addressing these problems if process improvements are initiated and competitiveness is strengthened.

LEARNING FROM FOREIGN COMPANIES

In the early 1980s, a few Chinese state companies already sought to learn from Toyota but failed to implement lean management in their day-to-day business operations. Frequent job rotations of the top management and excessive focus on performance pushed the executives to rather focus on short-term success instead of on long-term sustainability. Nowadays, Chinese private companies, often small and medium-sized firms, in particular have a solid basis. Their managements have energy, entrepreneurial spirit, and the will to dabble in new ideas. Fittingly, they are seen as the drivers of China’s next economic leap forward.

NOT RELINQUISHING ONE’S CULTURAL IDENTITY

Having said that, the Chinese have a traditional culture of respect for the elderly, caring for others, and ongoing improvements. Many Chinese business leaders have worked hard to implement the concept “happiness enterprise” in their own firms. We would like German companies to create the circumstances for a combination of traditional Chinese culture and German technology. This would help us to avoid wastefulness and build a culture of ongoing improvements.

PAYING ATTENTION TO ONE’S STRONG POINTS AND DEFICIENCIES

Currently, Chinese firms - just as companies from all other countries - are facing great changes, due to the beginning of a trend toward smart factories. The Industry 4.0 concept was developed in Germany for specific social and economic reasons. This is another opportunity for Chinese firms to learn from their German partners. Nevertheless, they should also pay attention to their own strengths and deficiencies. What is clear is that automation and smart manufacturing continue to be based on a stable lean work method of “flow” and “ongoing improvements.” That is why Chinese companies, in spite of new technologies, return to basics and effectively and efficiently organize the processes. “I think that lean management is the basis from which Chinese firms shall overcome their current challenges.”
Dr Marcus Chao, president, Lean Enterprise China [7].

1.5 Bottom line

The Chinese will make that happen with agility when they have adopted a quality mentality and when they are given advice on opportunities such as market development, a stable workforce, etc. Our perception: China wants to grow. China and its economy need to change. This can be done successfully with methods - or with a mix of methods as well - which will be applied to the change process based on experience and application. Both lean and agile are approaches that may be used to create progress and develop new markets.

Therefore a case study was made, which is based on consulting stays with Chinese companies. Despite a few procedural differences between the models lean management and agile, the similarities may be used and combined.

2 BACKGROUND

The consulting strategy is oriented on Ebertconsulting's own method, MSCDPS®, which gives a way to optimize processes in medium-sized companies and which follows the Toyota philosophies. This method is based on a two-way approach: product creation and human resources. The method focuses on both quality and innovation and relies on commitment and empowerment of the people involved.
The method, the MSCDPS® model and its nine characteristics are the following: employee participation, customer requirements, transparency and visualization, communication, executive and employee empowerment, issues as a guide, studying paragons, lean production processes, learning management (going and learning locally).

2.1 Problems of the companies

- Technical problems, which is a common issue with Chinese manufacturers: e.g., material quality;
- Organizational problems including too many suppliers;
- Non-functioning HR processes and department;
- No middle management;
- Very hierarchical structures;
- Introduction of a generation of successor owner-managers.

It costs a lot of power of volition and strength and involved people have to be supported intensely. This is part of the program and it is managed by intense personal coaching, mentoring, supervision, and the creation of a feedback culture. Patience is crucial. Change only happens in small steps. So the process of change has to be planned carefully, implemented successfully, and carried out with a long-term perspective.

2.2 Aims of the company

For the exemplary companies in China, it is necessary to use an external management consultancy as a driver to

- Improve product quality;
- Implement a sustainable product-development process;
- Improve quality with staff and partners;
- Increase market share;
- Develop new markets.
- development and strengthening of HR management

- may be an acknowledged requirement due to the political order.

2.3 Achievements

A new organizational structure could be introduced and works self-driven. Most of the technical problems could be solved with the help of mentoring teamwork and partner integration. A monitoring and Andon system to secure sustainability and continuous progress has been installed and is supervised with regular SKYPE meetings. Recruiting is initiated to gain new talents, and prepared by the improvement of international appearance.

The MSCDPS® approach targets both an agile organization and an agile production. This means that we start with the implementation of processes and, in particular, also with the so-called 5S concept for workplace order. The implementation will take place after agile approaches with pilots, which, following a successful testing phase, will be rolled out in all areas.

After order and transparency are established, the processes are precisely described and visualized to ensure repeatability and thereby start a sustainable, ongoing process of improvement. The first goal is flow in all organizational units. The long-term vision is one-piece flow and pull. For the development process, this means work in projects and competence centers should be the living example of communication and knowledge transfer from experts to all process participants. This encourages self-confidence and thus the willingness to take personal risks, which is a necessary requirement for a self-organizing product-development process as opposed to the copycat practice that has taken place so far.

New methods introduced for HR are: coaching, mentoring, training also the worker. New equipment procured, testing initiated and introduced, a product clinic now works totally independently.

2.4 Challenges during the process

As always, the challenges during the implementation are

- Integration of top management;
- Lack of self-assurance of workers;
- Process sustainability;
- Environmental standards have started to become valid, foundries are peeled off due to air pollution;
- Coaching up-and-coming successors so that they may meet future requirements;
- Lack of a drive for excellence (the competition does not fare better);
- Implementation of new methods for effective cooperation.

The consultant becomes the manager as both sides, management and stakeholders, are not accustomed to organizing change. Moreover, assuming responsibility is not looked upon as positive in the Chinese company. In view of our own standards, we have established a strong supervision concept to counter at an early stage the danger of paternalism by reflecting on our own role and the roles of others.

2.5 How to implement agile management

How is the introduction of agile management in companies managed? The prerequisite is that the company is shown to be mobile, open, and customer-oriented. Such an enterprise culture motivates the employees. The advised - and here exemplarily listed - companies have motives for agility: they are aiming at new markets, they are changing their structures, they are looking for new management models, and they want to create new working conditions for their employees.

The experience of other companies shows that middle management is very suitable as a driver. They recognize the structures and quick successes that are desired, for example, better customer relationships and current customer information, a sales department that has to respond more quickly and uncomplicatedly to customer requirements. The advantage in China is also the fact that management is changing: the successor generation is motivated, flexible, and thinks innovatively, provided the young, aspiring company successors are not hampered by older management generations. A clear position of top management is essential for agile change. The “movement” has to be a self-reinforcing on the different levels through positive, appreciative attitude and by giving guidance from the upper to the middle management. What hurts the company in the situation of a repositioning and the introduction of agile methods is fluctuation, if competent and well-trained employees leave the company.

What helps:

- Good automation with not too many small-scale processes;
- Innovative, comprehensive work, for example by encouraging teams of employees from different departments to solve problems and tasks.

What is required:

- Training and coaching for middle management;
- A corresponding organizational framework;
- Feedback sessions with experience exchange;
- Assessment for top management and management;
- Peer learning: form teams for knowledge exchange, for best-practice development.

2.6 Conclusion

The opportunities for Chinese companies are great. The change of generations, the desire for renewal, and the urge to enter the world market must change anyway. New machines, new tools, and new structures are needed and with new methods: so why not agile? Agile is the new future: efficient, stable, and then agile.

Why in China?

In China, there is a great need to meet new market requirements: the products have to make a leap in quality, the customer relationship and connection is given maximum importance, the understanding of the market is aroused, and there is an urge for the world market. What accelerates this development is that just a young to very young – partly younger than 30 years - well-trained new generation of managers and management is joining companies. These young people have completed their studies and first work experience in Europe, Australia, and the USA. They are culturally oriented and, as future owners of the company, highly interested in taking new paths. In the background, the fathers' generation supports with advice, which gives the newcomers a tremendous trust and helps to ensure that the top management also comes into the boat. The support is extremely high for the successors. To convince all stakeholders through exemplary quality and credibility in exemplary and professional action - is the on-site consulting approach.

In our work, transparency and documentation play an important role, e.g. monitoring systems are introduced, the team management is strengthened and methodological abilities through specific lessons are supported. Tasks are seen as challenges and the teams are accompanied, up to the offer of mentoring. The team leaders represent young employees, the hierarchy plays no role in the teams, this encourages participation and self-initiative. Significant importance is attached to the supplier and partner integration, the discussions, visits, and surveys on site. The young teamers inquire the needs of the customers, consider with them the service, give help for improvements. They learn the principle "from the customer's mind."

Through the introduction of the ANDON philosophy, deficiencies in the quality of the component parts were identified as a major problem of the assembly line. These problems could be solved by the training of the employees, the introduction of stringent monitoring, and the quality of supply. Now it is important to optimize the factory logistics, to switch to a real pull principle, to reduce overproduction and to integrate the design and production into teams in order to further improve the efficiency. Meanwhile, the managers regularly visit the teams and report how they support the work. They show the greatest interest in the success of the work and the company as a whole. Some of them have moved their offices to the workshop. The assembly-line employees see themselves as a pace-setter and clock for the company and are now demanding and organizing self-confidently constructive changes and quality-enhancing measures. By synchronizing the machines and work processes, waste could be targeted.

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REFERENCES

[1] Bergstein, J. (2015) Agility – überlebensnotwendig für Unternehmen in unsicheren und dynamischen Zeiten Unternehmensberatung Kienbaum Change-Management-Studie 2014/2015.

[2] HR Pioneers (2014) “Agil anpassen!” Artikel Personalmagazins in Ausgabe 11/2014.

[3] Förster, K., Wendler, R. (2012) Theorien und Konzepte zu Agilität in Organisationen, Dresdner Beiträge zur Wirtschaftsinformatik, Nr. 63/12, TU Dresden 2012.

[4] Oestereich, B., Schröder, C. (2016) Das kollegial geführte Unternehmen: Ideen und Praktiken für die agile Organisation von morgen; Vahlen, Auflage: 1.

[5] Armutat, S. et al. (2016) Agile Unternehmen – Agiles Personalmanagement, DGFP-Praxispapiere Best Practices 01/2016.

[6] Hochschule Koblenz, BPM-Labor - Labor für Business Process Management und Organisational Excellence, Prof. Dr. Ayelt Komus, Version 1.0 vom 06.05.2014

[7] Staufen AG (Hrsg.) (2016) 25 Jahre Lean Management: Eine Studie der Staufen AG und des Instituts PTW der Technischen Universität Darmstadt.

[8] Nowotny, V. (2017) Agile Unternehmen - Nur was sich bewegt, kann sich verbessern, 3. Aufl. BusinessVillage GmbH, Göttingen.

[9] Ramsauer, C., Kayser, D., Schmitz, C. (Hrsg.) (2017) Erfolgsfaktor Agilität – Chancen für Unternehmen in einem volatilen Marktumfeld, WILEY-VCH Verlag, 1. Aufl.

DEPLOYMENT OF PROCESS CAPABILITY ANALYSIS FOR SINGLE-PART PRODUCTION

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Abstract
A rising number of product variants together with decreasing lot sizes are a result of the trend of individualization. Besides the upcoming organizational issues, changes in the production technologies are required. Direct digital manufacturing contributes to solve this problem by enabling the production of parts right from the CAD data.
Process capability analysis is applied in several industries to prove the reliable compliance of products with quality requirements. As it is based on statistical methods, new challenges arise in the context of single-part production.
The paper describes and compares different approaches for the adoption of process capability analysis for single-part production with special focus on additive manufacturing technologies. The statistical background and the applicability of different capability parameters are discussed. An overview of existing research work is given and supplemented by own approaches for the adoption of statistical methods for single-part production. The aim of the research work is to establish a first approach for the qualification of new technologies in single-part production.

Keywords:
Statistical process control, Process capability analysis, Single-part production, Process optimization

1 INTRODUCTION

Driven by the development of the society, new challenges are arising in the product realization process. Companies in almost all industries are confronted with shorter product life cycles [1] and the trend of individualization [2]. Besides the resulting need for shorter innovation cycles, the decrease of lot sizes is one of the main issues arising from these changes.
Current production systems need to be adopted to this new situation. New organizational structures are required as well as changes in production planning and management. This includes the adaptation of quality management tools, as many of them are based on statistical methods and thus involve a sufficient number of tests for a reliable database. While these statistical methods are well applicable for large production volumes, small lot

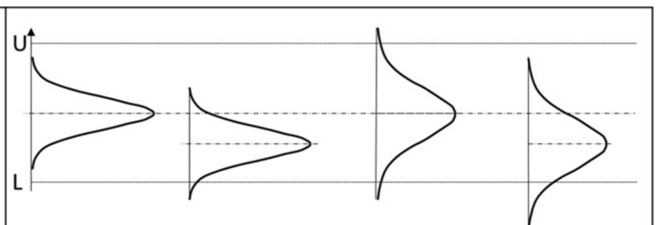
sizes or individual production need new approaches to ensure process and product quality throughout the whole production.

2 PROCESS CAPABILITY

“The process capability analysis gives the opportunity of evaluation of the natural variation pattern for a process and an estimation of the amount of nonconforming units that can be expected.” [3] The information gained from a process capability analysis thus enables a more precise planning of production and can also help to identify areas of improvement.
The statistical methods for quality management were developed in the 1920s and 1930s. The industrial application started in the 1950s in Japan and three decades later became a standard for companies in Europe and the United States. [4]
This initiated a change in the general understanding of quality management, as quality assurance measures were no longer limited to controlling the produced parts but enabled to predict the future performance of a production process. Today in many industries, a proven process capability is an important prerequisite for the application of new machines or technologies [5].

2.1 Determination of capability indices

With the application of the process capability analysis, it is determined whether a process is under statistical control. The most important factors for this are the process dispersion and the process location, as shown in Fig. 1. A process is capable only when the dispersion compared to the tolerance interval is small enough and at the same time, the process location is constantly within the specification limits.



dispersion	✓	✓	×	×
location	✓	×	✓	×
capability	✓	×	×	×

✓: compliance ×: non-compliance

Figure 1: Process performance index depending on process dispersion and location. [5, p. 62 modified]

The dispersion is evaluated by comparing the standard deviation to the tolerance interval for a quality characteristic. DIN ISO 22514-2 [6] defines the different capability indices. The process capability index C_p is calculated by

$$C_p = \frac{U - L}{X_{99.865\%} - X_{0.135\%}} \tag{1}$$

with

U: Upper specification limit
L: Lower specification limit
$X_{99.865\%}$: 99.865 % distribution quantile, upper reference limit
$X_{0.135\%}$: 0.135 % distribution quantile, lower reference limit

This calculation does only consider the process dispersion, but not the process location within the tolerance interval. To also assess the location, the minimum capability index C_{pk} is introduced as

$$C_{pk} = \left\{ \frac{X_{mid} - L}{X_{mid} - X_{0.135\%}} ; \frac{U - X_{mid}}{X_{99.865\%} - X_{mid}} \right\} \tag{2}$$

with

X_{mid}: Distribution midpoint

A number of capability and performance indices are defined for several evaluations. While the general calculation is the same for all these indices, they differ in the number of samples taken for the measurements and the time interval that is considered. Tab. 1 gives an overview of the different indices and their fields of application, according to [7] [3].
A capability index $C_p = 1$ means, that 99.73% of all parts are within the tolerance range if the attribute is normal-distributed. The index gets higher for smaller dispersion. Concrete threshold values have to be defined for each application and are commonly in the range of 1.33 to 2.

Table 1: Application of different capability and performance indices. [3] [7]

Index	Definition	Application
C_p C_{pk}	Process capability index Minimum process capability index	Long-term capability analysis for a stable process; Statistical process control
P_p P_{pk}	Process performance index Minimum process performance index	Preliminary capability analysis for a stable process; Performance analysis for a not stable process
C_m C_{mk} P_m P_{mk}	Machine capability index Minimum machine capability index Machine performance index Minimum machine performance index	Machine capability analysis, only applicable when all external factors are kept steady

Conventionally smaller thresholds are defined for long-term analysis compared to those of short-term or machine capability analysis. The requested minimum capability index is usually smaller than the capability index itself, e.g. $C_p = 1.67$, $C_{pk} = 1.33$ and $C_m = 2$, $C_{mk} = 1.67$ are common threshold values. [5]

2.2 Influence on quality costs

The significance of the process capability analysis does not only derive from the fact, that many industries demand a proven process capability for the introduction of new technologies, but also from a reduction in quality costs. While the traditional consideration of quality costs assumes that only non-conformal parts cause loss due to the resulting reject costs, current models apply the loss function defined by Taguchi, Fig. 2.

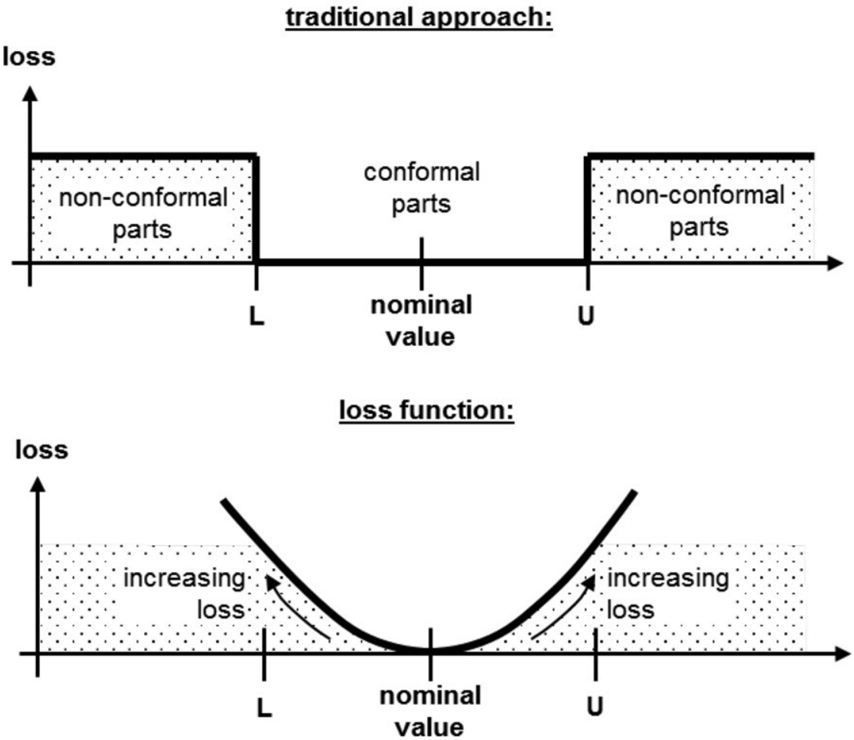


Figure 2: Loss according to traditional approaches and loss function. [8, p. 213 modified]

This model assumes that each deviation from the nominal value causes loss due to non-compliance with customer requirements and an increase in quality assurance effort. Thus, loss can be reduced by decreasing the dispersion and optimizing the location of the process. On the other hand, a narrowing of the tolerances usually increases the process costs, so that a careful calculation is required to find the overall minimum.

3 SINGLE-PART PRODUCTION

The requirements for any production system are strongly influenced by social developments. Individualization is one of the megatrends that currently have a strong impact on production, as it results in an increasing demand for individual or customized products. [9] In the production literature this is often referred to as “Mass Customization”.

This consequently leads to a decrease in lot sizes and even single-part production of highly individualized products, thus increasing the complexity of production management. To enable the high flexibility of production systems, that is necessary to meet these requirements, is one of the purposes of production process digitalization and the concept of Industry 4.0 [10]. The concept of Industry 4.0 aims to meet these needs by implementing organizational structures based on horizontal and vertical interconnections and data consistency throughout all business processes. This digitalization of manufacturing processes also influences industries that previously were dominated by manual processes, like dental technology, where completely new process chains have been established [11].
Besides suitable software solutions, new direct digital manufacturing technologies are required for highly flexible production systems, as unit costs for conventional mass production technologies like casting or injection molding are strongly dependent on quantities due to high tooling costs.
Additive manufacturing (AM) can be identified as one of the technologies that are well suited for individual production, as production costs here are mostly independent of lot sizes, which is shown in Fig. 3.

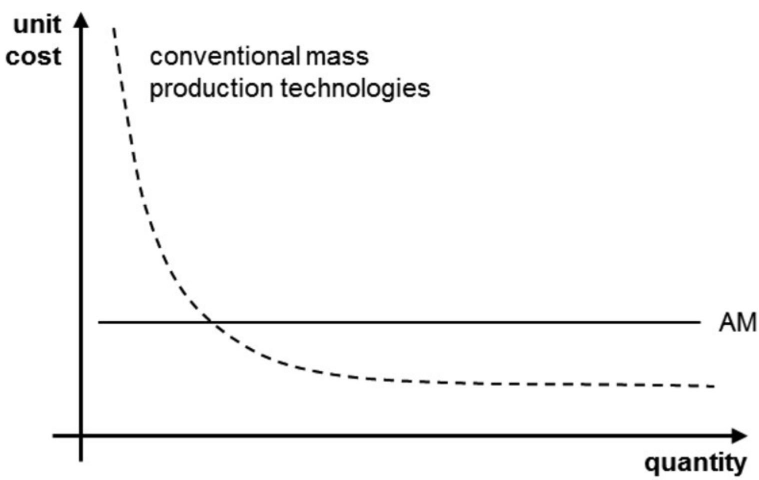


Figure 3: Comparison of unit cost for conventional and additive manufacturing.

Additionally, AM enables the manufacturing of complex geometries, that are impossible to produce with other technologies [12]. To reach the full potential, an overall change in the product realization process is required, starting from the design phase over production management to usage and disposal.

4 PROBLEM DESCRIPTION

The necessary changes in the product realization process also include quality management (QM). Current QM techniques in manufacturing, like statistical process control (SPC), are based on statistical analysis and require a large number of identical tests to deliver a sufficient database. Even for the evaluation of the machine capability, which is the analysis with the smallest sample number, testing of a minimum of 50 samples is commonly required [5]. In case of small lot sizes, the process will not deliver an appropriate number of parts for this testing, as the capability has to be proven for every attribute individually. Thus, the statistical methods in their current form are not suitable for analysis in single-part production.
While for some direct digital technologies, like CNC milling or turning, the achievable accuracy and repeatability have been explored in detail, for newer technologies, especially AM, only a few experience-based values exist. Furthermore, the characteristics of AM processes cause a number of specific issues for QM, like handling the large number of process parameters [13]. This situation, together with the limited availability of design rules and specified tolerance classes for these technologies, makes it extremely difficult to achieve a proven process capability.
This lack of statistical data impedes the introduction of new production technologies in many industries, as often a certain value for process capability has to be proven. Though a number of examples for the successful application of AM technologies for final part production exists [14] [15], a careful process qualification is needed for each application. This problem is also reflected by the fact that an increased reproducibility of the process output and the development of suitable quality assurance methods are among the crucial success factors, which can be identified for AM technologies [12].

5 SOLUTION APPROACHES

New processes commonly do not reach a very high process capability right from their introduction, especially when new technologies are involved. They have to be evolved towards an increased process capability. According to [16], five different levels can be identified for business processes, starting from a non-defined process with a very low capability towards a self-adjusting process at the top level of process control and reliability. Fig. 4 presents an overview of these five categories, their influence on the process capability and the quality control tools applied for the different stages.

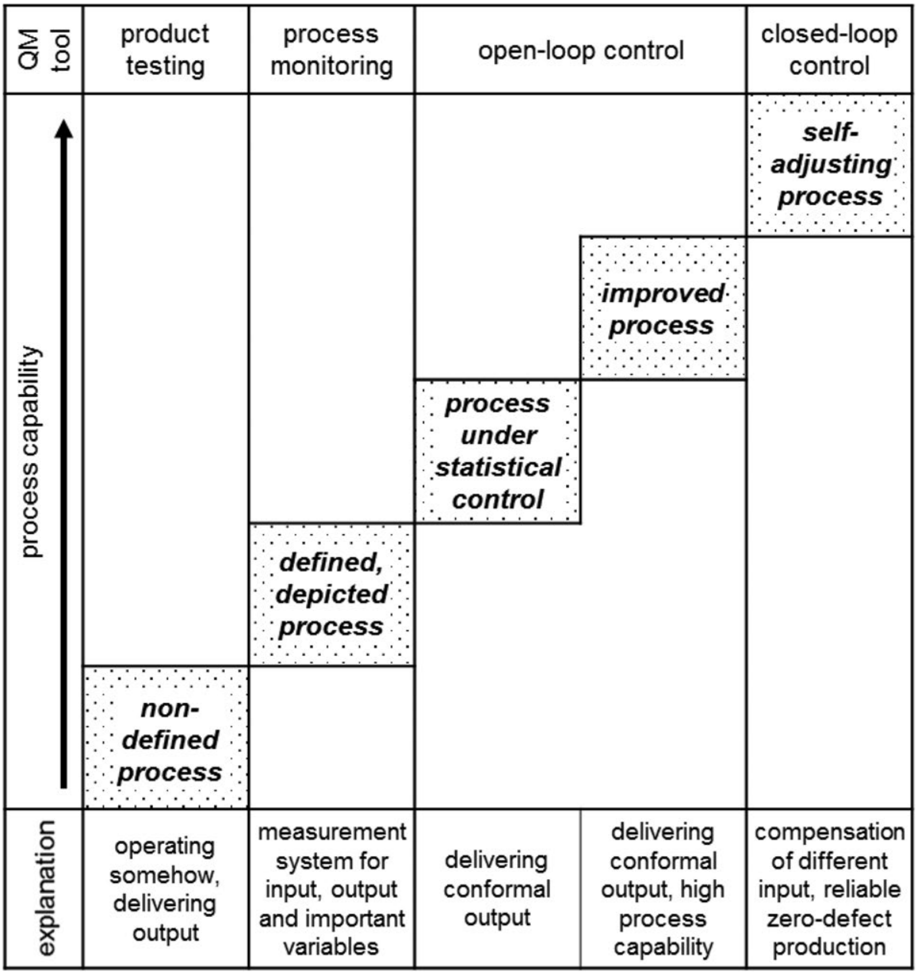


Figure 4: Advancement levels of process control and process capability.

This development is characterized by an increasing process knowledge, which is first gained by clearly defining and describing the process and later can be applied to introduce process control measures, and consequently leads to a high process capability. Following this theory, the self-adjusting process represents the desired state for every process, as it will autonomously react to variations of the process conditions to enable the constant delivery of a conformal output. However, obviously this level cannot be reached without passing through the other stages before, as the necessary preconditions are established there to set up a closed-loop control.

5.1 State of technology and research for additive manufacturing

Additive manufacturing for the production of end-use parts can be categorized somewhere in between the first two stages. Though certain experts, who are long-term experienced, have a very detailed process knowledge, that is not commonly available for the operator. Thus, detailed process definitions are still missing. Some machine manufacturers provide first approaches for process monitoring, but their significance is mostly not proven. Despite the machines capture a high data volume during the build process, this is not used for further analysis.

Extended research work has been done on different methods of process monitoring to detect defective products already during the build process itself. This is mostly focused on the observation of the melt pool or the laser beam characteristics. [17] [18] [19] These approaches do not include self-adjusting of the process but expect manual intervention by the machine operator in case of a detected error. A full implementation of these methods together with a suitable analysis of the captured process data would enable a comprehensive process monitoring.

Another approach is to integrate certain machine characteristics into product development and data preparation, thus increasing dimensional accuracy and repeatability for a certain AM machine [20]. This can contribute to an increased process capability by decreasing the dispersion.

5.2 Supplementary approaches for single-part production

For a further development of the AM process, it is necessary to gather more data of the process. This has to include process capability analysis, as the determination of the status quo is a prerequisite to initiate process improvements.

To enable the assessment of process capability the special requirements of single-part production have to be considered. One possible approach is to define a methodology for machine acceptance procedures, analogous to the existing regulations for subtractive machining [21]. This method has to regard the process specific characteristics of the production process that is analyzed. For AM, these characteristics can be the differences caused by varying position inside the build chamber as well as the application of appropriate tolerances. It is also important, to define the properties, that have to be evaluated. While for conventional manufacturing technologies the mechanical properties are usually predefined by the material used, in AM the material characteristics are formed mainly during the build process. Thus, their testing becomes more important.

To allow a machine performance analysis, which is at the best possible rate valid for single-part production, an appropriate sample part has to be chosen. This is possible for parts with certain variations, which still have a large number of characteristics in common, like dental structures that have a patient specific form, but a common function. For the production of non-related single parts, the determination of machine accuracy and repeatability has to be used to get an impression of the performance.

For long-term capability analysis, different concepts are conceivable: One is to produce a test specimen in every build job or lot. Therefore, it has to be ensured that the properties of this specimen are representative for the produced parts. A second possibility is to evaluate a property that is independent of the part geometry. For AM parts this can be the relative density or size of inner pores, as this influences other properties and is potentially suitable to evaluate the process quality.

6 CONCLUSION

The methods for process capability analysis are not directly applicable for single-part production. Due to their importance in many industries, they should be considered for single-part production as well. The influence of process deviation on the quality costs supports this approach.
For new technologies, the process capability analysis has the potential to enable process improvements and increase the maturity of the technology. This can be achieved by data collection and by gaining a deeper knowledge about the influencing factors and their interdependencies. However, a first step has to be the definition of the process itself, together with the setup of an appropriate monitoring. The ongoing research on monitoring methods as well as on the influencing factors and their interdependency will probably build the basis to achieve this level in the near future.
To enable further analysis, common properties of the different products have to be defined. They are the foundation to apply performance and capability analysis in single-part production. In the context of mass customization, only smaller variations in the products may occur while the general purpose remains the same. It is expected, that a basis of common properties can be found and used for the capability analysis. This becomes much more difficult in case of the production of completely independent products, where it will be more challenging or even impossible to adopt statistical methods.

REFERENCES

[1] Schuh, G., Reuter, C., Hauptvogel, A., Dölle, C. (2015) Hypotheses for a Theory of Production in the Context of Industry 4.0, in Brecher, C. (Ed.): Advances in Production Technologie, Springer International Publishing, Cham, pp. 11-23.

[2] Breuninger, J. et al. (2013) Generative Fertigung mit Kunststoffen, Springer-Verlag, Berlin, Heidelberg.

[3] DIN ISO 22514-1 (2016) Statistical methods in process management - Capability and performance - Part 1: General principles and concepts, Beuth, Berlin.

[4] Zollondz, H.-D. (2014) Die Entwicklung des Qualitätsmanagements im 20. und 21. Jahrhundert, in Pfeifer, T., Schmitt,R. (Eds.): Masing

Handbuch Qualitätsmanagement, Carl Hanser Verlag, München, pp. 16-37.
[5] Dietrich, E., Schulze, A. (2009) Statistische Verfahren zur Maschinen- und Prozessqualifikation, Carl Hanser Verlag, München.
[6] DIN ISO 22514-2 (2015) Statistical methods in process management - Capability and performance - Part 2: Process capability and performance of time-dependent process models, Beuth, Berlin.
[7] Schulze, A. (2014) Statistische Prozessregelung, in: Pfeifer, T., Schmitt, R.(Eds.): Masing Handbuch Qualitätsmanagement, Hanser, München, pp. 696-713.
[8] Brüggemann, H., Bremer, P. (2015) Grundlagen Qualitäts-management, Springer Fachmedien, Wiesbaden.
[9] Westkämper, E. (2013) Struktureller Wandel durch Megatrends, in Westkämper, E., Spath, D., Constatinescu, C., Lentes, J. (Eds.): Digitale Produktion, Springer Verlag, Berlin, pp.7-9.
[10] BITKOM e.V., VDMA e.V., ZVEI e.V. (Eds.) (2015) Umsetzungsstrategie Industrie 4.0, online available: https://www.bitkom.org/Bitkom/Publikationen/Umsetzungsstrategie-Industrie-40.html, 29.05.2017, 17:22.
[11] Huxol, A., Villmer, F.-J. (2016) Special Requirements for Additive Manufacturing of Dental Frameworks, in: Villmer, F.-J., Padoano, E.: Proceedings 6th International Conference Production Engineering and Management, Lemgo, pp. 15-26.
[12] Acatech – Deutsche Akademie der Technikwissenschaften, Nationale Akademie der Wissenschaften Leopoldina, Union der deutschen Akademien der Wissenschaften (Eds.) (2016) Additive Fertigung, München.
[13] Huxol, A., Villmer, F.-J. (2014) Additive Manufacturing Processes Quality Management, in: Villmer, F.-J., Padoano, E.: Proceedings 4th International Conference Production Engineering and Management, Lemgo, pp. 167-177.
[14] GE additive, online available: http://www.geadditive.com/#experience, 31.05.2017, 15:04.
[15] Stükerjürgen Aerospace Composites GmbH&Co.KG (2017) http://www.stuekerjuergen.com/de/sac/fertigungsverfahren/3d-printing/, 31.05.2017, 15:09.
[16] Kleinsorge, P. (1999) Geschäftsprozesse, in Masing, W. (Ed.): Handbuch Qualitätsmanagement, Carl Hanser Verlag, München, Wien, pp. 49-64.
[17] Berumen, S. et al. (2010) Quality control of laser- and powder bed-based Additive Manufacturing (AM) technologies, in Physics Procedia, 5, Elsevier, pp. 617-622, online available: http://ac.els-cdn.com/S1875389210005158/1-s2.0-S1875389210005158-main.pdf, 22.03.2017.
[18] Craeghs, T., Clijsters, S., Yasa, E., Kruth, J.-P. (2011) Online Quality Control of Selective Laser Melting, in Solid Freeform Fabrication

Sympsoium, online available https://sffsymposium.engr.utexas.edu/ Manuscripts/2011/2011-17-Craeghs.pdf, 05.05.2017.

[19] Ackerl, C. et al. (2015) Entwicklung eines Qualitätssicherungssystems für das Metall-3D-Drucken, in 09. Forschungsforum der Österreichischen Fachhochschulen, online available http://ffhoarep.fh-ooe.at/handle/123456789/355, 15.02.2016.

[20] Eschey, C. (2013) Maschinenspezifische Erhöhung der Prozessfähigkeit in der additiven Fertigung, Utz, München.

[21] VDMA 8669 (1999) Capability study for the acceptance of cutting machine tools, Beuth, Berlin.

PREPARE ORGANIZATIONS TO ACCEPT RISKS: A FEASIBLE RISK MANAGEMENT MODEL

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Abstract
Projects are well-known context of uncertainty and project managers have to deal with it in the face of other issues as productivity, efficiency, limited financial and human resource, time schedule etc. Previous studies and practices have proposed risk management models that include identification and assessment of risks and measures to control them, but in several cases the complexity of the model and the amount of data to feed it make its actual implementation difficult. The aim of the study here presented is to provide a feasible framework that can support risk acceptance on the basis of the identification and assessment of risks in an actual project management context. Accepting a risk can be counted as a strength of seizing new opportunities from uncertainty. The model, which the framework produces, can be designed and optimized step-by-step. Initially, the model is designed with a five-step DRIVE procedure, then it is reviewed and optimized by a DMAIK procedure. The proposed framework supports the building of a flexible and a practical model, which is efficient and effective for risk management in projects and can create new opportunities for a company by accepting the risk.

Keywords:
Risk, Project Risk Management, Risk Management Framework, Project management, Process improvement

1 INTRODUCTION

Projects are planned and scheduled in response to problems or opportunities and aim to achieve specific objectives; however, the application scenarios are subject to unpredictable events and a significant amount of data are based on estimations. Due to uncertain future events, uncalled-for outcomes are contingent during the life cycle of the projects. Organizations carry out projects in order to achieve strategic goals and produce results that affect their activities in the medium and long term and imply the commitment of a large variety and quantity of resources. Risk and opportunities can emerge at the beginning or during the development of projects, which cannot be overlooked. Events can be ambiguous, as far as their desirability is concerned; accordingly, companies usually classify them either as risks or opportunities. Nevertheless, managers need to prepare the organization and projects to face the consequences of the events to avoid any losses in case of risk or seize the advantages. In this respect, the risk management plan could play the role of a dynamic management tool that seeks new competitive advantage [1] [2]. In this paper addresses the comprehensive prospect of risk management Tab. 1, that uncertainty could be counted as an eligible milieu to gain new opportunities because a risk management is scouting favorable outcomes [2] [3] [4] [5]. Sir Winston Churchill said, “An optimist sees the opportunity in every difficulty, a pessimist sees the difficulty in every opportunity”. On the other hand, without any uncertainty or struggle, there will be no progress and innovation [6] [7]. So even for the developed organizations, the risk management plan could be a tool to keep organizational sustainability and concurrently open new lines of improvement and progress in many aspects including capturing new markets, developing new production, improving existing services or products etc. One promising way of tackling the conversion of risks to opportunities is to utilize a proper risk management model as a procedure to catch flexibility and quick response ability to take the advantage of uncertain outcomes. Several risk management frameworks have been proposed by researchers and practitioners, but most of them are identifying the basic steps or bias towards to avoid or transfer the risk. In fact, in this way, high costs will be incurred by the organization just because of a pessimistic view of managers and choosing wrong strategies to respond to risks. Some steps are common to all the frameworks and some of them are customized version of an existing model. In this paper, a new framework will be redesign and improved by two process improvement tools DMAIC[1], DRIVE[2] by keeping beneficial paces of existing models, modify, combine or merge suggested steps in other models and add some new measures with the aim of making a feasible risk management model to prepare the organization to accept the risks. In the following section, a short review of the most well-known risk management model is presented.

2 REVIEW OF LITERATURE

Morphologically the word Risk derived from one of the words “resicum” with Latin root, “rhizikon” with Greek root or “risque” with French root within the meanings are in related with threats or avoiding threats. Also, a literature review on the traditional concept of the risk clarifies that from the traditional point of view, risk was in liaison with a threat in an uncertain event. However, in the last decades, risk implied an event that could produce two or more

[1] Define, Measure, Analyze, Improve, Control

[2] Define, Review, Identify, Verify, Execute

outcomes and could be defined as a possible loss or gain. Different perspectives are illustrated in Tab. 1.

Table 1: Literature review of the traditional and comprehensive viewpoint of risk in definitions.

	Definition
Traditional prospect	The word "risk" is usually used in the context of a potential hazard or the possibility of an unfortunate outcome resulting from a given action [8].
	Probability of undesirable events [9].
	The study group views risk as the probability that a particular adverse event occurs during a stated period of time [10].
	Risk is a probable frequency and probable magnitude of future loss [11].
	Possibility of loss or injury [12].
	Hazard, chance of bad consequences, loss, exposure to chance of injury or loss [13].
	Risk is the chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard. It may also apply to situations with property or equipment loss [14].
Comprehensive prospects	An uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective [15].
	An uncertain event or set of circumstances that, should it occur, will have an effect on the achievement of the project's objectives [16].
	Thus 'risk' strictly refers to an unknown event drawn from a known set of possible outcomes [17].
	Risk is the chance of something happening that will have an impact on objectives. Activities involving risk can have positive as well as negative outcomes [18].

According to the transition of the concept of risk from a threat to an uncertain event that could include gain or loss, general risk management procedures should be adapted to the new perspective which emphasizes the opportunities in any uncertain event instead of focusing on threats. Also with respect to the plausible opportunities, risk management plans could be counted as a competitive tool for project managers. Aiming to this objective, it is necessary that risk management plans and strategies disclose and exploit the opportunities that stem from uncertainty in projects. The study here

presented takes into account these recent perspectives and counts risk as a source of opportunity.
Different risk management models were suggested by researchers and each one has its own pros and cons. Twenty models [27-50] – suggested by researchers, standard models or customized models implemented in organizations – were used as a foundation for redesigning and improving the existing risk management approach with the aim of implementing beneficial measures to accept the risk. All these models have four steps in common, namely Risk Identification, Risk Evaluation, Risk Response and Risk Monitoring. Some of these models include the basic steps and some of them are more detailed. Still, most of the frameworks are not immediately applicable as practical procedures, so organizations should use these basic models to create a customized model for their own use. Case studies depict that risk management plans improve resource allocation [19] [20], quality of operation [21] [22] [23], cost deduction [24], shortening time schedule [25] [26], improve flexibility [26], and improve monitoring of projects [25] [26]. All of these accomplishments are opportunities that were seized by risk management plans. On the other hand, most organizations are using frameworks to avoid loss as a consequence of risks. So accepting the risks could be an opportunity to open new avenues and exploit the uncertainty, differently from other organizations that want to avoid any kind of risk. According to this aspect, beside the other benefits of risk management strategies, making a decision between possible responses for a risk, acceptance strategy would be a competitive advantage. In this paper, we suggest an efficient way to prepare organizations to accept risks by redesigning a feasible risk management framework which is more suitable for project managers who are inclined to accept the risks. In the following section the methodology of design the new model will be discussed.

3 METHODOLOGY

3.1 General review of methodology

This study is part of an applied qualitative research that uses process improvement methods to reconstruct a risk management model by utilizing existing measures and approved steps of risk management frameworks, combine them and add specific features or definitions to make the steps of a new procedure aimed at improving risk acceptance in projects. A systematic literature review of academic and business organizations' documents and records, and unstructured interview (in-depth interview), as Legard et al. described [51], have been done to collect data and define the existing models, their steps and the best measures that could improve such procedures. Ten project managers were interviewed for this reason: they were selected among managers active in steel industry projects in Iran, who are eager to share their experience and knowledge, and also have related professional experiences in risk management. After data collection, the design procedure started.

DRIVE problem-solving procedure [52] was used to design the new model. The step by step process map of the methodology that was used in this research is illustrated in Fig. 1.

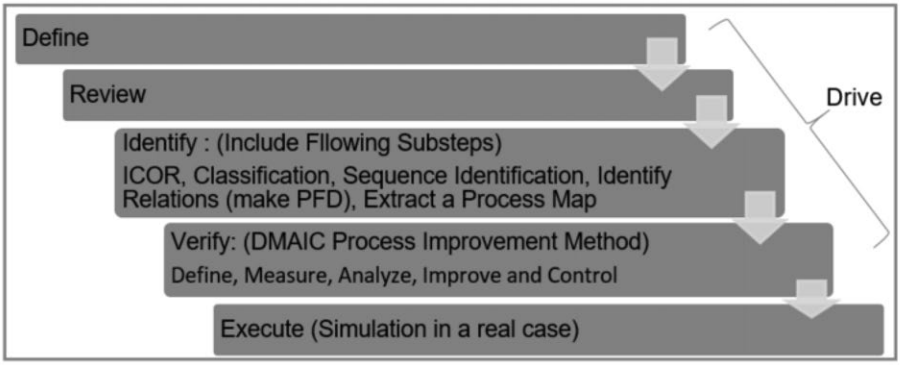

Figure 1: Step by step illustration of methodology in this research.

As depicted in Fig. 1, the identification and verification of the new process include sub methods for carrying out the integrated process improvement methodology. The third step of Drive consists of the following steps: identifying the basic elements of risk management framework by ICOR method, categorize the activities in 4 categories, identify the Sequence of steps and relation between them by Process Flow Diagram (PFD), identify main relations in PFD, and extract a Process Map. DMAIC method will be used in the fourth step of DRIVE procedure for verifying the new model. DMAIC is an abbreviation of the process amelioration phases composed of Define, Measure, Analyze, Improve and Control. The last step of DRIVE is Execution to approve the validity of the designed model. In this step, a simulation of a risk will be used to evaluate the response of the model.

3.2 Phase 1: Define

This procedure starts with the Define step that includes clarifying the problem and the objectives. In several cases, the complexity of the model and the amount of data to feed it make its actual implementation difficult. The aim of the study here presented is *to provide a feasible and dynamic framework that can support risk acceptance on the basis of the identification and assessment of risks in an actual project management context*. The resulting framework could be used in any kind of project.

3.3 Phase 2: Review

As a primary step, it is necessary to become familiar with the existing risks, methods, and strategies in projects to make any improvement in the total framework. To review the prevailing condition and existing risks, a literature review and unstructured interviews have been accomplished. The interviews were performed with 10 project managers who were involved in industrial projects in the steel industry in Iran. The defined risks provide a comprehensive review of the investigated sector – industrial projects in steel industry – with the aim to find the best model for treating the prevailing uncertainty and respond to the listed existing risks. More than twenty risk management models [27-50] were reviewed as the base processes aimed at combining, reforming and adding the necessary steps to improve and reconstruct a new feasible meta-model.

3.4 Phase 3: Identify

In this phase, all of the required base activities to respond to a risk would be defined according to the reference models. To this end, the ICOR Method is used to transform a total idea to feasible steps in practice (Fig. 2). The ICOR model of risk management process consists of independent activities: determine the scope and background, identify and define risks (define risks, identify possession and responsible, identify the motives), risk probability (RBS, qualitative evaluation, forecasting), quantitative evaluation (severity, impacts), position in probability-impact chart, SWOT (brainstorming, knowledge management and recorded information, literature review), response decision making, execute, monitoring, report.

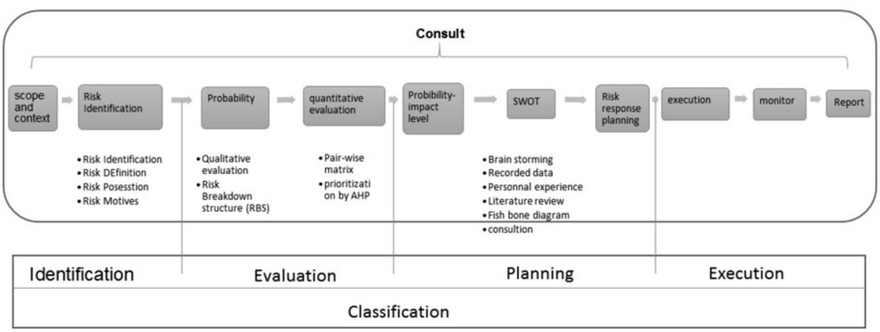

Figure 2: The ICOR model of risk management process and steps classification.

The next step in this phase is making a taxonomy to simplify and clarify the whole idea of several practical steps. We classified existing steps in 4 categories (Fig. 2). Then the succession of the activities will be defined and the relations will be identified to make PFD. Finally, the measuring point or the source of the feedback and the receiver should be identified.

3.5 Phase 4: Verify

In this step, DMAIC problem-solving method is used to improve the risk management model. DMAIC is an approved method which is used for problem-solving and improving the process as a core tool of Six Sigma projects: it could then be helpful to use it to solve the problems dynamically during the implementation of a risk management model. The aim of this step is to verify if the new risk management model takes advantage of all the characteristics of the DMAIC method to make it dynamic. DMAIC five steps (Define, Measure, Analyze, Improve and Control) were adapted to build the new meta-model (Fig. 3). The first sub step is Define. According to DMAIC definition, in this step, all the existing routes in the process should be defined to make a dynamic process. If the risky event does not happen, the model should guide decision maker to evaluate another one, so a conditional step added in the model that if any event does not happen, the decision maker leads to the start point of the model - see NR in Fig. 3. This conditional operator would be added after risk assessment. If the evaluated risky event, which had been chosen by sensitivity analysis, does not happen, the decision maker will go to the start point to evaluate the next risk. In this way during the life cycle of the project, all of the risks are evaluated and controlled dynamically as a cycle. This helps the model become more feasible than just a pure theoretical model. The second sub step is Measure. Also, the risk management model should include some measuring points to evaluate the functions, the performance of the made decisions and the way in which decisions are applied. So the model should include feedbacks to measure the deviation from the objectives. The source of the feedback could be located after all of the execution monitoring points, and the reports should be sent to the risk response planning step to revise the decisions, measure or the way of implementation of a measure; this feedback is indicated as FE in Fig.3. The third sub step is Analyze the expected condition comparing it with the existing situation. This measure should be done when an event, issue or risk happen. If the response is proper, the measures should be recorded to next use, because knowledge management is a basic prerequisite that supports risk management. If the response failed, the management process should turn to crises management and then recovery strategies. If the process heads for a recovery strategy, it should lead to risk evaluation and identification point of the risk management cycle to evaluate the opportunities and threats of the recovery plan. This route is indicated as REC in Fig. 3.

The fourth sub step is Improve the process. To provide a dynamic model, the improvement procedure is set inside the probability-severity chart. This measure is unique for this model and aims to improve the organizational capacity of risk acceptance by investigating any possibility to change the current position of the risk in the chart. To this end, the possible measures are evaluated with respect to organizational strengths, weaknesses, opportunities and threats of each measure to find a solution to move toward the reasonable risk acceptance area in the chart. This section, indicated as IMP in Fig. 3, turns the framework to a self-improving dynamic meta-model.

As the last step of DMAIC procedure, the model is controlled to be a close circuit process without breaks in the possible routes.

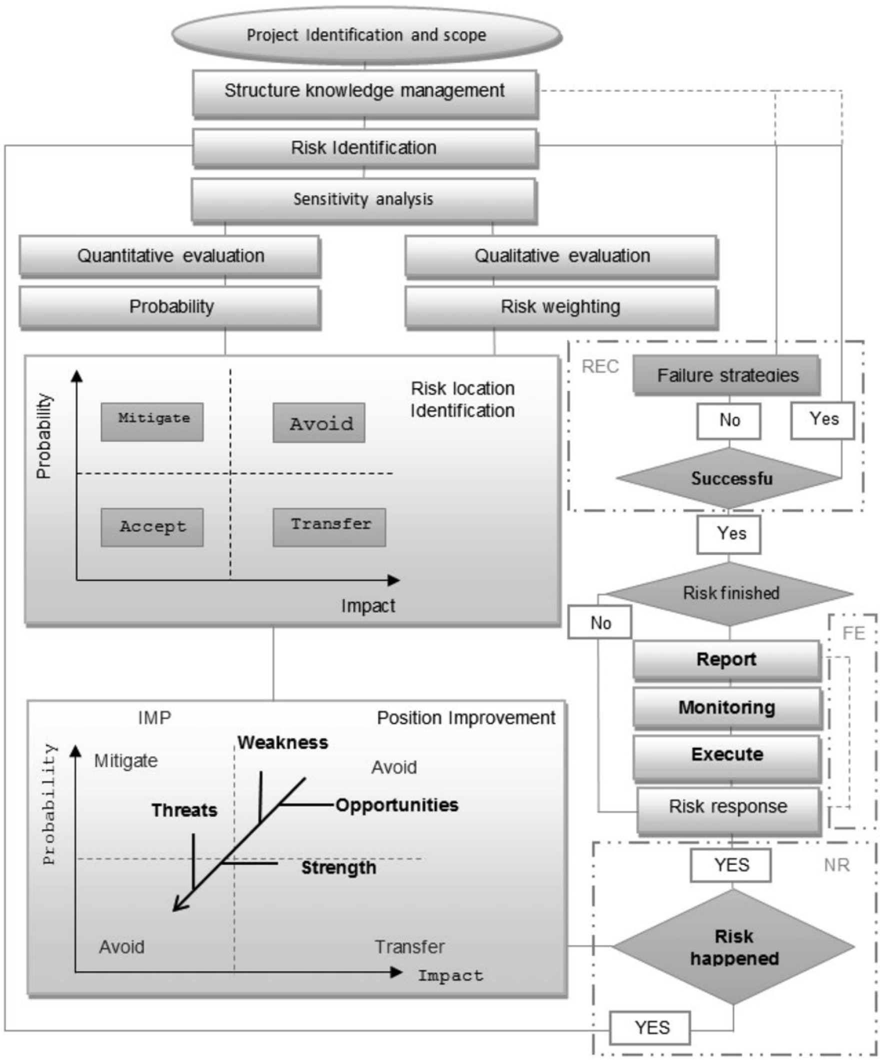

Figure 3: Improved meta-model.

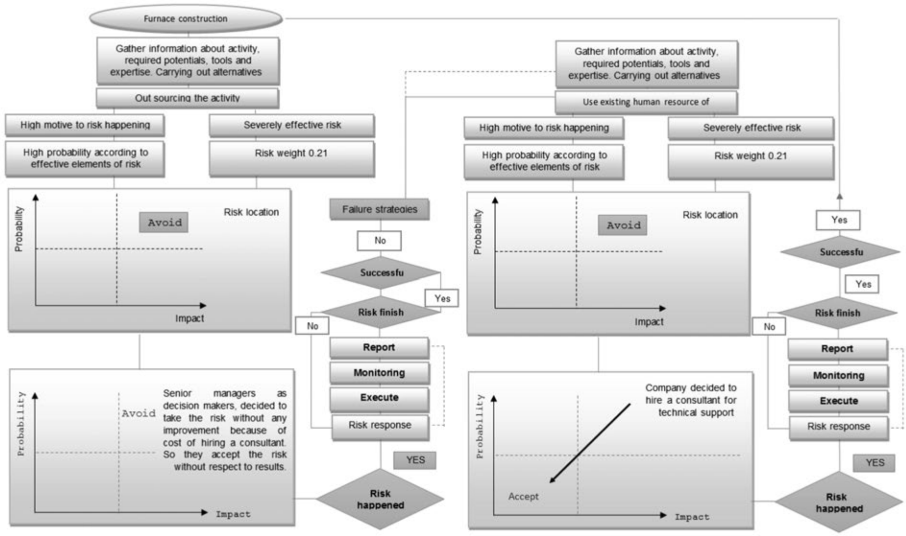

Figure 4: Model implementation in a real case.

3.6 Phase 5: Execution

The last step of the DRIVE process is an execution of the improved procedure. To this end, a simulation has been done on a real industrial case. The investigated risk was the decision to outsource one activity to a contractor. The project was the construction of a continuous Hot Rolling Mill Plan in IRAN and installation of the Reheating Furnace outsourced to an external contractor because of the limited knowledge and experience of the available human resources in the area. The risk of outsourcing was accepted but, due to the lack of information about the background of the contractor, the sub project of furnace construction failed and the project went into a recovery strategy. In the second loop, the risk of building the furnace by means of internal human resources and a consultant to overcome the technical weaknesses was accepted as a position improvement method in the probability-impact chart. This time the furnace sub project was successful and closed ahead of schedule. This case shows that according to this model and making some changes in the organization, a risk could be accepted and become an opportunity to compensate the lost time of the previous failure. The model usage is illustrated in Fig. 4.

4 DISCUSSION AND CONCLUSION

Focusing on the execution phase, the importance of three issues can be highlighted. First, risk management is an effective tool to meet the project goals and it is reasonable to use this tool instead of making decision according to personal inference. Indeed, the simulation of the case study showed that if the senior managers, after the first cycle of the model, had decided to accept the risk without any improvement, the project would have ended in failure. Second, the simulation showed that the proposed meta-model is an effective and efficient tool that can lead project managers to accept the risk successfully. Third, risk management model should include a section for failure strategies, since if a risk happened and adversely affected the project and its goal achievement, the project must react rapidly to save and recover its goals, as it happened in the case study (Fig.4). To sum up, the case study in the Execution phase showed that the meta-model is a framework for risk management that enables risk acceptance. A future development of the research will be focused on the evaluation of project changes in term of acceptance of different risks.

REFERENCES

[1] Bekefi, T., Epstein, M. J., and Yuthas, K. (2008) Creating growth: Using opportunity risk management effectively, Journal of Accountancy, 205(6): 72.

[2] Anderson, E. J. (2013) Business risk management: models and analysis, John Wiley & Sons.

[3] Hillson, D. (2002) Extending the risk process to manage opportunities, International Journal of project management, 20(3): 235-240.

[4] Chapman, C., Ward, S. (2011) How to manage project opportunity and risk: Why uncertainty management can be a much better approach than risk management, John Wiley & Sons.

[5] Westerman, G., Hunter, R. (2007) IT risk: turning business threats into competitive advantage, Boston: Harvard Business School Press.

[6] Kastelle, T. (2013) There’s No Innovation Without Uncertainty, 10 April 2013. [Online]. Available: http://innovationexcellence.com.

[7] Douglass, F. (2000) Frederick Douglass: Selected speeches and writings, Chicago Review Press.

[8] Correia, C., Flynn, D., Uhana, E., and Wormald, M. (1989) Financial Management, 2nd edn., Juta and Co. Ltd, Cape Town.

[9] Royal Society (1983) Risk Assessment: Report of a Royal Society Study Group, Royal Society.

[10] Dobson, I., Hietala, J. (Eds.) (2011) Risk Management-The Open Group Guide.

[11] Merriam-Webster (2004) Merriam-Webster's collegiate dictionary.

[12] McLean, I., McMillan, A. (2009) The concise Oxford dictionary of politics. OUP Oxford.

[13] BS OHSAS 18001, Occupational Health & Safety, BSI Group.

[14] PMI, (2008). A guide to the project management body of knowledge Project Management Institute. Newton Square, PA.

[15] Simon, P., Hillson, D., and Newland, K. (Eds.) (1997) PRAM: Project risk analysis and management guide, High Wycombe: Association for Project Management.
[16] Hillson, D. (2003) Effective opportunity management for projects: Exploiting positive risk, CRC Press.
[17] VV. AA. (2004) Handbook: Risk Management Guidelines, Companion to AS/NZS 4360: 2004. Standards Australia Internal Ltd, Sydney.
[18] Lyneis, J. M., Cooper, K. G., and Els, S. A. (2001), Strategic management of complex projects: a case study using system dynamics, System Dynamics Review, 17(3): 237-260.
[19] Kerzner, H. (2013) Project management: a systems approach to planning, scheduling, and controlling, John Wiley & Sons.
[20] Dale, B. G., Van der Wiele, T. and Van Iwaarden, J. (2007) Managing quality, John Wiley & Sons.
[21] Gido, J., Clements, J., and Clements, J. (2014) Successful project management, Nelson Education.
[22] Ayyub, B. M. (2003) Risk analysis in engineering and economics (Vol. 579), Boca Raton, FL: Chapman & Hall/CRC.
[23] Potts, K., Ankrah, N. (2014) Construction cost management: learning from case studies, Routledge.
[24] Edwards, P., Bowen, P. (2013) Risk management in project organisations, Routledge.
[25] Walker, D. H., Shen, Y. J. (2002) Project understanding, planning, flexibility of management action and construction time performance: two Australian case studies, Construction Management & Economics, 20(1): 31-44.
[26] IRM (2002) A Risk Management Standard. In London: Association of Insurance and Risk Managers, the National Forum for Risk management in the Public Sector (ALARM), Institute of Risk Management (IRM), Available: www. theirm. org/publications/doc.
[27] Cienfuegos Spikin, I. J. (2013) Developing a risk management maturity model: a comprehensive risk maturity model for Dutch municipalities, Universiteit Twente.
[28] Hillson, D. A. (1997) Towards a risk maturity model, The International Journal of Project & Business Risk Management, 1(1): 35-45.
[29] Opgenorth, K. (2017) What is the COSO Enterprise Risk Management Framework? (Updated), KnowledgeLeader Blog, Feb 2017, Available: info.knowledgeleader.com/bid/163293/what-is-the-coso-enterprise-risk-management-framework.
[30] Joint Task Force Transformation Initiative (2010). Guide for applying the risk management framework to federal information systems, NIST special publication, 800-37.
[31] Smith, P. G. (2002) Managing risk proactively in product development projects, in: IPLNET workshop, Switzerland.
[32] Leach, L. P. (2014) Critical chain project management, Artech House.

[33] Fairley, R. (1994) Risk management for software projects, IEEE software, 11(3): 57-67.
[34] Boehm, B. W. (1991) Software risk management: principles and practices, IEEE software, 8(1): 32-41.
[35] Dorofee, A. J., Walker, J. A., Alberts, C. J., Higuera, R. P., and Murphy, R. L. (1996) Continuous Risk Management Guidebook, Carnegie-Mellon University, Pittsburgh.
[36] Hillson, D. (2002) The Risk Breakdown Structure (RBS) as an aid to effective risk management, in 5th European Project Management Conference. Cannes, France.
[37] HM Treasury (2004) The Orange Book: Management of Risk-Principles and Concepts, London: HM Treasury.
[38] Kliem, R. L., Ludin, I. S. (1997) Reducing project risk, Gower Publishing.
[39] PMI (2004) A guide to the project management body of knowledge, Project Management Institute (Vol. 3).
[40] Bartlett, J. (2004) Project risk analysis and management guide, APM Publishing Limited.
[41] Pritchard, C. L. (2014) Risk management: concepts and guidance, CRC Press.
[42] Purdy, G. (2010) ISO 31000: 2009—setting a new standard for risk management, Risk analysis, 30(6): 881-886.
[43] Luko, S. N. (2013) Risk management principles and guidelines. Quality Engineering, 25(4): 451-454.
[44] Subramanian, A., Srividhya, V. S. (2008) 360 Degree RISK Management Model: A New Model to Rate, Mitigate and Exploit Opportunities, Project Management Institute.
[45] Nicoms (2017). Available: www.nicoms.co.uk/index.php /case-studies/risk-management/.
[46] Investors in risk management (2016), Available: www.iirmglobal.com /risk-maturity-assessment/iirm-risk-management-framework.
[47] SRA Regulatory Risk Framework, Authority Solicitors Regulation, March 2014. Available: www.sra.org.uk.
[48] Vlek, C. A. (1990) Beslissen over risico-acceptatie: een psychologisch-besliskundige beschouwing over risicodefinities, risicovergelijking en beslissingsregels voor het beoordelen van de aanvaardbaarheid van riskante activiteiten. Gezondheidsraad.
[49] Chapman, C., Ward, S. (2003) Project risk management: processes, techniques and insights. John Wiley & Sons.
[50] Moeller, R. R. (2007) COSO enterprise risk management: understanding the new integrated ERM framework, John Wiley & Sons.
[51] Legard, R., Keegan, J., and Ward, K. (2003) In-depth interviews, Qualitative research practice: A guide for social science students and researchers, 138-169.
[52] Boutros, T., Cardella J. (2016) The Basics of Process Improvement, CRC Press.

SESSION C
Direct Digital Manufacturing in the Context of Industry 4.0

NONDESTRUCTIVE QUALITY CHECK OF ADDITIVE MANUFACTURED PARTS USING EMPIRICAL MODELS

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Abstract
Additive manufacturing (AM) has matured rapidly during the last years due to the advancement of AM machines and materials. Nevertheless, the widespread adoption of AM is still challenged by producing parts with reliable quality. The aim of this paper is to introduce a first approach to apply in-situ monitoring for quality evaluation of produced parts. Based on the monitored data, a model is developed, in order to predict the quality of ready built parts.

Keywords:
Nondestructive quality control, Predictive analytics, Metal model, Additive manufacturing

1 INTRODUCTION

Additive manufacturing (AM) is increasingly used to design new products. Nevertheless, the deficit of quality reliability of these products is a key technological barrier that prevents manufacturers from adapting AM technologies. The lack of part quality means inadequate dimensional tolerances, surface roughness, embedded material discontinuities, and defects. Some quality issues can be attributed to AM process parameter settings. Others depend on the material integrity and the repeating accuracy of the machines. Repeatability of AM machines still needs to be improved. Therefore, the part quality of each part of a build job has to be ensured. This requires the application of nondestructive methods like contour scans, x-ray and ultrasonic, which are expensive and time-consuming. At the current state of technology, AM machines capture a large amount of sensor data during part production, which is used to evaluate the unobstructed function of the machine. This in-situ monitoring is currently not applied to evaluate the part quality.
The aim of this paper is to introduce a first approach to apply in-situ monitoring for quality evaluation of AM parts. Therefore, parts with a simple geometry are built several times on the same AM machine, some with different parameters some with the same parameters. The in-situ monitored data for every build job is saved. The porosity of the parts at different layers is documented and rated using metallographic analysis. The porosity is an important characteristic, as it is strongly influenced by the energy input into the system. On the other hand, it is the prerequisite for achieving good

mechanical properties. The in-situ monitored data and the evaluated porosity data form the basis for predictive analytics. These statistical methods combined with data mining techniques and experimental design are used to predict future events, in this case the quality of a built part.
Finally, the results of the developed predictive models are discussed as well as possibilities for future developments of the results.

2 STATE OF TECHNOLOGY

In-situ monitoring does already collect a number of parameters, but these parameters are currently not used for quality evaluation. In the following chapter, the different parameter groups and their potential use are presented and discussed. Moreover, methods for quality inspection of additively manufactured parts are discussed.

2.1 Process parameters

Process variables and their correlations can be broken down into four main groups [1]: feedstock, build environment, laser and melt pool. In addition, a fifth group is added, which includes photographic images of each layer before and after exposition to the laser. In the following, these groups are described in more detail.

Feedstock

Feedstock describes the part of the powder storage of the machine and the facility, which transports the powder into the build chamber. The material itself is also part of the feedstock. Feedstock parameters include, for example, the moisture content of the powder and the actual size distribution of the powder. Here, pourability could be one measured value. Material suppliers deliver data on composition limits and powder size distribution but do not provide information on the stock condition. It is well known that size distribution has a major effect on the produced density and porosity [2]. The recycling of the powder can increase the size of the powder particle [1]. Today the actual feedstock parameters are not measured or logged during the build job.

Build Environment

The build environment in most processes is the natural starting point for process monitoring. Many variables can be monitored, which enable a first quality management. Some machine providers use the build environment parameters to avoid hazardous situations, e.g. to stop the build process in case the oxygen content inside the build chamber gets too high. Predefined parameters of the material, like thermal conductivity, heat capacity and melting temperature are used to optimize the laser parameters during the pre-processing. Throughout the build process of an AM part, a well defined environment in the chamber is needed. Some machine producers provide quality reports with an optimal range of the environmental parameters. The quality reports contain chronological records of the development of these parameters. Tab. 1 gives an overview of the build environment parameters.

Table 1: Extract of build environment parameter [1].

Parameter	*Description*	*Controllable/ Predefined*	*Logged*
Shield gas	Usually Ar or N_2	Pred.	Yes
Oxygen level	Leads to oxide formation in metal	Controllable	Yes
Pressure	Influences vaporization of metal	Controllable	Yes
Gas Flow velocity	Influences convective cooling, removal of content	Controllable	Yes
Chamber temperature	Appears in heat balance, may impact residual stress	Controllable	Yes
Powder bed temperature	Bulk temperature of the powder bed	Controllable	Yes

Laser and melt pool

The quality of the generated part also depends on the stability of the melt process. Many research work is done to characterize the melt pool in its depth, length, and width. An optimization of the laser parameters, like laser power or scan speed, to stabilize the melt pool dimension for different part geometries, was made by Ilin [3]. Machine suppliers use different camera systems to monitor the width and length of the melt pool [4]. The depth cannot be measured in-situ, it is a derived parameter [2]. The applied energy is one of the major factors affecting the stability of the melt process. In turn, the energy is influenced by the laser parameters in terms of scan strategy and spot size. These parameters are often logged during the build process. Another approach is to analyze the melt pool radiation by using a photodiode and a camera, which record the radiation in the infrared range and take high-resolution images. Thus, irregularities during the melt process can be recorded. The information on the melt pool size and form can be visualized and manually evaluated by the machine operator or quality manager after the build process. A picture of every layer can be analyzed and in case of anomalies a detailed inspection can be initiated. At the current state of technology, an automated evaluation or reporting is not performed. [5]

Photographic images
In addition to the high-resolution cameras, simple snapshots are taken and used to monitor the build process. These snapshots have a comparatively low resolution and are taken firstly after melting a layer and secondly after the powder layer has been applied. The snapshots are analyzed automatically to find discontinuities of the powder layer, e.g. when the recoater blade is damaged. On Selective Laser Melting (SLM) machines this is done by analyzing the distribution of the measured shades of gray of the powder bed. If the shade of gray is within the normal distribution, the build job continues without delay. If the shade of gray differs from the predefined distribution the powder coating is repeated up to four times. If still an anomaly is detected, the machine operator is informed and decides whether the build job will continue or stop.
The images of every layer after melting are normally not used for quality control of a build job. The light reflections of the surfaces strongly depend on the position of the viewed surface to the camera and to the light sources. It is also influenced by the direction of the hatch and the orientation in which the surface was built. These relationships must be taken into account when evaluating the photographs.

2.2 Nondestructive quality inspection

The additive manufacturing process uses localized material addition on a layer per layer basis to build up a part. All these parts contain defects, which are expected and do not definitively mean the part is unfit for use [6]. As a result, inspections of high-value components are essential in order to assure that the manufactured part is fit for use. For individual AM parts nondestructive testing (NDT) is the only method that can be employed to gather the defect data required. Therefore, several technologies like x-ray inspection, computer tomography, ultrasonic testing or contour scans are applied to prove the quality of an AM part.

3 RESEARCH APPROACH

The research approach is based on the idea of using data mining processes and techniques to predict the mechanical properties of the built part from the logged process parameter. Mechanical properties correlate to a lot of process parameters which are logged. Supervised learning as a method for data analysis can be applied to estimate the unknown dependencies between known input-output data [7]. The input variables include the logged data of the AM process. The output variables are the chosen mechanical properties. Output variables are also known as targets in data mining. In a supervised environment, sample input variables are passed through a learning system. The subsequent output of the learning system is compared to the output of the sample. In other words, it is tried to predict the chosen mechanical properties of the built part based on the logged data. To get the training data it is necessary to build AM parts and perform the crucial NDT or destructive testing to receive the output variables for the training data.

4 CASE STUDY

The aim of the paper is to show that supervised learning methods can be used to predict the mechanical properties, which enables the quality evaluation of the parts produced. In this case, a very simple build process is chosen to prove if the research approach works. Therefore, simple cubes with the edge length of 8 mm and three cylinders have been built by an SLM process (Fig. 1). The support structure has a height of 4 mm.

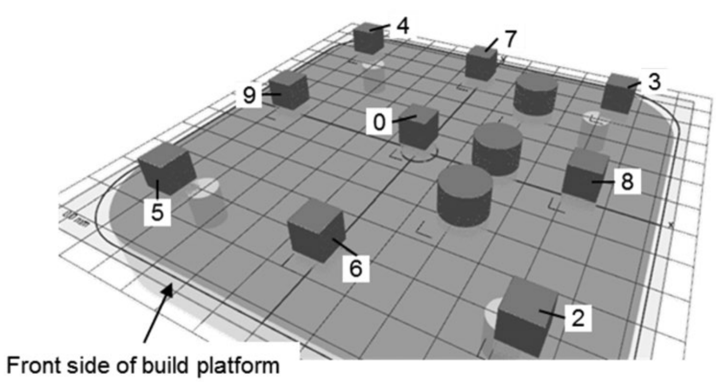

Figure 1: Arrangement of samples on the build platform.

The porosity of the cubes is chosen as target for the quality of the parts. During the SLM process, simple snapshots with relatively low resolution were logged after melting each layer. Tab. 2 shows the other protocoled data.
The porosity of the sample parts is evaluated by metallographic analysis. For this, a vertical cross section of the samples is grinded, polished and etched following a standard procedure for preparation. Microscopic images are taken in five defined positions of the section and are analyzed.

Table 2: Process parameter logged.

Parameter	*Description*	*Sample period*
Hatch	Direction of the hatch per slice and cube	12 times per slice
Oxygen level	Percentage of oxygen in the build atmosphere	4 times per slice
Gas Pressure	Pressure in the cabinet vaporization of metal	4 times per slice
Cabinet temperature	Temperature in the chamber	4 times per slice
Heater temperature	Temperature of the heater	4 times per slice

The parts are built three times with the identical parameter settings. The porosity of all built cubes is measured at certain areas. The results for cube 2 are listed in Tab. 3.

Table 3: Results porosity measurement, cube 2.

Position of measurement	*Porosity [%]*		
	Feb17	*Mar17*	*Jun17*
Center bottom (Cb)	0.52	0.35	0.06
Center top (Ct)	0.19	3.33	0.08
Center center (Cc)	0.10	0.86	0.10
Left center (Lc)	1.01	3.18	0.17
Right center (Rc)	0.26	0.03	0.02

In a first step, some pre-analytics are done. Fig. 2 shows the heater temperature versus the slice for the three build jobs with identical parameter settings. The jobs Feb17 and Mar17 behave similarly. The job Jun17 shows a different behavior.

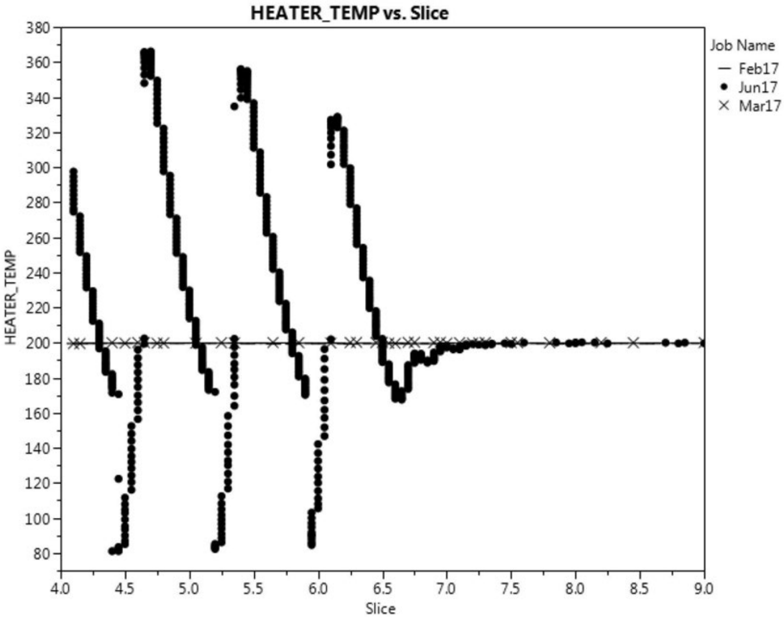

Figure 2: Heater temperature versus layer.

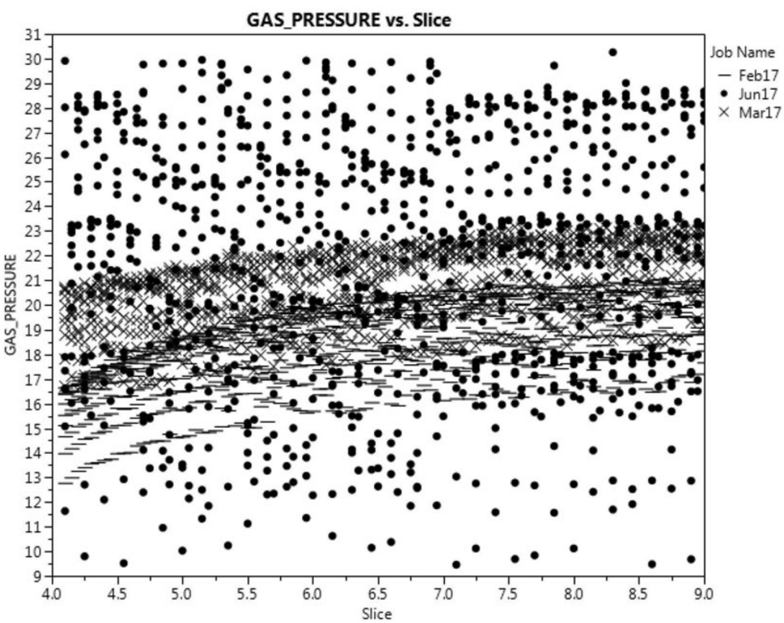

Figure 3: Gas pressure versus layer (slice).

The measured heating temperature of build job Jun17 differs significantly from the measured temperature of the other jobs. Until a building height of 8 mm the temperature fluctuates between 370 and 80°C. Above that building height no fluctuations are measured. Fig. 3 shows also the gas pressure for each building height. Again build job Jun17 stands out with a significant fluctuation of the gas pressure between 10 and 30 mbar. Despite these noticeable deviations, the evaluation of the porosity of all cubes of this build job shows a perfect porosity (Tab. 4). The build job Jun17 even has the best results for porosity of all build jobs. It is well known from the literature that a change of temperature leads to residual stress. However, in this case the residual stress has not been in the focus of the research.

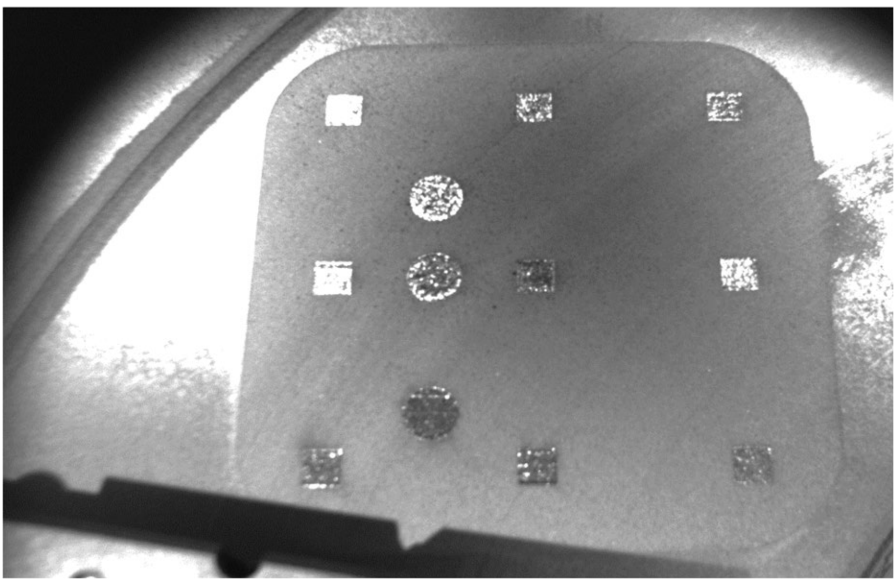

Figure 4: Snapshot after melting a layer on 10.95 mm height of job Feb17.

Fig. 4 shows a snapshot of the melted layer at 10.95 mm height in the build job Feb17. It is known from the porosity measurement, that this layer shows a low porosity. The brightness of the surface of a layer in the cube depends on the melting quality as well as on the hatch direction and the position of the cube relative to the chamber light and to the camera position. As a first step, simple snapshots are used to predict the porosity of the parts. For that matter, detailed information about the shape and the location of the pores are not important. The main goal is to find out if the porosity is small enough or suitable to fulfill the quality requirements. If the value of the porosity is too high, a detailed investigation by an NDT method, for example, x-ray, has to be done. Thus a single case decision on the applicability of the part has to be made.

4.1 Predictive model

To build the predictive model, training data is necessary. Therefore, the snapshots of the layer of cube 2 were taken. In this case information about the porosity is given. For each layer, an average value of the brightness in a gray scale is calculated. Additionally, the information for the porosity is added as “0” if the porosity is too high and “1” if the porosity is small enough. In a first step, a predictive model is built to calculate the average brightness of a layer of cube 2 with small porosity as a function of the hatch direction. In a second step, this correlation is used to forecast an average brightness value for a good layer and compare this value with the measured average gray value of other layers with the same hatch direction. If the measured average value of a layer is smaller than the predefined threshold for a good porosity, the layer is marked with a “0” to indicate a high porosity of the layer.
Fig. 5 shows the micrograph of the cube 2 from the build jobs Feb17 and Mar17. In build job Feb17, no larger pores are visible in the micrograph, as opposed to the micrograph of the build job Mar17. The exact evaluation shows porosities between 0.5% and 1.2% in the build job Feb17.

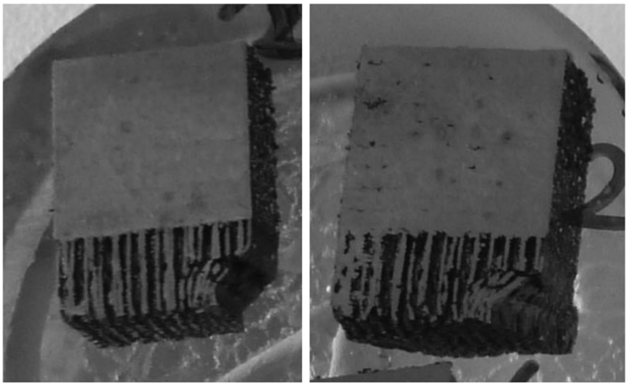

Figure 5: Micrographs of cube 2 - right job Feb17, left job Mar17 [8].

The snapshots of the slices 10 mm to 12 mm and the slices 7.6 mm to 8.35 mm of the job Feb17 are selected as reference.

4.2 Results

The prediction model is formed with the Gaussian algorithm. Fig. 6 shows the quality of the empirical model. For the validation of the model, the images of cube 2 (job Mar17) slices 9.45 mm to 10.35 mm are used. With these layers, the prediction model is expected to predict an inadequate porosity. For the validation, additional layers from the build job Feb17 are also used.

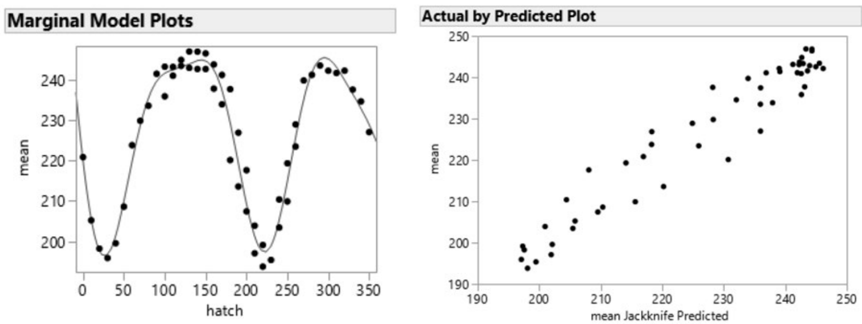

Figure 6: Empirical model.

The results of the validation are presented in the confusion matrix (Fig. 7). The matrix shows that only 25% of the prediction values are determined incorrectly. In the prediction model, no further process parameters have been included as input variables, since no differences in the process parameters between the jobs Feb17 and Mar17 could be determined during the preliminary analysis. The process parameters (Tab. 2) are stored approximately four times per layer and can thus not be assigned to a specific cube, which could be the reason for the indistinguishable process parameter. However, there are also process parameters not yet recorded, such as laser power, and scan speed. Several studies show [2] that laser power, scan speed, and heating temperature of the powder etc. have a significant effect on the melt pool temperature and geometry and therefore on the porosity.

Confusion Matrix		**to (predicted Target)**		
		1	**0**	**all**
from (real Target)	**1**	16	5	21
	0	2	5	7
	all	18	10	28

Figure 7: Confusion matrix.

5 DISCUSSION AND OUTLOOK

In order to work with this approach, the prediction model has to be supplemented with additional information. Only the information from the snapshots, the position of the component to the camera and the direction of the hatch currently have been included in the model approach. In the future, the empiric model will have to be enhanced by information from the logged process parameters.

The current model is not applicable for parts with complex geometry, such as lattice structures. A strategy for the evaluation of complex geometries has to include geometrical information from the machine control data. Here, the shape of the area that has to be melted in each layer is described, as well as the exposure strategy, including the hatch direction. Reference pictures for the complete build platform can be parceled into a regular raster. Together with the geometrical information, a reference picture for each layer can be calculated and applied for the comparison with the actual snapshot. Besides the calculation of the reference pictures, a careful definition of threshold values for the deviation between the reference and the actual image is required.

REFERENCES

[1] O'Regan, P., Prickett, P., Setchi, R., Hankins, G., Jones, N. (2016) Metal based additive layer manufacturing: variations, correlations and process control. Procedia Computer Science, 96, 216-224.

[2] Mani, M., Lane, B., Donmez, A., Feng, S., Moylan, S., Fesperman, R. (2015) Measurement science needs for real-time control of additive manufacturing powder bed fusion processes. National Institute of Standards and Technology, Gaithersburg, MD, Standard No. NISTIR, 8036.

[3] Ilin, A., Logvinov, R., Kulikov, A., Prihodovsky, A., Xu, H., Ploshikhin, V. Bechmann, F. (2014) Computer aided optimization of the thermal management during laser beam melting process. Physics Procedia, 56, 390-399.

[4] Everton, S. K., Hirsch, M., Stravroulakis, P., Leach, R. K., Clare, A. T. (2016). Review of in-situ process monitoring and in-situ methology for metal additive manufacturing. Materials & Design, 95, 431-445.

[5] Concept Laser (2017) QM Meltpool 3D, abgerufen am 24.6.2017, https://www.concept-laser.de/en/products/quality-management.html.

[6] Hirsch, M., Patel, R., Li, W., Guan, G., Leach, R. K., Sharples, S. D., Clare, A. T. (2017) Assessing the capability of in-situ nondestructive analysis during layer based additive manufacture. Additive Manufacturing, 13, 135-142.

[7] Ahlemeyer-Stubbe, A., Coleman, S. (2014) A practical guide to data mining for business and industry. John Wiley & Sons.

[8] Huxol, A., Scheideler, E.M., Villmer, F.-J. (2017) Influencing factors on part quality in selective laser melting in: Padoano, E., Villmer, F.-J.: Proceedings 7th International Conference Production Engineering and Management, Lemgo, pp. 167-177.

SLM BASED TOOLING FOR INJECTION MOLDING – FOCUS ON REDUCED EFFORT IN SURFACE QUALITY OPTIMIZATION

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Abstract
Additive manufacturing technologies can provide cost and time advantages in mold making, compared to traditional approaches. Nevertheless, their applicability is not yet completely proven, especially in terms of surface finishing. The aim of this research work is to create perfect mold inserts by Selective Laser Melting (SLM) and to optimize surface quality. Therefore a process is developed to reduce the effort of surface quality optimization including a high flexibility in design.

The tested process shows that simple and affordable methods can lead to usable molds with only minor restrictions in terms of appearance. Due to the initial reduction of layer thicknesses and distinct settings of laser melting parameters, the surface smoothness is significantly enhanced during the SLM building process. Subsequently blasting, manual grinding, as well as polishing operations, enable a selective smoothening of the surface up to a polished finish. As a result, the built tool parts can be used instantly for injection molding.

Keywords:
Tool making, Direct rapid tooling, Additively manufactured molds, Selective laser melting, Additive manufacturing process chain, Post-processing

1 INTRODUCTION

Selective Laser Melting (SLM) is an additive manufacturing technology that is nowadays applied for the production of metal prototypes and increasingly for end-use products. The direct generation of tools is another important application, which is also called direct rapid tooling. Rapid tooling benefits from an efficient tool generation at a higher freedom of design than traditional machining methods. A distinct limitation of all current SLM applications is the lack of smooth surfaces of the built part. [1] Depending on the shape and the alignment of the part, the surface appears rough, partially even with a mountain-like surface structure. This characteristic impedes the immediate application of the injection molding process right after the build process. When traditional tool shops deploy printed molds or inserts, they commonly post-process the printed tool parts with subtractive NC machining or EDM.

With such post-processes, surface qualities can be enhanced and target dimensions ensured. At the same time, the expected time and resource savings of additive manufacturing (AM) are wasted or over-compensated.
For customized product developments, field tests have to be conducted to evaluate the capabilities of new products before launch and purchase. For additively manufactured parts testing is neither reasonable nor reliable, because a finished AM part often has different material behavior than a printed copy. The physical and optical properties cannot be simulated sufficiently. Furthermore, for large build jobs, which are required for a proper field test, the state-of-the-art AM technologies are too expensive and time-consuming. On the other hand, the purchase of new molds, which are only produced for field tests, is also a very expensive business. High financial risks are taken, if the field tests with parts, produced by new tools, do not succeed. For insufficient results, either the mold needs to be changed, which creates additional costs, or the entire product concept is rejected which turns the tool investment into a huge loss.
So the challenge is to apply SLM in a cost-effective way and to integrate it into the process value chain. Therefore, three fundamental improvements are carried out. Firstly, the SLM process itself is optimized to improve the surface quality and to reduce the need of post-processing from the beginning. Secondly, the mold alignments and designs are adapted to the given capabilities of SLM in order to minimize the need of post-processing. Thirdly, testing and validation of simple, affordable post-processing technologies and procedures are carried out. These procedures include glass particle blasting, plasma polishing, manual grinding, and polishing operations. The optimum results and parameters of all three findings are combined into a complete process chain. The aim is to generate a lean, resource saving realization process of metal molds for injection molding applications with a minimum of post-processing effort.

2 SLM TOOL PRINTING: POTENTIALS AND CHALLENGES

The layer wise build-up of fused metal powder comes up with a high freedom of design which enables to build individual and complex parts. Weight reduction and a shorter time to market than traditional manufacturing technologies are further important advantages. SLM is not limited to the accessibility of tools, thus almost every shape can be printed. At the same time, remaining powder can be sieved and mostly reused, for either the same or following prints, which is again a strong economic and resource specific advantage. For the use case of tooling, SLM offers the opportunity to print, for instance, complex conformal cooling channels leading to decreased cycle times. The applicability and effectiveness strongly depend on the shape of the mold. The more difficult it is to dissipate heat from the tool, e.g. when applying long plungers, the more effective is the integration of conformal cooling channels.

In contrast to additive plastic powder bed printers, SLM printers require a connection to a metallic substrate [2]. Especially overhangs, inclining more than 40° require a mechanical support. The attached structures avoid thermal deformations of the build part. Their removal is very difficult and often causes poor surface quality. Thus, it is recommendable to avoid support structures attached to areas relevant for the demolding of plastic. In general, printed surfaces appear rough with roughness values far higher than required for a proper removability of plastic parts from the mold. A typical average roughness of around Ra = 10 µm is achievable with SLM technology. Another aspect is, that a proper ejection of solidified polycarbonate, requires draft angles of 6 to 7°. [3] This drastically limits the freedom of design of the end product and over-compensates the advantages of direct rapid tooling. The roughness of the print surfaces is even increased at horizontal top layers. Due to a low powder bulk density, the powder shrinks unevenly. This leads to mountain-like top textures. [4]
Analytical and experimental tests prove, that the staircase effect of layer wise build-up increases the tension and shear stresses of AM parts [5]. Therefore it can be expected, that the imprints of such textures into the injected plastic will consequently reduce the loading capacity of molded plastic, too.

3 SURFACE QUALITY ENHANCEMENT

Surface roughness and unevenness are fundamental realities of the SLM build process. These challenges must be addressed and mitigated to avoid many of the problems they may cause. [6] For the measurement of SLM surfaces, VDI 3405 (part 2) provides a profile method, which is a well-established method to measure and compare surfaces [7]. Thus, it is used in this research work. Due to the fact that surface quality depends on a number of parameters, an effortless way to generate and process SLM molds is targeted. Therefore, the improvement process is subdivided into three fundamental investigations.
The first two of them are impacting the minimization of the post-processing effort before and during the build process. Firstly, the impact of wall inclination on surface roughness is tested. These tests help to understand how a tool design must be optimized in order to achieve molds with their smoothest surfaces in crucial areas. Secondly, a parameter optimization of the SLM machine is proceeded to enhance the smoothness of the selected tool steel 1.2709. In a third step, simple and affordable post-processing techniques are analyzed to guarantee that the mold surfaces meet their target specifications.

3.1 Optimal tool design

Surface roughness is the most relevant factor for the ability to demold plastic parts from a molding post. The test object pictured below gives a first idea, how walls should be aligned within the build envelope to gain a low roughness directly out of the build process.

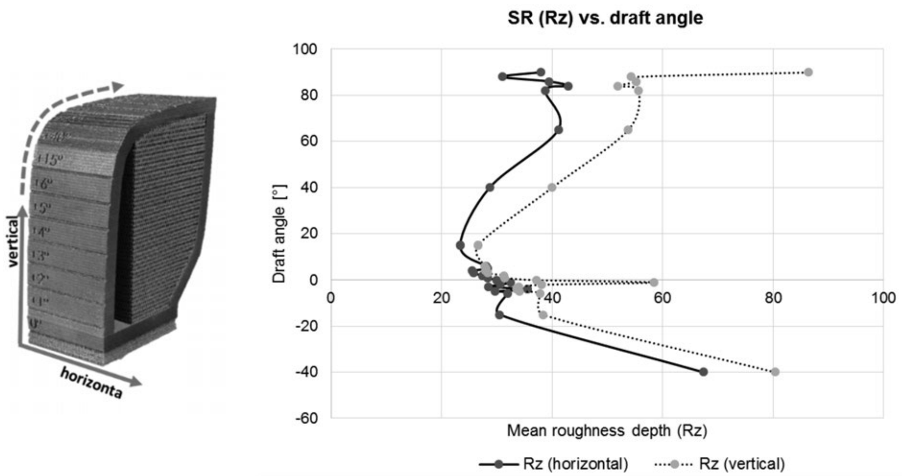


Figure 1: Impact of wall inclination on surface roughness.

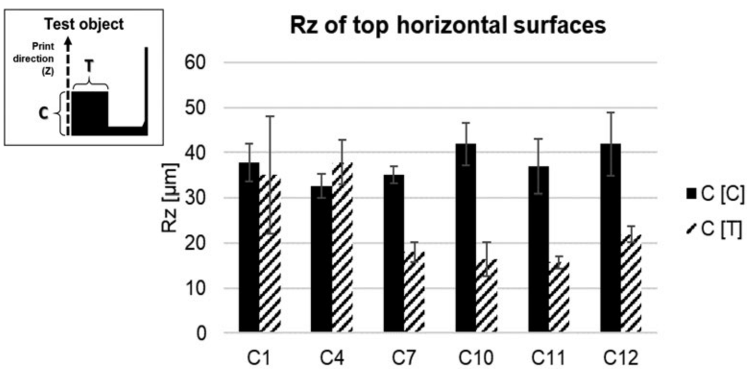
The lowest roughness values can be achieved at vertical walls with 3 to 20° of positive inclination. For a higher inclination, staircase and powder shrinkage effects increasingly lead to worse surfaces finishes. Therefore, the advisable draft angle for a minimum of post-processing is found at around 3°, which is equivalent to draft angles in standard tools. Subsequently, it can be concluded that:

- For the alignment of the mold within the built envelope, it is useful to deploy the substrate plate as a fixation to the stem tool. Thus, the print can easily be assembled to a stem tool. As a consequence, the print has to be aligned with the aperture to the top, which further brings lowest roughness to vertical walls and reduces the necessity of post-processing significantly.
- Cooling channels should not have any functional cross-sections. To avoid support structures, cooling channels can either be printed with oval or diamond shapes. Also, they should be orientated horizontally in the build process. However, the profile for vertically aligned channels is freely selectable. Besides, the top horizontal layers should not be undergone with channels at less than 5 mm distance. This avoids aftereffects from powder sacking in levels where the channels are generated.
- Material offset for ejector and sprue holes. A material offset needs to be designed to enable accurate drilling, ribbing or erosion after print.

- Accessibility of deep cavities. For mechanical post-processes like glass blasting, grinding and polishing operations, it is recommended to split the tool design so that inaccessible gaps can easily be reached.

3.2 SLM process improvement

The largest improvements in terms of roughness can be achieved by a reduction of layer thickness. A reduction from 50 µm to 25 µm comes along with a slightly perceptible decrease of vertical roughness and a significant decrease of horizontal roughness depth. Fig. 2 shows the impact of the different Rz values on horizontal surfaces.



Layer thickness [µm]		C1	C4	C7	C10	C11	C12
	50	x	x				
	25			x	x	x	x

Figure 2: Impact of layer thickness on horizontal surfaces.

A variation of laser power from standard parameters could also improve the surface quality. In case of tooling this improvement is so marginal that it can be considered as irrelevant. Thus, to make the mold capable for injection molding, a surface post-treatment is still required.

3.3 Post-processing

In collaboration with a globally operating SME for push feed systems, three post-processes have been tested. Their capabilities have been identified in order to reduce roughness, especially inside cavities, as they typically appear in industrial molds. The simulated cavities are shown in Fig. 3.

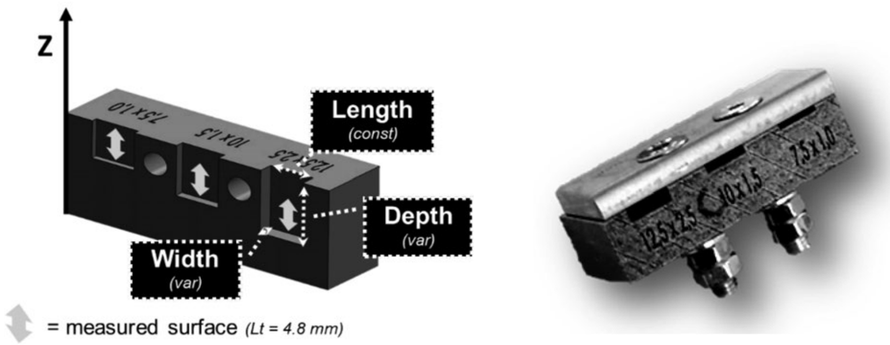


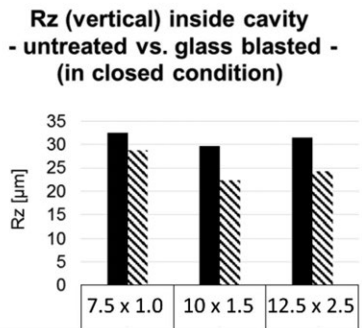
Figure 3: Cavity simulation.

Primarily the test object is printed, then covered with a non-corrosive plate. Afterwards, it is treated and analyzed. As a standard treatment for SLM parts, shot peening is well known to remove adhered powder particles from the print. According to Löber et al. [8], who investigated the smoothening capabilities of glass particle blasting, the same process has been applied to the samples shown in Fig. 3.

Glass particle blasting

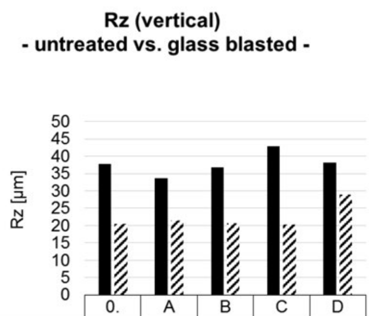
The following test and figures show that a considerable decrease of roughness can be obtained with tool steel parts. Therefore five test objects were treated with glass particles of around 50 µm diameter, accelerated at 7 bar air pressure and directed perpendicular onto the vertical backside. As a result, the mean roughness depth (Rz) was reduced by 41% in average.
Furthermore, the impact of the blasting on the side wall surfaces of the cavities was tested. Fig. 4 shows the measured reduction of surface roughness (SR), which is lower compared to the one of the previous test. The smallest improvement is gained in the inner surface of the tiniest cavity (7.5 x 1.0 mm). Taking into account also the results of the two larger cavities, the opening seems to have a slight influence on the efficiency of blasting. In none case, the achieved surfaces reach the required roughness limits to demold plastic damage free from a mold. On the one hand, the initially mentioned product requires a lowered roughness to enable the reliable ejection of plastic parts from side walls. On the other hand, it requests a high-gloss finish for the

transparent part of the product. This can only be achieved with consequent polishing processes. The chosen treatments are plasma polishing as well as manual grinding and polishing using handheld devices.



	7.5 x 1.0	10 x 1.5	12.5 x 2.5
Rz (vertical) untreated	32.55	29.61	31.39
Rz (vertical) glass blasted	28.83	22.25	24.25

Figure 4: Impact of glass blasting on different cavity enclosures.

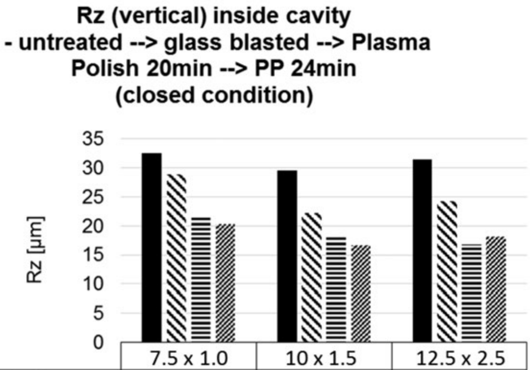


	0.	A	B	C	D
Rz (vertical) untreated	37.79	33.70	36.69	42.96	38.12
Rz (vertical) glass blasted	20.47	21.44	20.67	20.29	28.92

Figure 5: Impact of glass blasting on outer test surface.

Plasma polishing

The findings confirm the results of Löber et al., which were achieved with 316l stainless steel. They conclude “Plasma polishing alone only reduces SR to about 55 percent of the as-generated SR. Plasma polishing in combination with other mechanical post-processes reduces the SR to about 1 percent of the as-generated SR.” [8] Two of the as-generated samples, treated via plasma polishing, show a decreased SR by factor 5 on the outer walls. The samples are processed with different polishing times which result in a clear trend related to SR. A further decrease is predictable if the treatment is extended in time.



	7.5 x 1.0	10 x 1.5	12.5 x 2.5
Rz (vertical) untreated	32.55	29.61	31.39
Rz (vertical) glass blasted	28.83	22.25	24.25
Rz (vertical) Plasma polished (20min)	21.60	18.38	16.75
Rz (vertical) Plasma polished (24min)	20.25	16.70	18.10

Figure 6: Impact of plasma polishing on outer surfaces.

Considering the surface of the simulated cavity test object, the developed process chain consists of printing, glass blasting and plasma polishing for 20 to 24 min. The results of Fig. 6 show that the reduction of roughness follows a clear trend, which is less efficient for inner than for outer surfaces.

Consequently, the achieved surface condition is not polished to gloss and thereby not minimized enough to ensure demold ability, especially in the inside of the cavities. This is further underlined by a haptic inspection which does not reflect a perfectly smoothened finish either. In a visual assessment the objects partly show dark deposits. This effect is caused by the carbon content of the tool steel material. [9] The cavities have furthermore a rusty deposit which is obviously caused by remaining salty process-solution within the closed cavity. Even though both deposits impact the appearance of the test prints, from a process point of view they would not limit the removability of plastic parts.

The use of plasma polishing for molds would still require a post finish for cavities, especially for the ones deep inside.

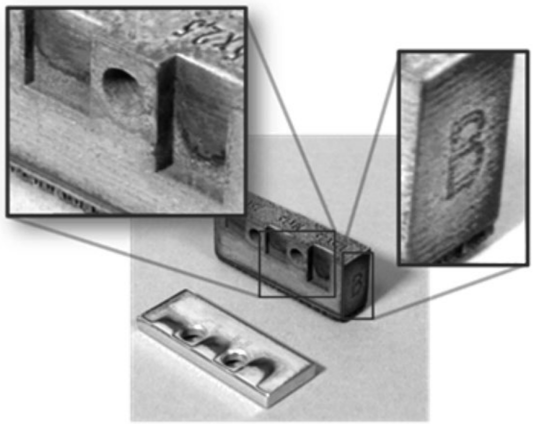


Figure 7: Appearance of cavity object after plasma polishing.

Manual grinding & polishing
The manual grinding and polishing are conducted with a spatula applied with grit or polishing paste. The spatula thereby dives translationally with high-frequency movement into the aperture.

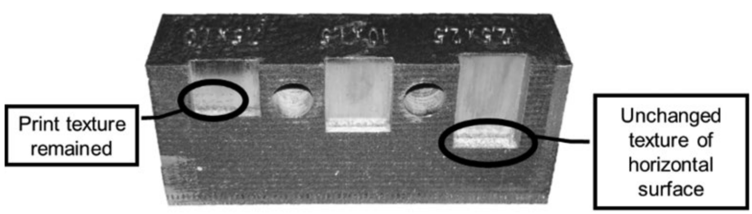
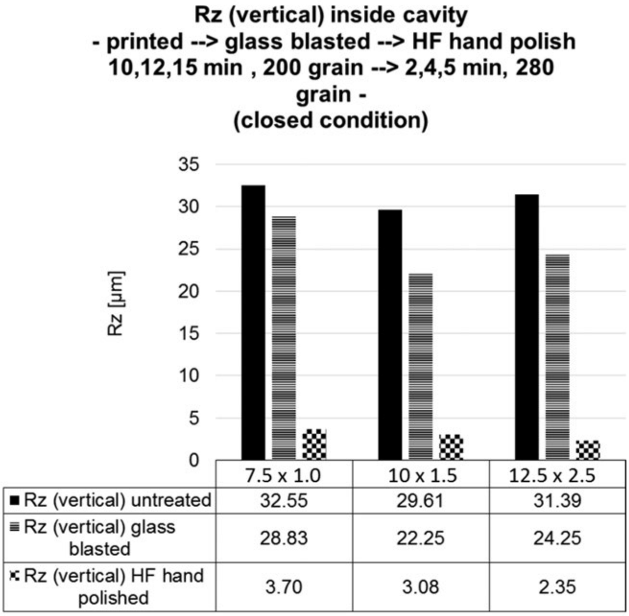


Figure 8: Appearance of cavity after manual grinding.

During the grinding process, the surface is optically controlled via oculars. It is noticeable that the intended shape of the test piece is retained. Only the horizontal ground surface is not improved further because the device is not able to create movements along that plane. As mentioned before this will not influence the deformability, only the appearance. Fig. 8 also reveals remaining print texture in the smallest of the three cavities. This might inhibit the ejection of plastic parts. But, due to the fact that the processing time and the achieved surface texture are correlated, a continuing treatment would remove such structures.

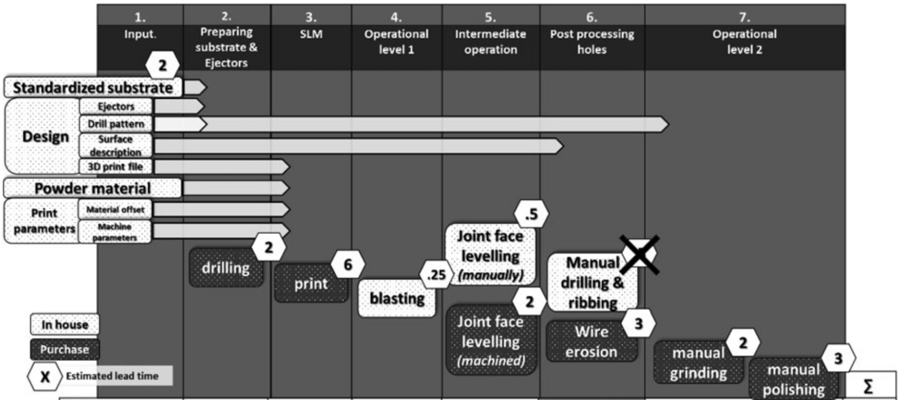


	7.5 x 1.0	10 x 1.5	12.5 x 2.5
Rz (vertical) untreated	32.55	29.61	31.39
Rz (vertical) glass blasted	28.83	22.25	24.25
Rz (vertical) HF hand polished	3.70	3.08	2.35

Figure 9: Impact of grinding on cavity surface.

4 PROCESS LAYOUT AND VALIDATION

Taking all gathered information into account, the mold is designed, printed and finished via blasting, plane grinding, selective manual grinding and polishing operation and a finishing of ejector holes. Overall the experienced process takes about 17 days for the generation and processing of the mold, at a cost of around 4.500 EUR. The amounts of time and money spent on the different parts of the value chain are shown in Fig 10. The process is not limited to the tested material only. As an example, cobalt-chromium alloys, mainly used for dental purposes [4], have a high mechanical resistance and are known to result in smoother surfaces than tool steel.



	2.	3.	4.	5.	6.	7.	Σ
Lead time [days] experienced	2	6	0.25	0.5 / 2	---- / 3	3	~ 17
working time [days] experienced	0.5	3.5 (40h+30h+10h)	0.25	0.5 / 0.5	---- / 0.5	1	~ 7
Investment [€] Based on supplier offers and internal cost rate	600 (Substrate & machining: 420 Sprue bush: 100 Ejectors: 80)	2.500	HR: 80 Machine: 0 (neglected)	HR: 160 Equipment: 0 (neglected) / 250	---- / 300	450	4.340

Figure 10: Process chain for rapid tooling.

Mold testing

The results from mold processing and injection molding are shown in Fig. 11 and 12. The joint faces seal the molding post entirely. Only very little burrs appear in the contact area where the removable insert is plugged.

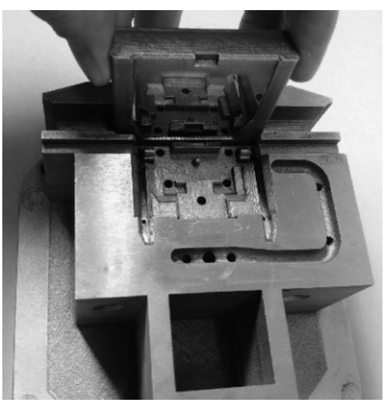


Figure 11: Finished mold insert.

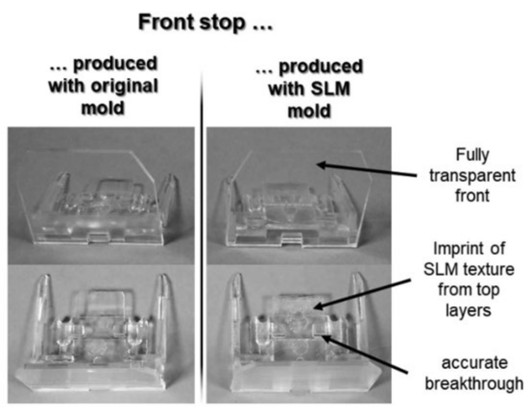


Figure 12: Comparison of standard and rapid tooling part.

The horizontally printed mold surfaces are intentionally not machined, which causes imprints in the plastic that do not impact the functionality. The quality check further proves great appearance of the transparent front face and optimal mechanical strength. All breakthroughs appear accurately and 60 pieces have been produced successfully in the first test run.

5 CONCLUSION

The investigation approves the applicability of SLM in a process chain with non-automated pre- and post-processing to build molds via direct rapid tooling. Surfaces can be improved according to distinct surface requirements. This avoids complex machining on the one hand and comes up with functional and required surface qualities on the other. Nevertheless, the powder bed technology has still some disadvantages compared to subtractive processes. The dimensional accuracy and surface quality is limited, it also shows lower reproducibility.

In any case, for state-of-the-art SLM technologies, post-processing is inevitable. Plasma polishing has been identified as an effective and easy-to-use treatment, but for tooling it is not efficiently applicable in most cases.

Despite the presented process, there is still potential for further research in the field of part design. This work shows only the applicability of an existing part, which is optimized for injection molding but not specifically designed to run a rapid tooling approach. An adapted design could simplify the tool generation, make removable inserts superfluous and would reduce the need of grinding and polishing.

In comparison to traditional mass production tools, the rapid tooling molds of this case study initially require one standardized stem tool, to which the printed inserts are assembled. For this reason, an overall comparison in terms of cost and lead time is difficult, because production tools are usually delivered with a frame and are therefore more expensive by principle. If the lead time and cost of such standard tools are compared to the approach investigated in this paper, a clear advantage for rapid tooling of inserts is distinguishable, especially if higher efficiencies due to conformal cooling are utilized.

ACKNOWLEDGEMENT

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REFERENCES

[1] Huxol, A., Villmer, F.-J. (2016) Special requirements for additive manufacturing of dental frameworks; In: Villmer, F.-J., Padoano, E. (editors) Proceedings of the 6th International Conference Production Engineering and Management, pages 15 -26, Lemgo, Germany.

[2] Gebhardt, A. (2014) 3D-Drucken. Grundlagen und Anwendungen des Additive Manufacturing (AM). Carl Hanser, Munich, Germany.
[3] Menges, G. (1991) Spritzgieß-Werkzeuge. Anleitung zum Bau von Spritzgieß-Werkzeugen. Hanser, Munich, Germany.
[4] Unterberg, P., Realizer GmbH, Germany (2016) Experiences with SLM. Borchen, Bad Salzuflen, Germany.
[5] Scheideler, E.M., Villmer, F.-J., Adam, G., Timmer, M. (2016) Topology optimization and additive manufacturing. - a perfect symbiosis? In: Villmer, F.-J., Padoano, E. (editors) Proceedings of the 6th International Conference Production Engineering and Management, pages 27 - 38, Lemgo, Germany.
[6] REM Surface Engineering (2016) Additive Manufacturing Surface Finish. http://www.remchem.com/industries/additive-manufacturing/. Retrieved at December 16, 2016.
[7] Verein Deutscher Ingenieure e.V. (2013) VDI-Richtlinie 3405 (Part 2). Additive manufacturing processes, rapid manufacturing, Beam melting of metallic parts. Qualification, quality assurance and post processing 2013 Beuth, Berlin, Germany.
[8] Löber, L., et al. (2013) Comparison of different post processing technologies for SLM generated 316l steel parts. Rapid Prototyping Journal 19, 3, 173–179.
[9] plasotec GmbH (2015) Verfahrenstechnologie Plasmapolieren und Elektropolieren. http://www.plasotec.de/verfahren-technologie.html. Retrieved at October 25, 2016.

EXTENDING THE SLICED V-MODEL TO SMART PRODUCT DEVELOPMENT

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Abstract
The increasing industrial digitization is the driver for the fast emergence of many industrial smart products. To stay competitive, the manufacturing companies of these smart products need to optimize their internal lifecycle processes. Mainly, they have to converge the software and hardware lifecycle processes. However, even if this strategic necessity has been recognized, manufacturing companies struggle to develop and implement a roadmap of such convergence.
Starting point for the realization of harmonized lifecycle processes are process models describing process activities and the underlying data models. This research addresses the latter one and aims to create a generic lifecycle data model. The research team created and evaluated such data model referring to development artifacts such as requirements, parts or test cases and to lifecycle artifacts such as revisions, versions and baselines. The generic lifecycle management model was evaluated by a practical development of a smart product. By this, the research provides a valuable result to maintain and increase the competitiveness of manufacturing companies.

Keywords:
PLM, ALM, Systems Engineering, VDI guideline 2206

1 INTRODUCTION

The increasing share of software and demand to provide data-driven services challenges the product lifecycle processes of smart products in manufacturing companies. Smart products are an evolutionary extension of mechatronic products by adding i.e. communication capabilities or so-called Self-X features to them.
To support the development of smart products concepts of Systems Engineering are applied. There are several definitions of the term Systems Engineering. However, commonly the term describes the management of the parallel development processes of all participating disciplines based on a top down approach [1]. The main advantages of Systems Engineering are its interdisciplinary approach to address the overall realization of smart products, especially in the early phase of the development. However, Systems

Engineering does not focus on methods and tools to manage the smart product's lifecycle i.e. releases, versions or issues.
For this, there are today separate lifecycle management methods and tools for hardware (mechanics, electronics) and software. The hardware-related lifecycle model is referred to as product lifecycle management (PLM). PLM is defined as the business activity of managing the company's products across their entire lifecycles in the most effective way [2]. The software-related lifecycle model is referred to as application lifecycle management (ALM). ALM "indicates the coordination of activities and the management of artifacts (e.g., requirements, source code, test cases) during the software product's lifecycle" [3].
As both lifecycle management processes are managed within different disciplines and by different tools, there is an increasing need to converge these different disciplines and tools. This is also known as PLM/ALM integration*.* PLM/ALM integration ensures efficient and harmonized lifecycle management processes in the future.
Before the PLM/ALM integration realization, it is important to model all relevant processes. Process models describe process activities and the underlying data models. This research addresses latter one and aims to create a generic lifecycle data model. The term generic means that the created data model is considered as a source for deriving specific individual data models, which a company will create. As modeling language, UML was used as it is well established and proven in practice [4].
This article is structured as follows: Section 2 presents related work. Section 3 describes the design research and the details of the data model. Section 4 explains its implementation and evaluation. Section 5 outlines the conclusions and the future work.

2 RELATED WORK

The VDI guideline 2206 describes a systematic top down approach for the development of mechatronic products [5]. As smart products are an evolutionary extension of mechatronic products, this approach is also applicable for this context. The top down approach of the VDI guideline 2206 is based on the V-model (Figure 1). Originally, the V-model is a software development model [6]. The VDI guideline 2206 extended it to meet the needs of the mechatronic product development. However, at the time when the VDI guideline 2206 was written the need to consider the PLM/ALM integration was not as eminent as it is today. Therefore, it lacks a special focus on this topic.

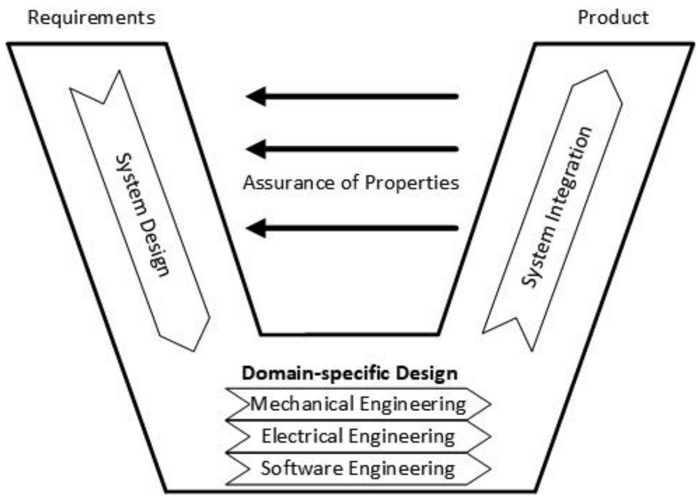

Figure 1: The VDI 2206 development model [5].

The development of use cases for the PLM/ALM integration along the V-model of the VDI guideline 2206 is addressed in [7]. Starting from a general task distribution between PLM and ALM, the phases are analyzed, where PLM and ALM are connected, means there is the need for data exchange between both processes. For these data exchanges, use cases were created. However, this work did not intend to create a PLM/ALM data model.

A data model following the core structure of the original V-model was developed in [8]. This approach is called Sliced V-model and applies items. Items describe development tasks as described in [9] or development artifacts, such as requirements and test cases, as described in [10]. The Sliced V-model defines several item types and their relation between each other creating a data model (Figure 2). This data model, already using UML as modeling language, refers to the software related artifacts. It belongs to the ALM portion of a smart product development. However, in [8] it was not intended to consider the PLM portion of a smart product development. Therefore, such data is not part of the original Sliced V-model.

The original Sliced V-model was considered as the valid starting point for the PLM/ALM integration data model. It models development artifacts and their relation and uses UML. It contains all basic concepts that are needed, but it clearly must be extended to model a comprehensive smart product development.

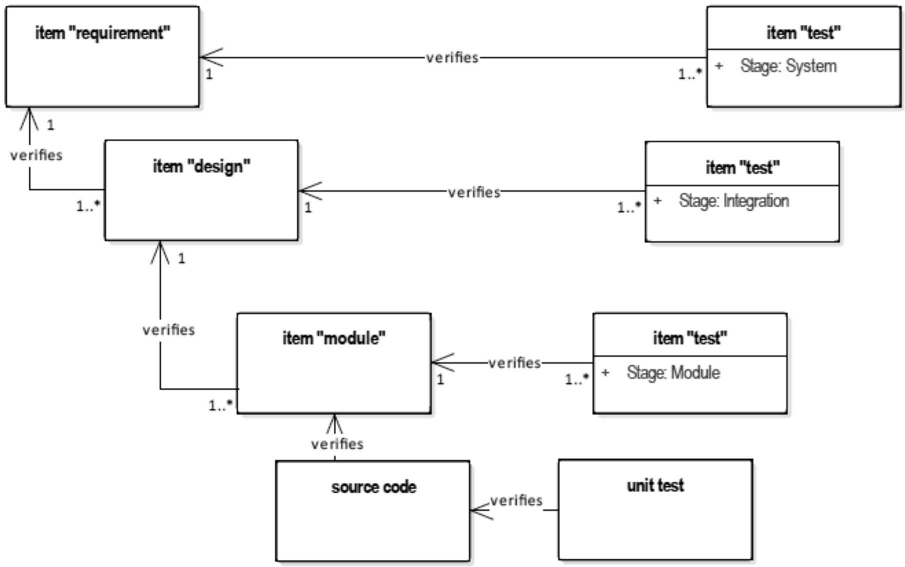

Figure 2: Data model of the Sliced V-model [8].

3 EXTENDING THE SLICED V-MODEL

The approach of the research team to create a PLM/ALM integration data model consist of two major steps: first analyze the artifacts created in each V-model phase, then analyze the relation between these artifacts.
Table 1 is the result of the first step and shows the artifacts and assigns them to the V-model phase accordingly. Some of the artifacts were reused from the original Sliced V-model [8]. The assignment considers the phase where the artifacts are mainly used. In practice, some artifacts may be created in an earlier phase than stated in Tab. 1.
In the second step, the research team analyzed the relation between the artifacts. In order to model these relations, a UML class diagram is used as shown in Fig. 3. The item "requirement" serves as a starting point. On the right side of the model, there is the original Sliced V-model showing all ALM artifacts. On the left side of the model is the new Sliced V-model extension: it shows all PLM artifacts.

Table1: Assigned artifacts to the V-model.

V-Model phase	Artefact
Requirements	Item “requirement” from [8]
System design	Item “design”: this type of item represents the hardware design. Item “design” from [8]
Domain-specific design	Item “CAD-Assembly”: represents a CAD-construction which contains several parts Item “CAD-Part”: represents a single part in a CAD-construction Item “module” from [8] Source code from [8]
System integration	Item “BOM”: groups the following items: Item “EBOM”: engineering bill of material Item “MBOM”: manufacturing bill of material Item “dataset”: contains for user data (e.g. a word document) Item “test from” [8]
Product	Item “CAM part”: is a NC-program

The item “requirement” is linked to the item “design”. On principle, there is only one item “design”. For better readability, the team decided to show the item twice in the UML-diagram. The item “design” describing the PLM part of the design is linked to several items: the item “CAD assembly”, the item “CAD part” and the item “CAM-part”. Furthermore, an instance of the item “design” can be linked to other instances of the item “design”.

To describe the relationship between the items the UML relation association and aggregation is used. This means that each item can exist without the related item. This is very much true in practice. For example, one can create a CAD drawing without having a linked item “design”.

In this model, only the link between the work item “requirement” and the item “design” on the PLM side describes a portion of the PLM/ALM-integration. The team is aware that this is far from being enough. E.g., there is certainly a link needed between the item “test” and some PLM items, e.g. “design”. However, as the evaluation did not include these links yet, these were omitted in this initial Sliced V-model extension.

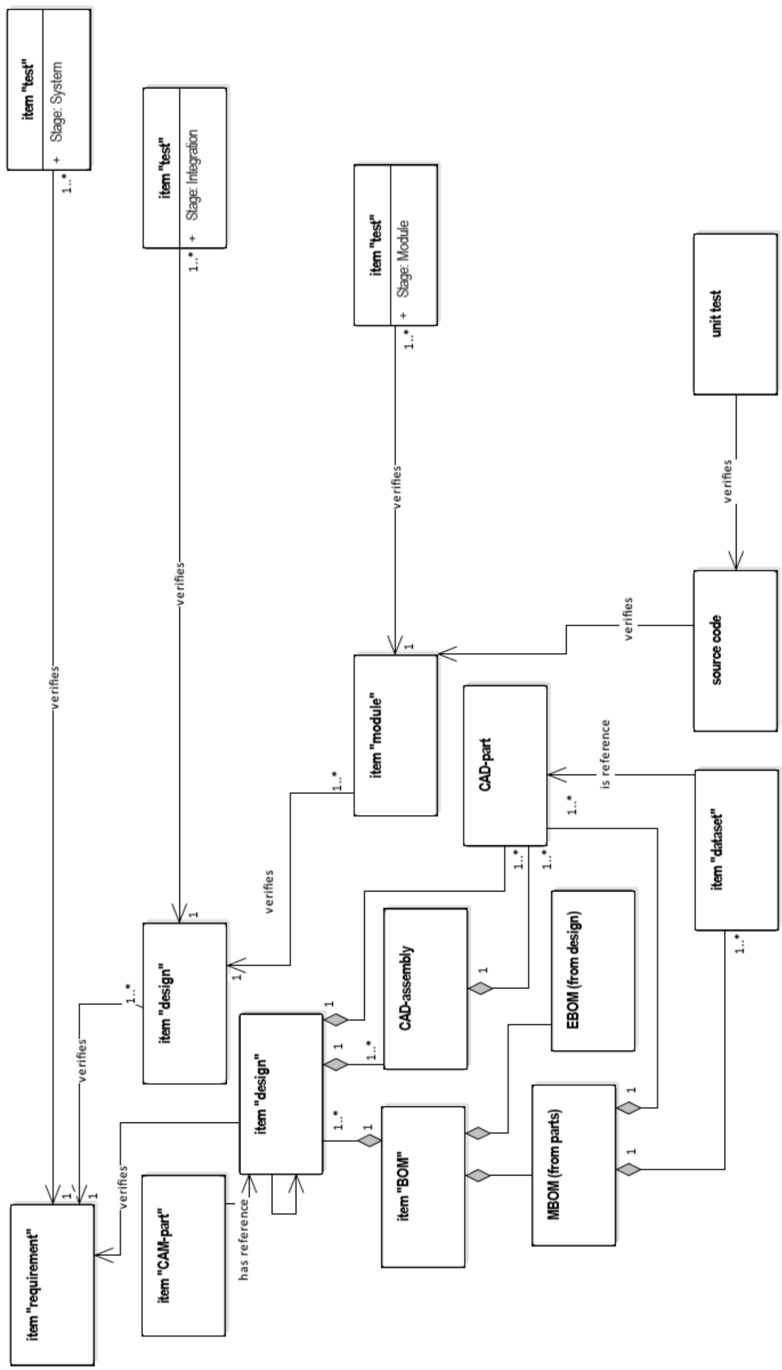

Figure 3: Extended data model of the Sliced V-model [8].

4 EVALUATION

The evaluation of the generic data model is conducted by a practical oriented product development in the SmartFactoryOWL, an initiative of the University of Applied Sciences OWL and the Fraunhofer Society [11]. To evaluate and optimize the product lifecycle of mechatronic products a modular multifunctional device, the so-called SmartLight, was developed. This device contains:

- 3D printed housing;
- LED-orbital;
- IoT-module (Internet of Things);
- Firmware;
- Milled or 3D printed base.

To develop such a device, the research team is using the commercial software solutions of Siemens Industry Software. Siemens Teamcenter is the PLM System applied in this use case. The software development is organized in Polarion, which is the ALM system in this case. With the help of a PLM/ALM-Connector, it is possible to create a connection between ALM and PLM items. According to the extended Sliced V-model shown in Fig. 3 the process starts with the collection of requirements. For this evaluation, Polarion is used as the leading requirements management system, because the document-based form of the program offers a good overview and good capabilities to structure the requirements. To break down the requirements the so-called stake holder model was used which was developed from [12].
After the requirements break down the design items are created and linked to the requirements. The design items are created during the system design phase. As this phase is a cross-domain phase, the design items contain domain-independent content. With a so-called OSLC-link (Open Services for Lifecycle Collaboration) [13] a connection between the PLM design item, located in Teamcenter, and the corresponding requirement items, located in Polarion, is created. An exemplary link situation is shown in Fig. 4: the design item is linked to several requirements.
The domain specific content is created in the domain-specific design phase, where the hardware designer starts the construction of the housing and the software designer starts programming. For the hardware design, Siemens NX was used. The hardware designer creates CAD parts or CAD assemblies in NX, which are linked to the design items in Teamcenter.

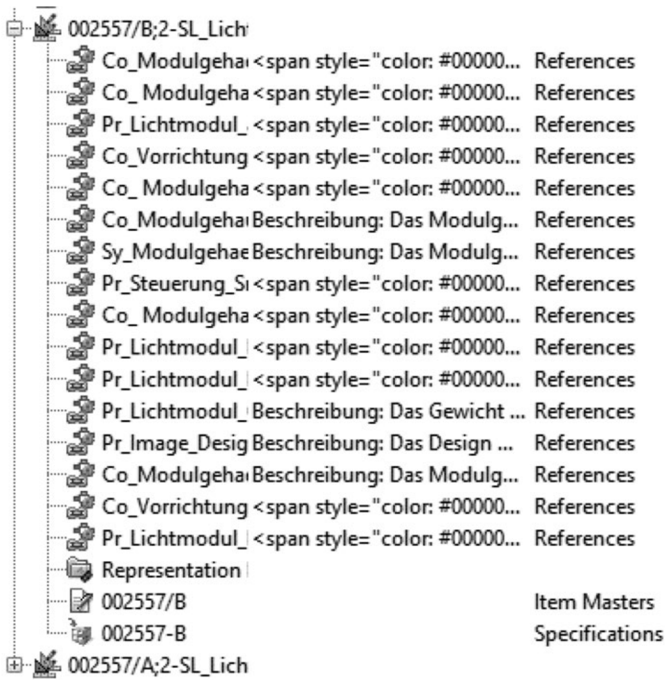

Figure 4: Teamcenter OSLC-link.

Due to the links between CAD parts, design items and requirements, the hardware designer has direct access to all requirements. This is a significant process improvement caused by the PLM/ALM integration. The software items are managed in Polarion and the source code is stored in a version control system. In this evaluation, it is Apache Subversion (SVN) [14]. During the whole process, the product manager can change the requirements of a product, the hardware designers and the software designers are immediately informed so that they can react quickly on changed requirements. This can be considered as another significant process improvement caused by the PLM/ALM integration. To get hardware and software information of a product together the parts need to be structured in a bill of material (BOM) as shown in Fig. 5.

Latest Working | Date - "Now" | Not Specified

BOM Line	Quantity	Item Description	EOC - Effective Occ. Conf...
002562/A;3-SL_Lichtmodul_V2.2		ESP-im Sockel zum Stec...	True
002662/A;2-SL_Lichtmodul_Gehaeuse		Gehaeuse	True
002654/A;4-SL_Lichtmodul_Unterteil		Unterteil_V4	True
002655/A;2-SL_Lichtmodul_Oberteil		Oberteil_V4	True
002664/A;2-SL_Lichtmodul_Elektronik			True
002599/A;2-SL_Lichtmodul_LED-Ring		002599	True
002610/A;2-SL_Lichtmodul_ESP-Druck		002610	True
002611/A;2-SL_Lichtmodul_ESP-DMG		002611	True
002688/A;1-SL_Lichtmodul_Sockel		002688	True
002587/A;2-SL_Lichtmodul_Sockel_ESP-DMG-kl...		002587	True
002583/A;2-SL_Lichtmodul_Sockel_ESP_klein		002583	True
002586/A;3-SL_Lichtmodul_Sockel_ESP_groß		002586	True
002692/A;1-SL_Lichtmodul_Stecksystem		002692	True
002588/A;2-SL_Lichtmodul_Halterung_ESP_DMG		002588	True
002584/B;3-SL_Lichtmodul_Halterung_ESP_D...		002584	True

Figure 5: Teamcenter BOM.

To represent all data needed for the production, two bills of materials are generated. The first one is the so-called engineering bill of material (EBOM) and the second one is the so-called manufacturing bill of material (MBOM). Figure 6 shows exemplary the MBOM created during our evaluation containing the hardware and the software parts. The electronic parts, in this case, a Particle Internet of Things (IoT) module, represents the link to the ALM-System.

MBOM SmartLight

Latest Working | Date - "Now" | Not Specified

BOM Line	Quantity	Item Description	EOC - Effective Occ. Conf...
000270/A;1-SmartLight			True
000271/A;1-Gehaeuse			True
000273/A;1-Oberseite			True
000274/A;1-Unterseite			True
000275/A;1-Halterung_Elektronik			True
000276/A;1-QI_Modul			True
000272/A;1-Grundplatte			True
000277/A;1-Akku			True
000278/A;1-Elektronik			True
000279/A;1-Particle			True
000305/A;1-SmartLight_binary			True

Figure 6: Teamcenter MBOM.

8 CONCLUSION AND FUTURE WORK

The rapid progress of the industrial digitization forces the emergence of more and more smart products. Manufacturing companies producing these smart products need to adapt their product management processes in order to stay competitive. One of the many challenges they face is the harmonization of the hardware related development processes, also known as PLM, and the software related development processes, also known as ALM, which are in practice often disconnected.

In this article a strategy was presented to address this challenge: before the implementation of PLM/ALM-integration, an appropriate data model must be created. In this research, a data model was developed following the V-model development process. The research team analyzed which data items are created in each development phase and the relationships between the data items. To show the data items and the relationships the existing so called Sliced V-model was used. However, as it was developed with the focus of software development processes it was extended to smart product development processes.

To evaluate the created data model a practical product development of the so-called SmartLight is used. The evaluation shows that the data model is fit for purpose to be used in practice.

However, the evaluation is done on just one single product development. For a broader evaluation, it needs to be evaluated on more smart products. Furthermore, the evaluated product does not represent a real product. Therefore, it is open if the Extended Sliced V-model contains all data items needed in real-life scenarios. However, this approach is flexible: new data items can be integrated smoothly in the Extended Sliced V-model.

Further research work should address the quantification of process improvements of the developed approach as well. For this, research should analyze key performance indicators and implement appropriate measures together with practitioners. Such future work can be built on existing work, e.g. on [15] [16].

REFERENCES

[1] Blanchard, B.S., Blyler, J.E. (2016) System Engineering Management, 5. Ed. Wiley.

[2] Stark, J. (2011) Product Lifecycle Management: 21st Century Paradigm for Product Realisation. Decision Engineering. Springer-Verlag London Limited.

[3] Kääriäinen, J. (2011) Towards an Application Lifecycle Management Framework: VTT (179).

[4] Object Management Group, htttp://www.umlorg.org, 19th June 2017.

[5] VDI guideline 2206 (2004) Design methodology for mechatronic systems. Beuth Verlag, Berlin.

[6] Boehm, B. W. (1979) Guidelines for Verifying and Validating Software Requirements and Design Specifications. In: Samet, P. A. (Edt.): Euro IFIP 79, North Holland, pp. 711-719.
[7] Deuter, A., Otte, A., Höllisch, D. (2017) Methodisches Vorgehen zur Entwicklung und Evaluierung von Anwendungsfällen für die PLM/ALM-Integration. Wissen-schaftsforum Intelligente Technische Systeme, Paderborn, S. 211-222.
[8] Deuter, A. (2013) Slicing the V-model - Reduced effort, higher flexibility, Proceedings of 8th International Conference on Global Software Engineering, ICGSE'13, pp.1-10.
[9] Treude, C., Storey, M.-A. (2012) Work Item Tagging: Communicating Concerns in Collaborative Software Development, IEEE Transactions on Software Engineering, 38, pp. 19-34.
[10] Mockus, A. (2013) Analogy Based Prediction of Work Item Flow in Software Projects: a Case Study, Proceedings of the 2003 International Symposium on Empirical Software Engineering, IEEE Computer Society, pp. 110-119.
[11] SmartFactoryOWL (2017) http://www.smartfactory-owl.de, 19th June 2017.
[12] Haße, A., Michielsen, C. (2013) The Missing Link – between Requirements and Design, Proceedings of the Poster Workshop at the Complex Systems Design and Management Conference (CSDM), Paris.
[13] OSLC (2017) https://open-services.net/, 29th June 2017
[14] Subversion (2017) https://subversion.apache.org/, 29th June 2017
[15] Deuter, A., Engels, G. (2014) Measuring the Software Size of Sliced V-model Projects, Proceedings of International Workshop on Software Measurement and the International Conference on Software Process and Product Measurement, IWSM-Mensura'14, pp. 233-242.
[16] Deuter, A., Koch, H.-J. (2015) Applying Manufacturing Performance Figures to Measure Software Development Excellence, 25th International Workshop on Software Measurement and 10th International Conference on Software Process and Product Measurement, IWSM-Mensura’15, Springer International Publishing, pp. 62-77.

INVESTIGATION ON THE DIRECT MANUFACTURING OF WAVEGUIDES AND SENSORS USING FLM TECHNOLOGY

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Abstract
Additive manufacturing (AM) technologies have not only revolutionized product development and design by enabling rapid prototyping. They also gained influence on production in general, mainly because of their direct manufacturing capabilities. In the context of Industry 4.0 and the related process automation, innovative and advanced production technologies with completely new approaches are required [1]. AM technologies contribute to this with their advantages like freedom of design, cost efficient product individualization, and functional integration. On the other hand, AM still shows shortcomings in exploiting its full potential. Most current AM technologies are only applicable for manufacturing with singular materials. In particular, opportunities for processing of optically or electrically conductive materials are still missing. This paper contributes to the advancement of additive manufacturing of two different material variants or even two completely different materials. A special focus is laid on producing a part that combines mechanical with optical or electrical functionalities in one process step. The ultimate goal is to integrate sensor functionalities into an AM object, e.g. strain gauges. Extrusion processes, predominantly Fused Layer Modeling (FLM), are preferred in this research due to their mechanically simple machine setup in which additional functional materials can be adapted easily to the build process. In a first step, the general manufacturability has been evaluated. Thereafter, the resulting optical transmission properties have been analyzed. Especially the attenuation has to remain below a threshold value to accomplish a minimum signal-to-noise ratio.

Keywords:
Additive manufacturing, Embedded optical waveguides, Electrical conductors, Embedded systems, FLM technology, Sensors

1 INTRODUCTION

A large number of requirements on a component are mechanical in nature. They have to be taken into account and implemented in various combinations during production. However, automation continues to progress, and each product component becomes increasingly “smart”. This means that the functional range of a component grows. In addition, the dimensions and

masses of the same component are optimized on and on. Each user of a product places claims his or her own requirements, which have to be produced in a cost-effective manner.
At this point, traditional manufacturing techniques such as turning, milling, eroding, in the metal processing industry, as well as the injection molding, extrusion or thermoforming of the plastics processing industry, reach their limits. Instead of having to produce each component individually or by hand using conventional production processes, additive manufacturing is used.
In the current FLM technology, several materials and components are used to provide prototypes or individual products with appropriate mechanical properties. However, mechanical, electrical or optical components are separated from one another. Each of these components is manufactured individually in several steps and then assembled into functional units.
Using experimental investigations, this work describes the integration of optical conductors in one process step in order to use sensors in geometrically optimized FLM components. This not only reduces the throughput time of a component in the manufacturing process, it also lowers the cost of the entire production.

2 CONCEPTUAL AND THEORETICAL BASICS

2.1 Fused Layer Modeling (FLM)

Fused Layer Modeling is also known as Fused Deposition Modeling (FDM®), which is a strand-laying process [2]. The layer by layer build process results from the softening and local application of thermoplastic material by a heated nozzle or print head. The desired component is produced by the direct consolidation of the extruded material.

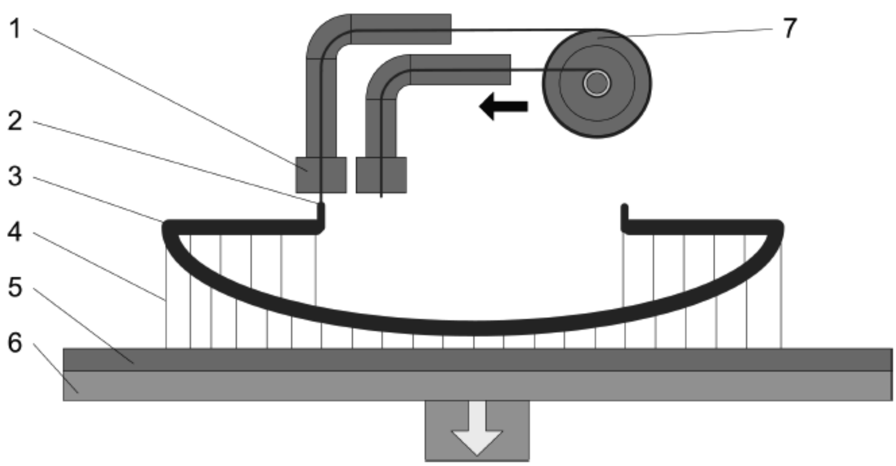


Figure 1: Schematic diagram of fused layer modeling [2].

Figure 1 shows the structure of an FLM system. The material is in filament form on coils (Pos. 7). The material is drawn in through two heated nozzles (Pos. 1), with which the molten filament is applied strand by strand (Pos. 2). These nozzles are moved in a plane to completely create the individual layers. The generated component (Pos. 3) is supported by a support structure (Pos. 4) at overhanging parts. The movements in vertical direction are carried out by the build platform (Pos. 6), which is equipped with a lifting device in order to ensure the layered construction.
The adhesion of the deposited strands is affected by melting the surrounding strands, so that the stratified strand enters into a connection via the melt with the surrounding strands [3].

2.2 Optical waveguides

Optical waveguides are components, which can guide light through an optical transparent medium. The application fields of these waveguides are illumination, sensor or communication applications. Optical waveguides consist of an optical transparent core material with an index of refraction of n_C and a cladding material with an index of refraction of n_M. To guide the light through the waveguide, the index of refraction of the cladding material must be smaller than the index of the core

$$n_M < n_C.$$

Based on Snell's law of refraction [4], the angle of total internal reflection can be calculated by

$$\sin \beta_C = \frac{n_M}{n_C}.$$

If the angle β of the incident light is greater than β_C the incident light is total reflected at the core cladding interface.

Figure 2 shows an optical waveguide. The light is coupled from the surrounding air (n_0 = 1) into the waveguide. The angle between the transmitted light and the perpendicular is α. The light propagates within the waveguide and hits the core cladding interface. The angle between the perpendicular and the light is β. Due to the total internal reflection, the whole optical power of the incident light is reflected.

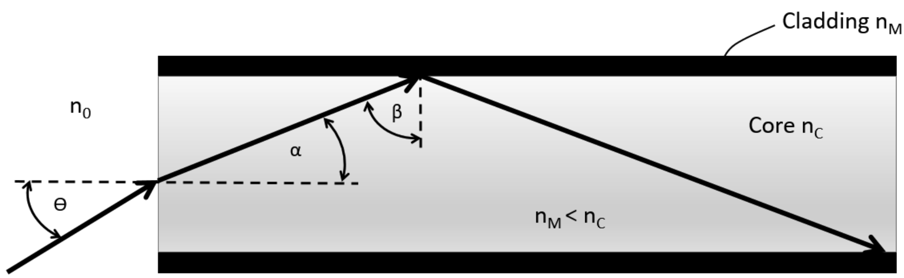


Figure 2: Optical waveguide and one internal reflection of the incident light at the core cladding interface.

In order to get maximum coupling results, the surface of the optical waveguide must be polished towards a smooth and flat surface.

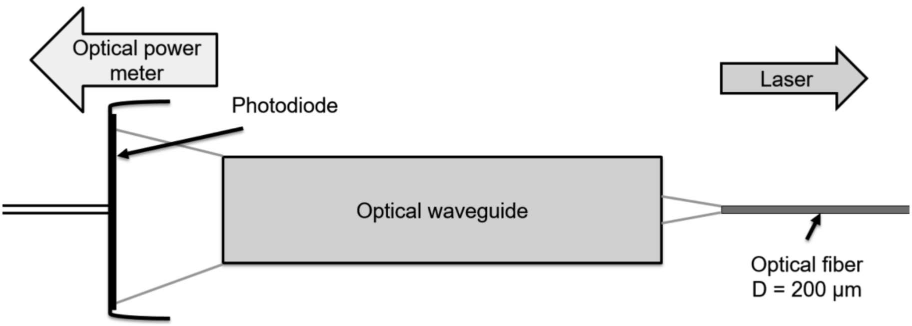


Figure 3: Measurement setup to analyze the attenuation of an optical waveguide.

To validate the quality of an optical waveguide, the attenuation of a light beam passing through this optical waveguide is measured. In Fig. 3 the measurement setup is displayed. This setup consists of a laser source (not displayed), an optical fiber with a core diameter of 200 µm and an optical power meter with a photodiode. The optical waveguide is placed between the optical fiber and the photodiode.

The laser source emits light at different wavelengths with a defined optical output power. This light is coupled into and transmits through the optical fiber. The optical power at the end face of the optical fiber is P_0. This optical power is coupled into the optical waveguide. At the end face of the optical waveguide the photodiode detects the transmitted optical power P_1. Based on the defined optical output power of the optical fiber and the detected optical power of the photodiode the attenuation a of the optical waveguide is calculated by [5]

$$a := -10\text{dB}\ \log_{10}\frac{P_1}{P_0}.$$

2.3 State of the technology

Industries are interested in high-strength and lightweight products. Therefore they are keen on the application of reinforcement fibers, but also of optical waveguides by additive manufacturing [6]. With FLM processes,such filaments as carbon fiber, Kevlar or glass fibers are currently printed as continuous fibers aiming at mechanical reinforcement [7].
Printing of optical waveguides into components is currently only available with non-FLM technologies like Multijet [8]. Applying Stereo Lithography (SLA), a two-step process has been shown in which waveguides are printed with SLA in the first process step. In a second step, they are cladded with an optically non-conductive material. [9] Furthermore, the printing of glass material is currently under research using laser heated extrusion processes [10]. Besides optically transparent filaments, electrically conductive filaments are available for the application in FLM processes [11].
Until now, the research does not show processes in which translucent fibers are directly printed into non-translucent materials.

3 EXPERIMENTAL INVESTIGATIONS OF PROCESS TECHNOLOGY TOWARDS INTEGRATION OF OPTICAL WAVEGUIDES

There are different methods to integrate optical waveguides into a printed shell part. One method is to insert a separated manufactured optical fiber during the manufacturing process of the structure. Another method is to produce the optical waveguide simultaneously during the manufacturing of the structure. In this paper the latter approach will be analyzed.

3.1 Selection of suitable materials

Plastic optical fibers are typically made of PMMA or PC. However, materials such as PLA and PETG are also used in transparent form for decorative applications. To compare the transmission behavior of these materials, identical lengths of 100 mm in filament form are used. The comparison is made by attenuation measurements, in which the individual filaments are protected from the ambient light by an adjacent shell. Additionally, the illumination of the whole environment is switched off in order to avoid any distortions of the results. The measurement is carried out with a laser working at the optical output power of 1.6 mW and the two wavelengths λ = 635 nm and 850 nm.

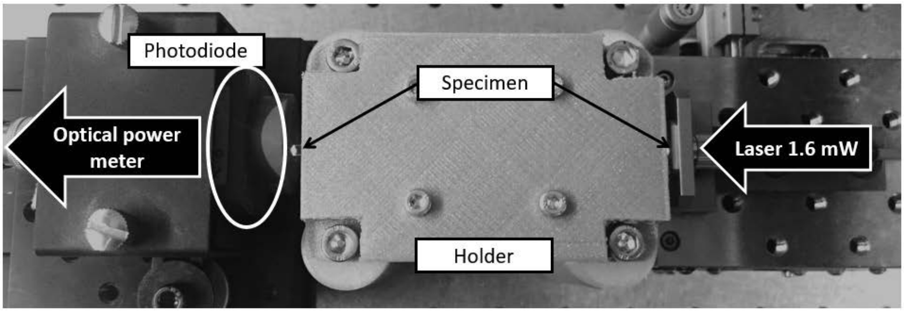
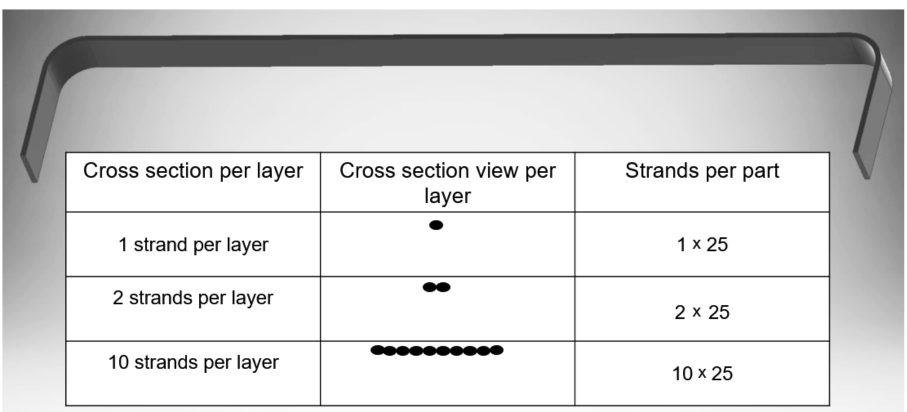


Figure 4: Build-up of attenuation measurement with 100 mm of filament.

3.2 Printing of individual waveguides and measurement of the attenuation

The selected materials are printed in different linear-oriented forms in the FLM process. The printed waveguides have a height of 5 mm and a length of 120 mm. In addition, the waveguides are provided with a radius at the ends in order to be able to deposit dirt or jammed material. These radii are cut off after the manufacturing. The length of the analyzed optical waveguide is 100 mm. Additionally, the end faces of these waveguides are polished. The cross sections of the samples vary from one strand per layer over two strands per layer up to ten strands per layer. The strand cross-section is defined by the nozzle geometry and the driven path in the Z-direction.



Cross section per layer	Cross section view per layer	Strands per part
1 strand per layer	●	1 x 25
2 strands per layer	●●	2 x 25
10 strands per layer	●●●●●●●●●●	10 x 25

Figure 5: Printed optical waveguide without sheath.

3.3 Imprinting of optical waveguides in sheath material

In this experimental investigation, the optically best material from the preliminary tests is printed in a sheath housing of optically dense material. The dimensions of the component are defined by the optically dense material to 10 mm x 5 mm x 100 mm (width x height x length). The optical strands in the various forms are positioned in the center of the optically dense material.

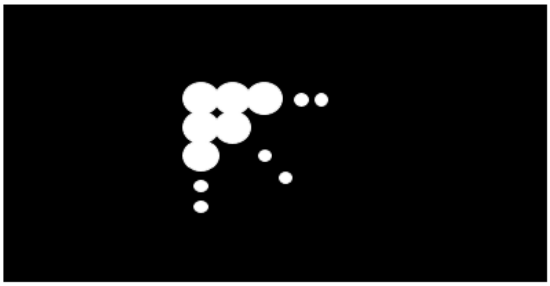


Figure 6: Cross-sections of the samples used.

Table 1: Number of strands for the samples used.

Number of strands	1	4	10	20	40
Strand order (width x height)	1 x 1	2 x 2	2 x 5	4 x 5	4 x 10 8 x 5

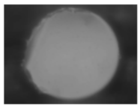
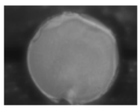
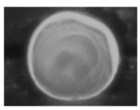
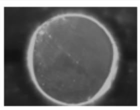
4 RESULTS OF THE EMBEDDING OF OPTICAL WAVEGUIDES

During the sample preparation for the attenuation measurement, a problem has occurred with the polishing. To produce a flat polished surface, a grinding and polishing device is required for each shape and size, which clamps the end of the sample which is stressed at grinding and polishing.
During the attenuation measurement, the influence of extraneous light sources has been particularly noticeable. In order to avoid the influence of scattered light, the measurement has been calibrated.

4.1 Materials for optical waveguides

The samples from the unprocessed filaments all show a strong attenuation. In Table 2 the analyzed materials are compared towards their attenuation of the transmitted light. In the cross-sectional view, it is noticeable that PLA and PETG transmit the light but the turbidity at the used wavelength reduces the optical power of the light extremely. This is clearly shown by the results of the attenuation measurements. With PMMA, a clear cross-section with several streaks can be seen. Here, the attenuation is much less compared to PLA and PETG. PC filament shows the least attenuation results of all. The results are reflected in the cross sectional illustrations in which PC shows by far the clearest picture.

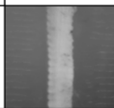
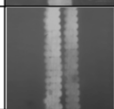
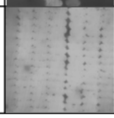
Table 2: Comparison of filament materials for light transmission.

Material	Cross section	Attenuation at 635 nm	Attenuation at 850 nm
PLA		10.2 – 12.4 dB	7.4 – 8.5 dB
PETG		4.8 – 5.4 dB	2.8 – 3.1 dB
PMMA		1.1 – 1.4 dB	1.2 – 1.5 dB
PC		0.9 – 1.2 dB	0.9 – 1.3 dB

4.2 Characteristics of printed optical waveguides

All optical waveguide samples are manufactured individually to avoid protrusions in the construction of the specimen or overriding of already printed specimens. The attenuation of the transmitted optical power is measured with all four materials, as in the previous experiment, in order to check the quality change of the attenuation in each material. The attenuation has strongly increased. Table 3 visualizes the measurement results of the attenuation measurement of the printed components. It is striking here that the attenuation with a small cross-section is significantly poorer compared to larger cross-sections. The best result is shown by PC with a large core cross-section.

Table 3: Comparison of the materials for light transmittance in printed form.

Layer structure	Cross section	Wavelength	Attenuation with PLA	Attenuation with PETG	Attenuation with PMMA	Attenuation with PC
1 strand per layer		635 nm	< 20 dB	< 20 dB	12.2 dB	6.7 dB
		850 nm	< 20 dB	< 20 dB	12.0 dB	6.0 dB
2 strands per layer		635 nm	< 20 dB	15.2 dB	11.0 dB	5.5 dB
		850 nm	17.0 dB	13.0 dB	11.5 dB	5.1 dB
10 strands per layer		635 nm	< 20 dB	11.3 dB	8.8 dB	4.2 dB
		850 nm	15.2 dB	11.4 dB	9.2 dB	3.5 dB

4.3 Imprinting of optical waveguides into sheath materials

By the results of previous studies, the PC has been used with the sheath material ABS. ABS is used as this is a widespread applied plastic and shows a good process stability in the FLM process. The printing process proceeds in two steps per layer. First of all, the ABS for the coat will be printed. After that, an additional component is created by the PC-tipped nozzle. This is required for the cleaning of the nozzle until the actual light waveguide in the respective layers will be printed.

When printing only one strand of optical waveguide, the surrounding material is melted so strongly by the hotter PC strand that the PC and ABS are completely connected to one another and no light beam passes through the component. 1, 4, 10, 20 and 40 strands were also printed into one component as shown in Table 3. It is noticeable that in each of these experiments there are opaque areas in the optical waveguide. With 4 and 10 strands, the mixing of the materials is still too strong, so that no light beam penetrates through the conductor. At 20 and 40 strands, a light beam passes only partially through the conductor. By undefined dirt from the ABS on the nozzle of the PC, deposits are introduced into the conductor at undefinable places.

5 CONCLUSION AND OUTLOOK

It is possible to realize an optical waveguide in the FLM process. In order to be able to impress the optical waveguides in a housing, further questions have to be investigated. This paper shows that it is possible to make a waveguide within a sheath, but the process itself has to be optimized. Further research work with specific questions tied to this paper has to be made, in order to minimize or even to stop the melting of the surrounding strands in certain areas. A lot of new questions arise, for instance, what happens when optical waveguides are produced, which run diagonally through a component and are regularly interrupted by new layers.

For applications in future products, it is highly required to embed additional functionalities into complex geometries, e.g. optical waveguides. A future development might be the simultaneous integration of optical waveguides during the manufacturing process of mechanical parts. With this, optical signals can be transmitted through mechanical parts, cases or frames without the later attachment of optical fibers.

REFERENCES

[1] Neu, M., Grünberg, O., Christophliemke, T., Stübbe O. (2017) Modeling, simulation and measurement of a bidirectional optical interconnection system for industrial applications, In Proc. SPIE 10109, San Francisco, CA, USA.

[2] VDI 3405 (2014) Additive manufacturing processes, rapid manufacturing, Beuth Verlag, Berlin, Germany.

[3] Villmer, F.-J., Witte, L. (2015) Large-Scale 3D Printers: The Challenge of Outgrowing Do-It-Yourself. In: Padoano, E; Villmer, F.-J., (editors) Proceedings of the 5th International Conference Production Engineering and Management, pages 111 -122, Trieste, Italy.

[4] Pedrotti, F. L., Pedrotti, L. M., Pedrotti, L. S. (2008) Introduction to Optics, Pearson Education, Amsterdam, The Netherlands.

[5] Saleh, B., Teich, M. (2007) *Fundamentals of Photonics*, Wiley-VCH, Weinheim, Germany.

[6] Inaba, F. (2013) Optische Computer, Springer Verlag, Heidelberg, Germany.

[7] Lutz, J. (2016) Mark One, der weltweit erste Kohlefaser 3D Drucker mit Endlosfaser, http://johannes-lutz.de/home/der-weltweit-erste-carbon-3d-drucker-mit-endlosfaser/. Retrieved on June 16, 2017.

[8] Willis, K. D. D., Brockmeyer, E., Hudson, S., Poupyrev, I. (2012) Printed Optics: 3D Printing of Embedded Optical Elements for Interactive Devices, Cambridge, Massachusetts, USA.

[9] Heinrich, A. (2017) Additive Fertigung von optischen Komponenten, Hanser, Rapid.Tech, Erfurt, Germany.

[10] 3Druck.com (2015) LLNL Forscher erziehlen bedeutenden Fortschritt bei der 3D-Druck von transparenten Glas, https://3druck.com/3d-druckmaterialien/llnl-forscher-erzielen-bedeutenden-fortschritt-bei-3d-druck-von-transparentem-glas-5457571, 3Druck.com, Wien, Austria.

[11] 3Druck.com (2015) Leitfähiges 3D-Druck Filament F-Electric Update, https://3druck.com/tags/leitfaehiges-filament/, 3Druck.com, Wien, Austria.

SESSION D
Industrial Engineering and Lean Management

OPTIMIZATION OF AUTOMOTIVE LOGISTICS NETWORK WITH LATE PRODUCT INDIVIDUALIZATION

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Abstract
Due to a high level of competition in automotive industry, it is essentially important for automotive companies to develop innovative strategies and technologies in production and logistics. Postponement of production difference, i.e., customer individualized demand has been considered as an innovative strategy and more or less implemented in the production process, mostly before and during the final assembly. This paper proposed the concept of postponing the individualization of some components after the assembly. The idea is to use the idle times especially during the distribution process when vehicles are accumulated to generate big transportation batches or the follow-up transport does not start immediately. The individualization is carried out in specially realized workshops. Objectives of the approach are to reduce variations in the manufacturing, to shorten delivery times and to give consumers the ability to reorder individual components shortly before delivery. This kind of postponement of individualization induces the requirement of redesigning the logistics network, which means the selection of workshop locations and the new selection of the suppliers for the individualized components. To reach this aim, a software tool has been developed. In the tool, the data required in the logistics network such as suppliers and workshop potential locations are managed in a MySQL database and the optimization of the network is achieved by the especially developed non-dominated sorting genetic algorithm-II (NSGA-II). The design and development of the solution individuals and the fitness functions, which are the most important elements of a genetic algorithm, are based on the mathematical model of the logistics network design with product late individualization. Different scenarios are considered and generated to examine the applicability of the methodology in automotive practice. The optimization model and the heuristics of genetic algorithm are validated through the Pareto solutions for different scenarios.

Keywords:
Automotive industry, Logistics network configuration, Late product individualization, Postponement, NSGGA

1 INTRODUCTION

The famous slogan by Henry Ford, “Any customer can have a car painted any color that he wants so long as it is black”, has become a past legend. Nowadays automotive producers are able to provide consumers different variations of cars. In Europe, there are still about half of the vehicles being sold from stock [1]. The rest vehicles are customer-built vehicles with a delivery lead time of more than 40 days [2]. Even the production can be extremely reduced, it is still difficult to achieve the target of two weeks to deliver the car after being ordered [3]. If the distribution process between the factory and the customer lasts long, the order-to-delivery will still last very long, especially when the vehicles are moved by sea, as the lead times for sea transport will always be long and constrained in flexibility due to the size of the ships, compared to land or air.
Idle times especially occur during the distribution process, when vehicles are accumulated to generate big transportation badges or the follow-up transport does not start immediately, respectively. To use the non-productive idle time during the distribution process for value adding activities, instead of postponing the difference of customer requirements to the end of the production in the plants, some could also be moved to the distribution process. To accomplish the individualization during the idle times in the distribution process is the main idea of late product individualization (LPI) [4] [5]. This idea enhances the downstream logistics flexibility of the automotive supply chain. Fluctuations in individual model sales occurring after OEM plant capacity decisions may then be better coped with [6]. Undoubtedly, the distribution network of cars has to be changed, once some processes are added inside because of LPI. The suppliers of LPI components may also be influenced, which results in the reconfiguration of the logistics network for automotive late product individualization.
The remainder of the paper is organized as follows. The concept of postponed individualization is firstly given in Section 2. The logistics network configuration problem and model are introduced in Section 3. The software program of logistics network designer including the solution method based on genetic algorithm and case study are presented in Section 4 and the paper is concluded in Section 5.

2 LATE PRODUCT INDIVIDUALIZATION

When late product individualization is mentioned, the most associated word coming to mind is postponement. Literally, late product individualization is explained the same as the concept of postponement. Postponement is defined as keeping a product as generic as possible and as late as possible in the supply chain, where differentiation starts when an order or demand is available [7]. In other words, the differentiation caused by individualization is moved downstream, i.e., nearer to the customers in the supply chain. This is

also the essence of LPI, aiming at reducing inventory caused by demand uncertainty [8].
Instead of just using the term postponement, late product individualization is especially newly named. The reason of using LPI is to emphasize the use of idle times in automotive industry during the distribution process. Efforts to use postponement strategies in the automotive industry are used only very selectively and concentrically at the factories of the original equipment manufacturer. That is why LPI emphasizes that the non-productive idle times during the distribution process can be used for value adding activities.
As shown in Figure 1, some activities of vehicle assembly are taken out of the production process at OEM factories and relocated into the further distribution process where the idle times occur according to individual customer orders [4].

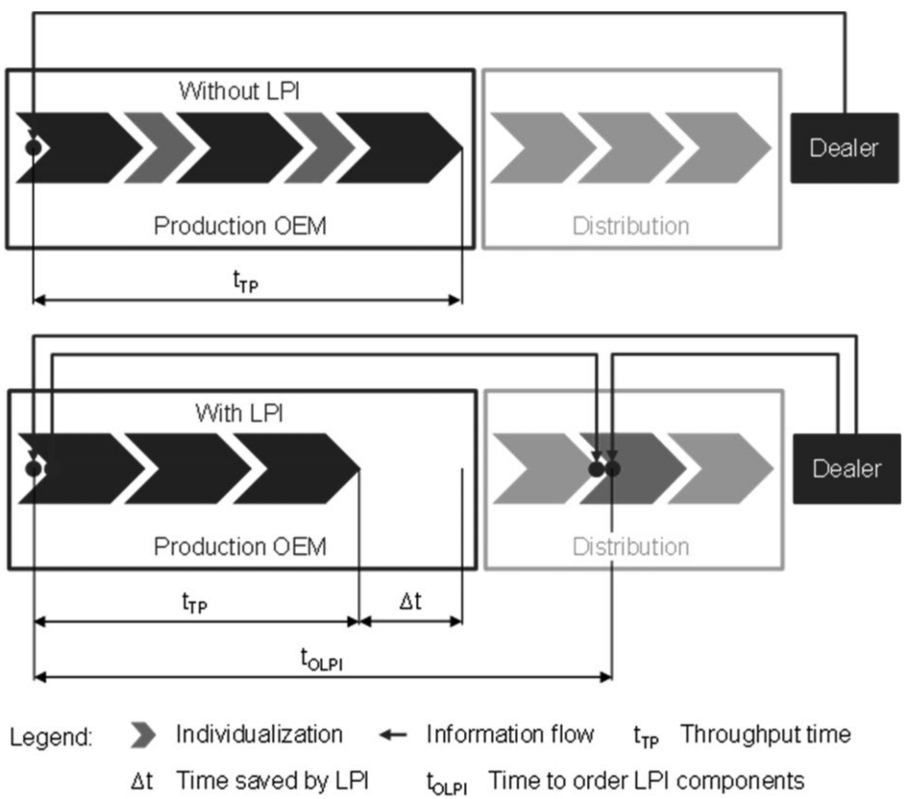


Figure 1: Concept of postponed individualization.

3 LOGISTICS NETWORK CONFIGURATION MODEL

From the comprehensive review [9], it is to notice that logistics network design has been always an interesting and important issue. The logistics network design configuration problem for late product individualization in automotive industry must be identified. The elements of parameters, variables, objectives, and constraints from the viewpoint of modeling should be clearly defined in order that optimization method can be adopted to find solutions.

3.1 Problem description

To describe the automotive logistics network design problem especially for late product individualization, the basic and general features, terms, conditions, and assumptions are characterized as follows.

- The automotive network provides several cars which are named as models. The different car models can be ordered by customers. Here, customers refer to retailers in different customer zones.
- Each car model has some LPI components for customers to finally choose. Each component has some potential suppliers to satisfy the component requirements. Each supplier can have one or more plants. All the plants from the same supplier are located at different locations.
- The requirements in the planning horizon from different customers for the car models and the LPI components are known.
- The factories of OEMs, i.e., where to produce what kinds of car models, have been known and fixed. Limited by the production line, only one plant serves the same market and produces the same car models. It is neither necessary nor practical to produce the same car models in different plants.
- The almost finished car models are transported from the factories to the workshops for final assembly according to customers' individualization requirements for LPI components. Every built workshop can realize the late product individualization for all of the car models. There is no capacity limitation on each workshop.
- Every car model is completely individualized in one workshop and then ready for delivery to the customers.
- To finally individualize the car models ordered by a certain customer, all the orders for the same car from the same customer are dealt with one workshop.
- Once the workshops know the requirements for the LPI components from the customers, they start to assemble the components to the cars. The workshops either have to keep the inventory of LPI components or receive the LPI components from suppliers just-in-time.

An example is shown in Figure 2, which can be used to exhibit such network when late product individualization is implemented.

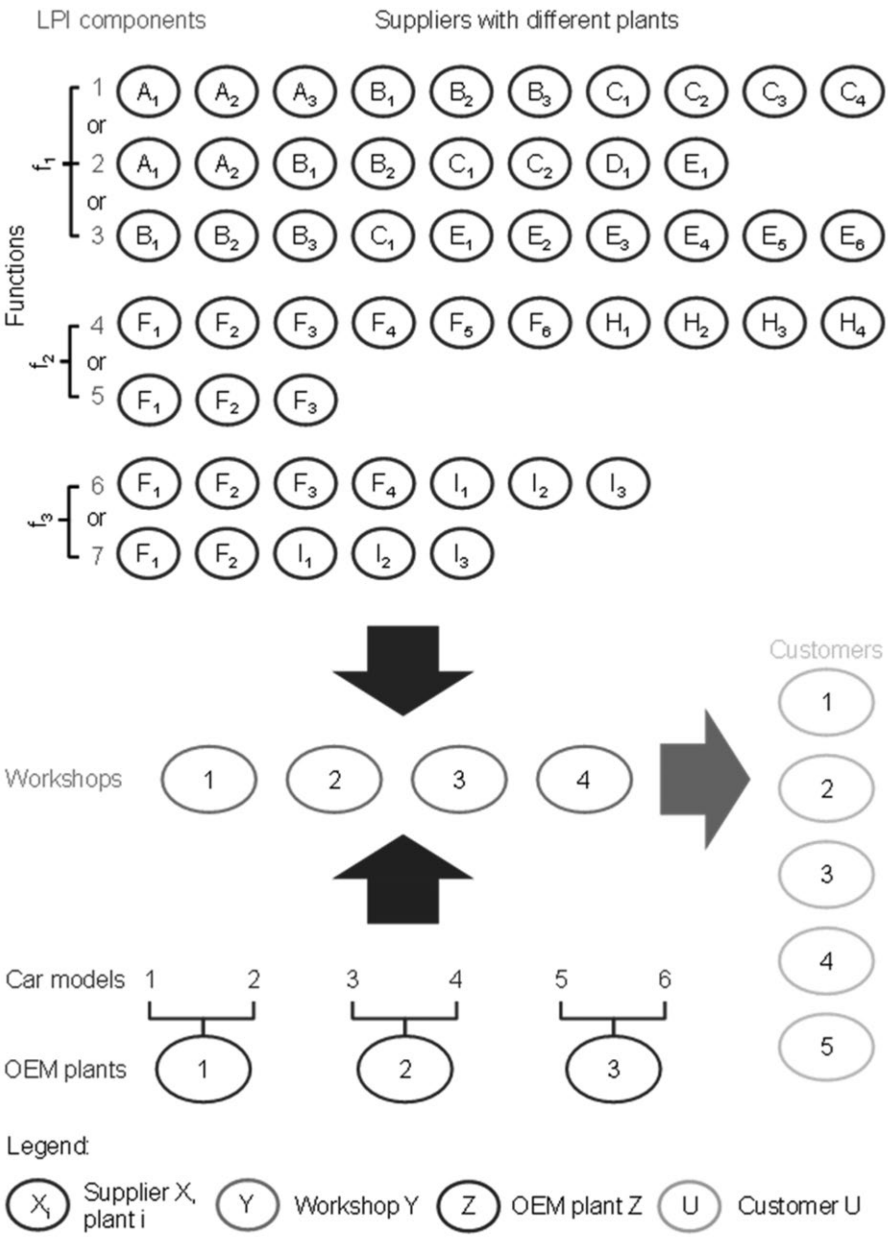


Figure 2: General LPI logistics network design model.

In this example, there are three OEM plants. Each plant produces two different car models. Hence, there are totally six different car models provided by this network. These car models can be moved to any selected workshop locations from the four potential ones for further assembly. It could be, only one location is finally selected for workshop or four workshops should be built for the logistics network. In each case, the finished cars are distributed from the selected workshops to the final five customers. The transportation amounts from the OEM plants to the workshops and from the workshops to the customers depend on the requirements of the customers for different car models. Customers can individualize three functions, which are numbered from one to three. Each LPI function has either two or three alternative components. Totally, there are seven components numbered from one to seven in the figure.

Corresponding to each component, there are some supplier plants which can provide the offer. Different plants from the same supplier are represented by the same capital letter but different numbers in oval icons. For example, for LPI component 1, there are three different suppliers which are represented by A, B, and C. Either Supplier A or Supplier B has three plants which are numbered from one to three. Supplier C has four plants which are numbered from one to four. The same supplier can provide different components. For example, except for LPI component 1, supplier A offers also LPI component 2. All of these suppliers are potential ones for the LPI components. They all have the possibility to be selected for one or certain workshops.

3.2 Decisions

Two sets of decisions should be made in order that the network can run. The first set of decisions is to decide which potential workshops are used to serve which customer's demands for car models. Once a workshop location is selected, it implies that the workshop should be built to implement the late product individualization strategy. The second set of decisions includes the selection of suppliers and supplier plants from which the workshops receive the corresponding LPI components for the final assembly.

3.3 Supplier selection mode

When suppliers are selected, it is necessary to decide at first what kind of supplier selection mode to use. The selection mode quite often used in automotive industry means that for each LPI component, only one supplier can be selected. But all the plants are the potential plants which can be selected for any selected workshops (Fig. 3). Once a supplier is designated as the supplier for a component, there is no limitation on how many plants from the supplier can transfer the component to the workshops.

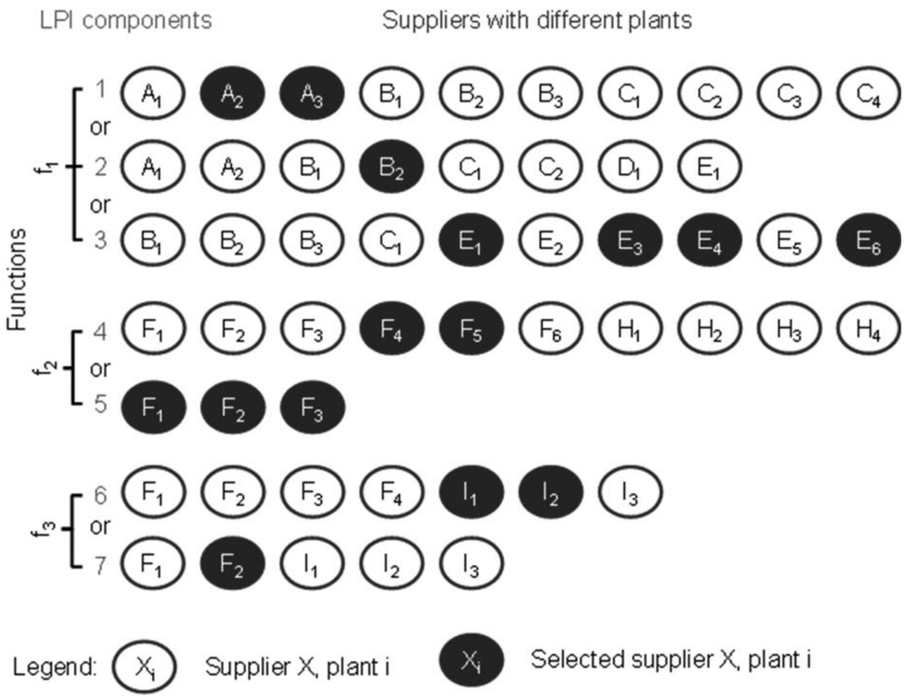


Figure 3: One supplier with several plants for one LPI component.

3.4 Objective of cost

In the model, three objectives are considered. Firstly cost, no matter what kind of cost elements are included inside, is a general objective which is almost always used in logistics network design optimization. More than half of the research use cost or profit as objective in the logistics network design. The model for LPI network is not an exception in costs. One objective considered in the model is also to minimize the network total costs, composing of costs for LPI components, transportation costs from suppliers to workshops, transportation costs of cars from plants to workshops, transportation costs of cars from workshops to customers, and finally the fixed costs of establishing and maintaining workshops at the selected locations. It is assumed that variable costs that depend on working time are the same for every solution.

3.5 Objective of supply lead time

Since the main aim of late product individualization in automotive logistics is to reduce the delivery time to the customer, it is reasonable to suppose that the workshops start the assembly process when the orders from customers

come. In other words, to realize this, either the workshops need to keep inventory of the LPI components or the suppliers need to offer the LPI components to the workshops just-in-time. For both cases, the supplier lead times (SLT) required from the suppliers to the workshops are determinative on costs for workshops and suppliers.
The shorter the supplier lead times are, the lower are the costs induced on the whole logistics network. Hence to minimize the supply lead time from the selected supplier plants to the workshops is defined as another objective. It is defined as the average time of all the time required from the selected supplier plants to the corresponding workshops.

3.6 Objective of delivery lead time

After the customers place the orders to the workshops, the time required for finally individualizing the cars at workshops is not considered here because of two reasons. Firstly, it can be supposed that the time is quite short and can be ignored. Secondly, the workshops need almost the same time for assembling different car models. Even the time required to realize LPI at workshops is quite long, it does not make difference in latest individualization time from different customers and hence will not influence the decisions.
A certain customer only needs to wait for the time required for transporting the cars from a certain workshop to the location where the customer is. Delivery lead time (DLT) of the network is defined as the average of the time required for the workshops to the customers for different car models.
The obvious benefit of adapting three objectives is that a set of Pareto solutions considering cost, supplier lead time and delivery lead time of the network can be obtained. From the Pareto solutions, the final decision maker can select the proper solution by balancing cost, shorter supplier lead time and delivery lead time of the network. If only cost is considered as objective, then at the end of the optimization, there is only one solution which concerns only this aspect, the lowest cost.
On the one hand, the supplier lead time can be quite long. From the viewpoint of either suppliers or workshop viewpoint, no side would like to have more inventory. On the other hand, the delivery lead time can also be extended resulting in poorer customer service. Hence, theoretically more objectives are more applicable and reasonable than one objective. This is also proved by the computational experiments.

4 PROGRAM OF LOGISTICS NETWORK DESIGNER

In this section, the program of logistics network designer is presented. The tool aims at helping the planners increase the planning quality and reduce planning effort and planning time need to be devoted. The planning results are more objective and reproducible. The system should offer the planners the chances to select the solution which is optimized on the one hand and acceptable on the other hand. The system should also help the decision makers identify the cost drivers in the network so as to modify the network situations for better solutions.

4.1 System structure

As shown in Figure 4, the system is composed of three modules and one database. The first module of "Preprocessing" and the second module of "Postprocessing" both act as the interface between the users and the rest of the system.

Through the interface of "Preprocessing", the network data and the master data are separately managed. The network data refers to the network design problems to be solved. The management of the data includes the establishment, the maintenance, the modification and even just view of it.

The "Postprocessing" module offers the users different views of the solutions obtained from the algorithms. The users can check the Pareto solutions and select one solution from inside by following the strategy and preference of the company. It is possible for the users to vividly see the network on the screen. By checking the costs elements, the users can identify which costs mainly compose the total costs, for example, workshop variable costs or car transportation costs.

Different network applications, master data, and solutions of different networks are stored in a database. In LPI Network Designer, MySQL is used as the database system because of its open-source nature and its seamless integration with a number of programming languages, including Java. Different tables are used to record the network data, such as tables representing the facilities, tables of the LPI components and cars, tables of the customer requirements for cars and LPI components and so on.

The third module of the system is the "Coreprocessing" module, which accomplishes the optimization process by single-objective genetic algorithm (SOGA), or non-dominated genetic algorithm II (NSGA-II) [10] or both. The algorithms of SOGA and NSGA-II are both included in the system. The main reason of keeping SOGA in the tool is to keep the single solution when only costs are considered as the reference for the decision makers. Although it is not recommended, the users can also only use the SOGA when they concern only the costs of the network.

It would need too much time if the genetic algorithms catch the data from the database to calculate the fitness of each chromosome in each generation for the evaluation aim. Hence, another sub-module "model formulation" inside is responsible for getting the network data from the database before the algorithm starts the evolutionary process. The network data is then stored in the data structure of lists. It is not necessary to visit the database for the fitness calculation and the GAs can work at the normal speed. The module "model formulation" acts as the interface between the database and the genetic algorithms.

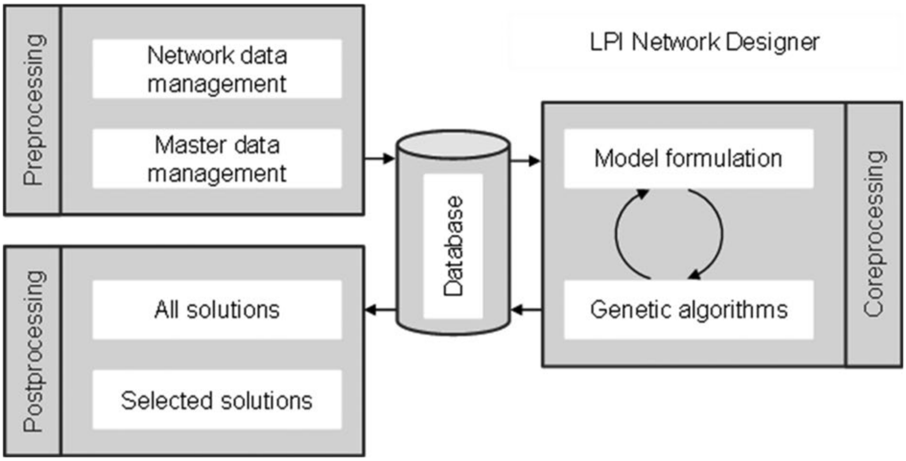


Figure 4: Structure of the LPI Network Designer.

4.2 Case study

In all of the steps the users need to do, the heaviest one is the input of the required data of the network. The GUI, as shown in Figure 5 makes this process already easy to operate and understand. After checking the consistency of the data by clicking the right menu or toolbar, the users can click the toolbar of “Call SOGA” to start the optimization with SOGA to get only the single-objective solution or click the toolbar of “optimize” to get the Pareto solutions with NSGA-II as well.

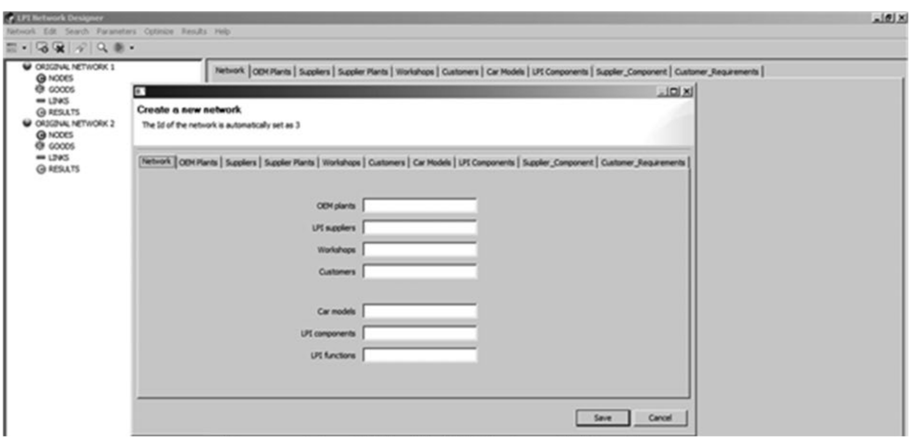
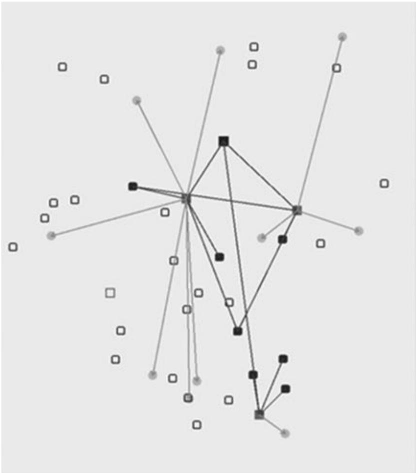


Figure 5: GUI of LPI Network Designer.

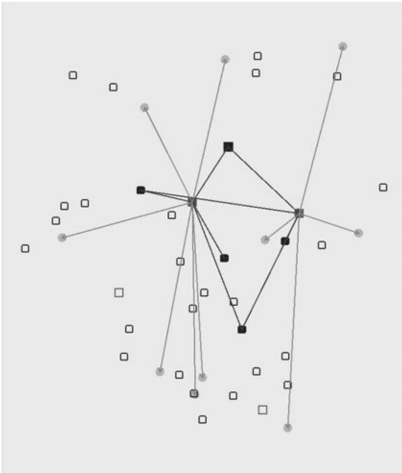
It is always recommended that the users should call both SOGA and NSGA-II to get all the Pareto solutions of the network or partial Pareto solutions after being filtered. For example, a filter can be defined that only the solutions with no more than 10% of the total costs obtained by SOGA are collected for output, while others are just ignored because the total costs are too much higher than to be accepted.

From the obtained Pareto solutions either filtered or not, an acceptable solution with a better balance of costs and lead times can be selected. After the solution is selected, the users can check the network structure of the selected supplier plants, the selected locations for workshops, and the transportation flows of LPI components and cars. Users can also view different costs so as to identify the main cost composition. As the last step, the users confirm the acceptance of the solution.

Figure 6 shows the networks of two solutions. One is the optimal solution with SOGA and the other is the selected solution from Parto solutions with NSGA-II. If the two network structures are compared, they both look almost the same. The main difference is that the selected solution has three workshops while the optimal solution has two workshops. Corresponding to this workshop, new suppliers for the three LPI components are added.



(a) The optimal solution



(b) The selected solution

Figure 6: Network structure of the selected solution.

5 CONCLUSION

Move the most uncertain customer requirements to be satisfied later in the distribution process is a promising way for the automotive industry. The concept of late product individualization provides many benefits for the automotive industry. It is possible for the OEMs to meet the trend of mass customization by giving customers the possibility to order personalized cars. Short delivery times can be realized because some assembly steps are postponed to a later point in the supply chain and nonproductive idle times during distribution are overlaid by value adding assembly of LPI components. The program with integrated genetic algorithms for logistics network design especially for automotive late production individualization enables the configuration of logistics network convenient and intuitive.

REFERENCES

[1] Holweg, M., Miemczyk, J. (2003) Delivering the '3-day-car': the strategic implications for automotive logistics operations, Journal of Purchasing and Supply Management, 9 (2): 63-71.

[2] Holweg, M, Jones, D.T. (2003) The challenge: building cars to order – can current vehicle supply systems cope? Manufacturing Operations and Supply Chain Management: The Lean Approach, London: Cengage Learning.

[3] Gleißner, H., Femerling, J.C. (2008) Logistik. Wiesbaden: GWV Fachverlage.

[4] Schulze, L., Gerasch, M., Mansky, S., Li, L. (2008) Logistics management of late product individualization, Application in the automotive industry. In: International Journal of Logistics Economics and Globalization, 1 (3-4): 330-342.

[5] Schulze, L., Mansky, S. (2009) Klimek, J.: Late product individualization in automotive industry, LogForum, 1 (4): 11.

[6] Hopp, W.J., Iravani, S.M.R., Xu, W.L. (2010) Vertical flexibility in supply chains, Management Science, 56 (3): 495-502.

[7] Lee, H.L., Billington, C., Brent, C. (1993) Hewlett-Packard gains control of inventory and service through design for localization, Interfaces, 23 (4): 1-11.

[8] Schulze, L., Li, L. (2009) A Logistics network model for postponement supply chain, IAENG International Journal of Applied Mathematics, 39 (2): 108-114.

[9] Li, L., Schulze, L. (2011) Uncertainty in logistics network design: A review. In: International MultiConference of Engineers and Computer Scientists 2011 (IMECS), Volume II. Hong Kong: Newswood Limited.

[10] Deb, K., Pratap, A., Agarwal, S., Meyarivan, T. (2000) A fast and elitist multi-objective genetic algorithm NSGA-II, IEEE Transactions on Evolutionary Computation, 6 (2): 182-197.

SIMULATION TOOL FOR RESOURCES OPTIMIZATION IN A PRODUCTION DEPARTMENT

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Abstract
The purpose of this paper is to compare two different optimization algorithms to minimize the makespan of different products within a factory department.
The variables of the optimization process here proposed are the number of machines for each machine group, defining and improving layout, and respective requested shifts.
The optimization is subject to the annual demand by the market for each part type. The plant works under production fluctuation and the objective is to justify production strategies.
The plant, which produces large engine parts, is currently under definition.
Given the process plan for each type of part, processing machines have been identified and estimated production data are taken such as process performances.
In order to simulate and optimize the production, two software are used in combination: Discrete Event Simulation (*DES*) software and Multidisciplinary Design Optimization (*MDO*) software. The two optimization algorithms under comparison are the Genetic Algorithm and pilOPT® a newly developed algorithm based on Response Surface Method (RSM).

Keywords:
DES, MDO, Resources, Layout

1 INTRODUCTION

Production scheduling problems are multi-objective by nature, and in most of the cases, these objectives are in conflict amongst themselves. The authors [1] [2] consider solving a Hybrid Flow Shop (*HFS)* scheduling problem by minimizing the *makespan* and inventory cost through a multi-objective-hybrid-metaheuristic approach, which combines genetic algorithm and variable neighborhood search. They declare that the approach is robust, fast and simply structured.
This work faces also the inverse problem related to the definition of the production plant layout together with the production scheduling needed to meet prescribed production capabilities [3] [4].
The method discussed here focuses directly on the performances and defines automatically the general features of the production system so that the

performances can be achieved: *DES* tool turns from a validation tool to a design tool.
In this case, the purpose of the optimization is to find out the optimal general features: the right set of input variables so that the output achieves our goals. Thus, implying the idea that the performances are the objective and using optimization as a research tool, the basis of the here discussed method is fixed. Therefore, this way of designing a production system, in comparison with the first one, is faster and gives the user more information.
The plant discussed here is Hybrid Flow Shop. In general, *HFS* is a set of *n* jobs to be processed in *m* stages. In our definition of *HFS*, the following assumptions are made:

- The number of processing stages *m* is at least 2.
- Each stage has $k \geq 1$ machines in parallel and in at least one is $k > 1$.
- All jobs are processed following two production flow branches starting from Flexible Manufacturing System (*FMS*). A job might skip any number of stages, assumed it is processed in at least one of them.
- Some jobs can have loops in the production system.

A typical approach to define a production system has usually three phases:

- Defining the desired performances of the production system.
- Setting the general features of the production system.
- Verifying the performance level of the production system.

Repeat phase 2 and phase 3 until the production system achieves the established performance avoiding undesired behaviors in the production system such as bottlenecks. The second phase uses *DES* tools to understand the behavior of the production system.
The here discussed method focuses directly on the performances. Thus, implying the idea that the performances are objectives and using optimization as a research tool.
Using then objective function such minimizing unbalances and maximizing throughput leads to the following results:

- Waiting time reduction and consequently, activity time increasing;
- Maximizing total output;
- Limiting total tardiness.

What it will do is to define shifts and number of machines per group avoiding bottlenecks and reaching predetermined performance, keeping the working stations as balanced as possible.
Objective functions are minimizing Earliness $\min(\sum_i E_i)$ and maximizing Tardiness $\max(-\sum_i T_i)$. This optimization is so multi-objective.

2 PRODUCTION STEPS

In this section, a brief explanation of the production is presented.
The product types manufactured in the department are three: Cylinder Heads (*CH*), Connecting Rod Lower Part (*CRLP*) and Connecting Rod Upper Part (*CRUP*).
After the arrival in the raw part storage, each product enters a *FMS* in order to be machined and prepared for the further operations. The *FMS* consists of four stations, two for machining *CHs* and two for *CRLPs* and *CRUPs*.
After machining, the product is deburred washed for the residuals and measured in order to control the quality. The machining phase is repeated from two to three times depending on the product considered. After the *FMS* stations, each product enters a dedicated flow line branch (Fig.1).

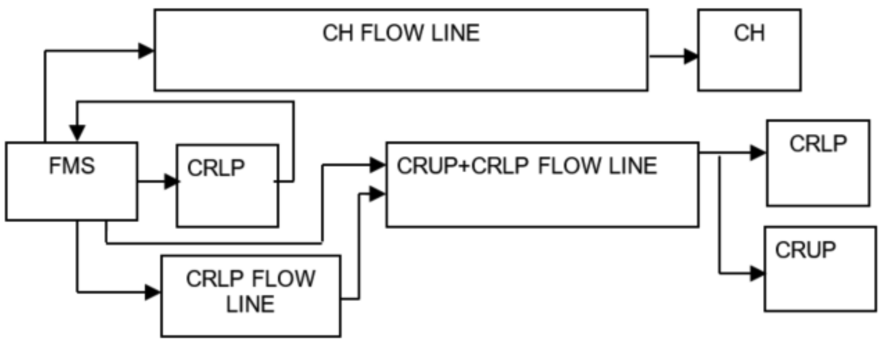

Figure 1: The production flow.

2.1 Cylinder Heads (*CH*)

After machining and final dimension control in the *FMS* stations the *CHs* go their own flow line branch starting with the Ultrasonic Cleaning station, where the finest residuals of the deburring are removed, then they proceed to a nickel planting station. After the nickel planting and a cycle of washing the assembly of the seats begins.
Once the seats are mounted, the *CHs* are tested in order to identify potential leakages. There are three stations of test, two performed with air (5 and 60 bar) and one performed with water (10 bar).
If all the tests are successful, the *CHs* enter the valves mounting then go to the impregnation, where they are treated with a special kind of synthetic resin in order to manage possible casting defects.
Once the impregnation phase is finished, the *CHs* go to the final assembly and then is ready to be used by the next department.

2.2 Connecting Rod Lower Part (*CRLP*)

Once the first diameter check in the *FMS*, the *CRLPs* are sawed in half in order to allow an easy mounting on the engine, but as the sawing produces more raw surfaces, the two halves of the *CRLPs* are sent again in the *FMS* for re-machining, deburring and checking.
After the second diameter checking the *CRLPs* are washed and assembled with the screws that will be used during the engine mounting, then re-washed. Once assembled, they are sent to a shot blasting station, where the internal diameter is treated in order to improve their resistance to stresses. As the shot blasting causes residuals, the *CRLPs* are washed again.
The final part of the *CRLPs* production is a second flow line branch of the plant with a sequence of tests that inspects potential imperfection both on the surface and inside the piece: Magnetic Check (for the surface) and Phased Array (for the internal material).

2.3 Connecting Rod Upper Part (*CRUP*)

As the diameter check in the *FMS* is finished, the *CRUPs* are washed, and then follow the same pattern, the second flow line branch, of the *CRLPs*: they are shot blasted, washed and then checked with the magnetic control and the phased array. After the imperfection check, the *CRLPs* are weighted and their diameter is controlled.

3 COMPUTATION

3.1 Dynamic simulation

Dynamic simulation is a powerful tool for operational research and for the philosophy of continuous improvement (kaizen in terms of Lean production [4]).
It allows the organization to evaluate most of the alternatives as support for tactical and strategic decisions.
Dynamic simulation provides the user with a large amount of information that is hard to obtain without a computer support, by modeling complex systems with some degree of accuracy.
In this project, the software used was WITNESS® Horizon, developed from Lanner Group, a software based on Visual Interactive Simulation.
By R.D.Hurrion: “Visual Interactive Simulation is one which has features for graphical creation of simulation models, dynamic display of the simulated system and user interaction with the running program. Interaction implies that the simulation halts and requests information from the user or the user stops the simulation at will and interacts with the running program”.
Starting a simulation model, the most important step is putting clear goals that is the guide for the decisions to take in model building in terms of priority and choice of variables to insert.

The contest of a simulation model also concerns where the model begins and where it ends. It is important to limit it as much as possible, or, in other words, it is important to model the minimum necessary to achieve the desired results. At the first stages of the model building, small additions to detail usually lead to substantially increasing the accuracy, while once the model is completely detailed, other additions do not bring almost any results in terms of accuracy. As an example, for reasons related to the simplicity required by the model, this choice was made: the transportation times within the factory are very small (many of their duration is less than one minute), so, most of them were modeled with Single-stroke or included in the cycle time of the respective machine.
The optimization computation consists of three phases.

- Multi-objective optimization cycle by using an innovative surface-based response algorithm *pilOPT®* and a Genetic Algorithm *(GA)* to compare with.
- From the Pareto front of the first phase, a clustering methodology has been used in such a way as to group the best solutions into more compact sets.
- Just clustering step provided a number of clusters, they are used as Design Of Experiments (*DOEs*) for the second optimization cycle. The second optimization cycle, tying the two targets into a single objective function in order to use a simpler and more robust algorithm to find a small number of optimal solutions.

3.2 Discrete Event Simulation (*DES*)

Given the production plan just exposed, the next phase is to build the model of the plant with a *DES* software. The software is WITNESS, developed by Lanner Group, which is an extremely versatile program, easy to learn and very powerful.
Each phase of the production plan has been modeled, and the logic used to give the machines order was a Pull logic: the product begins its production cycle if and only if an order of the customer has been released.
Each production station has the same logic: if the next station requires the product, the previous station will work.
In the built model, the number of machines and the cycle time are evaluated on the previous department construction or on the estimated needing of the department.
Once the model has built, a validation of the model is mandatory. This was the more critical part of the project, as the department was not full operating and there was not enough historical data on which validation could be based. In such a condition, the model validation was totally empirical: an esteem of the output was compared with the output of the model and, as the resulted error was enough small, the model was considered valid.

Table 1: Validation results.

Product	Evaluation	Simulation	Percentage error
CH	40	35	12.2
CRLP	90	78	13.3
CRUP	90	76	15.5

3.3 Multidisciplinary Design Optimization (*MDO*)

The model, once validated, was used to perform optimization of the performances of the department using a Multidisciplinary Design Optimization (*MDO*) software, *ModeFRONTIER*, developed by Esteco.
The variables for the optimization model were the number of stations for each working group (e.g. Pressure test, Magnetic Check) and the number of shifts for the groups.
For each working group, an independent number of station and an independent number of shifts has been stated.

Design Of Experiment (DOE)
The first phase of the Optimization process is the definition of the Design Of Experiment.
The *DOE* must define the distribution of the points in the variables' space of definition, that are processed by the Scheduler to optimize the required performances. Within *ModeFRONTIER* several kinds of *DOE* are developed. In the current work, to use the Uniform Latin Hypercube (*ULH*) has been taken, that guarantees a certain uniformity in the variables' distribution [6] [7] [8].

Scheduler
Given the distribution of variables, the Scheduler processes it following a specific algorithm, creating new combination of variables to obtain the required performances.
In this paper, there will be a comparison between two algorithms: the Genetic Algorithm and an innovative proprietary algorithm named *pilOPT*® [9].

pilOPT
pilOPT® is a multi-strategy self-adapting algorithm that combines the advantages of local and global search and it balances in an intelligent way the real and *RSM*-based (virtual) optimization in search for the Pareto front.
pilOPT® gives remarkable performance even when handling complex output functions and constrained problems. It is generally recommended for multi-objective problems, but it can also handle single-objective problems [10].
No parameters are required in *pilOPT*® but the number of design to be computed, so it is also very easy to use.

Genetic Algorithm

The Genetic Algorithm is a well-known algorithm, which simulates the evolution of a species during the optimization.

There are three phases in the *GA*: selection, crossover and mutation.

In the selection phase, the algorithm chooses the individual that it evaluates to be the more eligible to achieve the optimum solution. There are two kinds of selection:

- Roulette selection: a probability function is assigned to each value in the population; the more probable values are chosen to be in the second phase.
- Local selection: the *GA* follows a random “path” and in the way choses the more suitable individuals; the number of steps in the path and the number of paths are both random.

The crossover phase is the central point of the entire algorithm: it creates a new population (a new distribution of variables), possibly better than the previous.

Again, there are two kinds of crossover:

- Binary crossover: each variable has a binary code assigned, and they are switched between the individuals.
- Directional crossover: it evaluates also the function; there are specific formulas to use, that are not matter of this paper.

The last phase of the algorithm is the mutation. It is the least important step; one or two individuals resulted from the crossover phase are modified randomly switching some of their binary code.

Input variables

The first input is to control the number of machines that are active during the model execution.

The purpose of this parameterization is to define the number of machines that each group needs in order to pursue the desired goals.

These goals are: avoiding parties having completion times greater than the due dates and ensuring that the saturation (percentage of use) of the machine groups is below 75%.

In this work, the variables that the *DOE* distributes in their definition space and the Scheduler modifies are two kinds:

- number of machines;
- number of shifts;

In the following table, there are the minimum and maximum number of machines for each process; the number of shifts goes from 1 to 3 for each process. The maximum number of machines was set according to the maximum number that the factory was willing to allow in the structure, so it was not a free choice of the writer.

Table 2: Variation range for machines.

Group	Minimum	Maximum
M1 - Nickel Plating	1	2
M2 - Seat assembly	1	2
M3 - PT 6 bar	1	2
M4 - PT 10 bar	1	4
M5 - PT 60 bar	1	4
M6 - Valve assembly	1	2
M7 - Impregnation	1	3
M8 - Final assembly (CH)	1	3
M9 - CRLP assembly	1	2
M10 - CRLP disassembly	1	2
M11 - Shot Peening	1	2
M12 - Magnetic Check	1	2

Obtaining goals is the task of the optimization cycle, while it is necessary to devise a method for varying the number of active machines because it does not appear possible to implement such a control by WITNESS itself.
The second input is used to control working shifts per machine group.
During a single simulation run, the shift remains constant while it changes from simulation to simulation.

Output variables
The main objective of the factory department is to deliver the products to the next department exactly when it is supposed to: this means that the products must not arrive in the finished storage early nor late.
In this frame of mind, we monitored two output variables in the simulation model:

- Earliness: measures how early the products arrive.
- Tardiness: measures how much late the products arrive.

3.4 Optimization
The optimization has been divided into three phases [5]:

- First round of optimization: multi-objective optimization; in this phase, we used the two considered algorithms. Using pilOPT® algorithm 5000 designs have been generated, while GA generated 15000 designs.

- Clustering: the results given by the first round of optimization were collected in macro-groups using the Euclidean distance; each algorithm produced 5 clusters.
- Second round of optimization: mono-objective optimization (objective = earliness + tardiness); in this phase the DOE was given by the previously mentioned clusters and the optimization algorithm was the mono-objective operational research algorithm called SIMPLEX. This second optimization is necessary to obtain a single final design for each cluster. Thus, the results of the optimization can be compared.

4 RESULTS

In this section, the results of the second phase of optimization are collected. The results of the first round of optimization are not included as they are low legible.

Table 3: Final optimization results.

	pilOPT®		Genetic Algorithm	
	Earliness	Tardiness	Earliness	Tardiness
Cluster 0	4776	-59505	5136	-29255
Cl1 - Cluster 1	4676	-39474	4200	-29285
Cl2 - Cluster 2	4676	-39474	4200	-29255
Cl3 - Cluster 3	4277	-29285	4214	-29505
Cluster 4	4776	-49890	4200	-29255

The enlightened rows indicate non-convergent clusters: the results in these lines cannot be considered valid.
For each cluster, the number of shifts is collected in the following Table 4.

Table 4: Final optimization results: shifts.

	pilOPT®											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Cl1	2	3	3	3	2	3	2	3	3	3	2	2
Cl2	1	3	2	3	2	3	2	3	3	2	1	2
Cl3	2	3	3	3	2	3	2	3	3	2	2	2
	Genetic Algorithm											
Cl1	2	3	1	3	2	2	1	3	3	2	2	3
Cl2	3	1	3	3	3	2	3	2	2	3	3	2
Cl3	2	2	3	3	3	2	2	3	3	2	2	2

While the number of machines is collected in the following Tab 5.

Table 5: Final optimization results: machines.

	pilOPT®											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Cl1	1	2	2	3	3	1	3	2	2	2	1	2
Cl2	1	2	2	4	3	1	3	1	2	2	2	2
Cl3	2	2	2	3	3	2	3	1	2	2	2	2
	Genetic Algorithm											
Cl1	1	2	2	3	3	1	3	2	2	2	1	2
Cl2	1	2	2	3	3	1	3	1	2	2	3	3
Cl3	2	2	2	3	3	2	2	1	2	2	3	2

The machine’s saturation in Tab.6.

Table 6: Final optimization results: machines’ saturation.

	pilOPT®											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Cl1	0.1	49	12	10	10	28	34	36	4	7	26	9
Cl2	0.2	42	18	11	13	28	41	32	4	9	62	10
Cl3	0.1	47	12	10	10	28	39	47	5	10	45	17
	Genetic Algorithm											
Cl1	0.1	48	18	9	11	29	39	39	5	8	30	18
Cl2	0.2	46	16	10	14	28	32	35	5	8	26	15
Cl3	0.1	49	12	10	10	28	34	45	5	9	35	12

5 DISCUSSION

As you can see the results given by the *GA* are slightly better regarding the earliness, while noticeable improvements are more consistent in the tardiness column.
However, the approaching to the desired objectives has a cost. In fact, as exposed in the Optimization section, the *GA* required significantly more designs to be evaluated than *pilOPT*®, precisely three times the designs of *pilOPT*®, with a consequent increase of the computing time (two days versus a week and a half).
In the working world, time is the bigger problem. The question that arises is: are the better results worth the amount of time lost?

pilOPT® is very fast, but in this paper, we probably overestimated its speed; however, as the results are not very dissimilar, the authors suppose that with a little increase of designs (e.g. 8000 instead of 5000) *pilOPT®* could exceed the results of *GA* with less time.
This is obviously just a hypothesis, more significant proves could be collected with another round of simulation, that is a possible improvement of the actual work.
This job’s aim was to optimize the department’s performances, but it can be used also to foresee the department’s behavior in different work conditions. As you can see in Table 6, the machine saturation is far less than 75%, that is the normal workload of a department station, but this result is not to be considered despicable, because the idea of the factory’s head was to absorb the current subcontracting within the factory, in order to reduce the subcontracting fees. Considering this, another development of this work could be the addition of this extra amount of workload and the consequent research of new bottlenecks, new distribution of shifts and number of machines as well.

REFERENCES

[1] Konak, A., Coit, D.W., Smith, A.E. (2006) Multi-objective Optimization Using Genetic Algorithms: A Tutorial, Reliability Engineering & System Safety, 91, Issue 9:992–1007.

[2] Pugazhenthi, R., Xavior, A. (2014) A Genetic Algorithm Applied Heuristic to Minimize the Makespan in a Flow Shop, Proc.Eng. 97, 1735-1744.

[3] Lassig, L., Mazzer, F., Nicolich, M., Poloni, C. (2017) Hybrid flow shop management: multi objective optimization, Procedia CIRP, Elsevier, 2017, vol. 62.

[4] Womac J. P., Jones D. T., Lean thinking - BanishWaste and Create in Your Corporation, Simon and Schuster, New York, NY, 1996.

[5] Lassig, L., Nicolich, M., Poloni, C. (2015) Assembly line management: multi-objective optimization, 5th Int. Conference on Production Engineering and Management, Trieste, Italy.

[6] Chen, H., Huang, H., Lin, K. J. D., Liu, M. Q. (2016) Uniform sliced Latin Hypercube designs, Applied Stochastic Models, Business and Industry, September 2016.

[7] Taranenko, A. A. (2016) Permanents of Multidimensional Matrices: Properties and Applications, Journal of Applied and Industrial Mathematics, vol. 10, n. 4, pp. 567-604.

[8] Jiang, B., Ai, M. (2017) Construction of uniform U-designs, Journal of Statistical Planning and Inference, vol. 181, pp. 1-10.

[9] Costanzo, S., Xue, Z., Engel, M., Chuang, C.H. (2015) MultiStrategy Intelligent Optimization Algorithm for computationally expensive CAE simulations, Proceedings of NWC2015, NAFEMS World Congress, San Diego, California, 21-24 June 2015.

[10] Muñoz, M. A., Sun, Y., Kirley, M., & Halgamuge, S. K. (2015) Algorithm selection for black-box continuous optimization problems: A survey on methods and challenges. Information Sciences, 317(C), 224–245.
[11] Ma, L., Ma, M., Ma, C., Deng, J., Liu, X., Zhao, L. (2016) Simulation and optimization study on layout planning of plant factory based on WITNESS, International Journal of Security and Its Applications, 2016, vol.10, n. 5, pp. 275-292.

AN INSTRUCTIONAL PROGRAM TO SUPPORT EARLY EQUIPMENT MANAGEMENT IN A MANUFACTURING COMPANY

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Abstract
The fast pace of change in the modern world forces companies to manufacture new products in a short amount of time with the best technologies available in the market. For this reason, new manufacturing equipment is implemented in the shop floor with the aim of a vertical production ramp-up after the installation. Nevertheless, many problems, which were not initially taken into account, arise causing delays during the start of production. In the first part of the paper, an overview of Early Equipment Management will be presented. This methodology has the aim of making competitive installations through the anticipation of the problems that may arise during equipment's life and the main goal is to start the production in the shortest possible time. In the second part of the paper, a case study concerning a manufacturing plant will be described. Taking advantage from the installation of a new welding robot, an instructional program for workers has been implemented to reduce the learning time for the equipment setup and for assembling different parts of the products. This will allow a fast ramp-up and waste reduction.

Keywords:
Assembly, Shop floor, Early Equipment Management, Operator assistance, Video instructions

1 INTRODUCTION

Management of manufacturing equipment presents many problems such as identification of effective maintenance policies, quality variability, and difficulties in achieving high values of Overall Equipment Effectiveness (OEE) in a short time. In particular, when a company purchases a new equipment, in the first phase after the installation many problems, which were not initially taken into account, arise and they may cause a slow production ramp-up. Electrolux Professional S.p.A., a company based in Pordenone (Italy) that provides products for cooking and laundry dedicated to professional users, aims to implement the World Class Manufacturing (WCM) concepts in its plants and, in this respect, a key pillar to implement is Early Equipment

Management (EEM). Other companies have gained an advantage with the application of WCM inside their shop floor; for example, FCA Automobiles saved 760 million euros in the period 2006-2009 and had the objective to reach 2.6 billion euros in 2014 [1]. Electrolux Professional wants to exploit WCM, whose application has yielded positive results in other manufacturing industries, in order to maintain and increase its competitive advantage towards competing companies. EEM has the aim of making competitive installations not only from the point of view of technology innovation but also from that of continuous improvement through the anticipations of the problems that may arise during equipment's life. The main goals that the company wants to achieve through the application of WCM are:

- to produce with zero defects;
- to ensure a rapid start-up production;
- to minimize development time;
- to ensure compliance with the schedule set in the programming phase.

All this is possible by designing the equipment using the experience gained from other similar units already installed in the shop floor observing both the phase of production start-up and that at planned operations. For this reason, Electrolux Professional wanted to take advantage of the installation of a welding robot that uses a new technology for the company: the idea was to create a base of experience that could be exploited for the future installation of other similar systems and used for a systematic implementation of the pillar EEM. The literature about EEM is still poor and provides techniques that can be applied from the design to the installation of the equipment; conversely, in this case, the focus is to use a tool after the installation step with the purpose of reducing the production start-up time. In fact, Electrolux Professional is a company with high product mixes and low production volumes, compared to industries with mass production, and, in this case, workers have not enough time to repeat the same assembly processes because of the high variability of the products, which implies a longer learning time. If the employees do not have much time to learn how the new equipment works, the time for the ramp up will become longer. Other studies have shown how dynamic work instructions increase activity performances in assembly lines: this same logic was applied in the new welding workstation. In summary, the solution tested in this paper is the development of a program to be installed in a PC with video instructions for the set-up of the equipment to simplify the assembly process and to avoid waste.

2 OVERVIEW OF EXISTING TECHNIQUES

2.1 World Class Manufacturing

World Class Manufacturing is a synthesis of different concepts, principles, and techniques for the management and operation of companies employed in manufacturing. It is guided by the results obtained by Japanese companies after World War II and represents an evolution of the ideas that were used in the automotive, electronics and heavy industry in order to achieve a competitive advantage. WCM system is based on the reduction of all types of costs and wastes through the contribution of all employees. The main goals of this system are to reach zero in waste, defects, faults, and stocks and the values are the involvement of people, the creation of better values and more satisfied customers [2].

Hayes and Wheelwright first used the term “World Class Manufacturing” in 1984. Since that moment, the concept has been enhanced by other authors who have reinforced some of the original ideas, added new methods and ignored others. The work of Hayes and Wheelwright is important for several reasons. First, they were the first to use the term WCM, laying the basis for the work of future authors. Second, they described WCM as a set of principles and practices that could help to reach superior performance in manufacturing. At the end, they underline that it is important to have a clear set of priorities. [3] The next evolution of WCM is due to Schonberger that reinterpreted the original concept creating a new model. He theorized that innovative managerial practices in operations should be based on the Japanese manufacturing systems Toyota Production System (TPS), Just in Time (JIT) and Total Quality Control (TQC) including all their tools. However, from the late 1990s, the WCM concept was not used anymore in favor of “lean production”. This term was used for the first time in the book “The machine that changed the world” written by Womack, Jones and Roos [4]. During the next year, lean production has been refined assuming other denominations like lean organization, lean manufacturing, lean thinking [5]. Nevertheless, WCM has not been completely cleared away. The Japanese H. Yamashina resumed the term, evolved the concepts of WCM and today it stands as a renewal of the lean model. In the 2000s some worldwide companies as Ariston Thermo Group, FCA Automobiles, Unilever, Royal Mail, Volvo Powertrain gathered together in the WCM association and they have shared a WCM model for excellence [4]. According to FCA Automobiles, WCM is “a structured and integrated production system that encompasses all the processes of the plant, the security environment, from maintenance to logistics and quality. The goal is to continuously improve production performance, seeking a progressive elimination of waste, to ensure product quality and maximum flexibility in responding to customer requests, through the involvement and motivation of the people working in the establishment” [6]. FCA has customized the WCM method with H. Yamashina redesigning and implementing the model that is based on the typical Japanese temple-shaped structure. This model, shown in Fig. 1, is made up of 10 technical pillars and

10 managerial pillars. WCM is developed in 7 steps for each pillar and they are identified in three different phases: reactive, preventive, proactive. The approach needs to start from a testing area and then extend to the entire company. The focus in WCM is on continuous improvement. Measurements are important because “if you can’t measure it, you can’t manage it and thus you can’t improve it” [6]. In this way, it is important to define the Key Performance Indicators (KPIs) that measure the results of the improvement and performances.

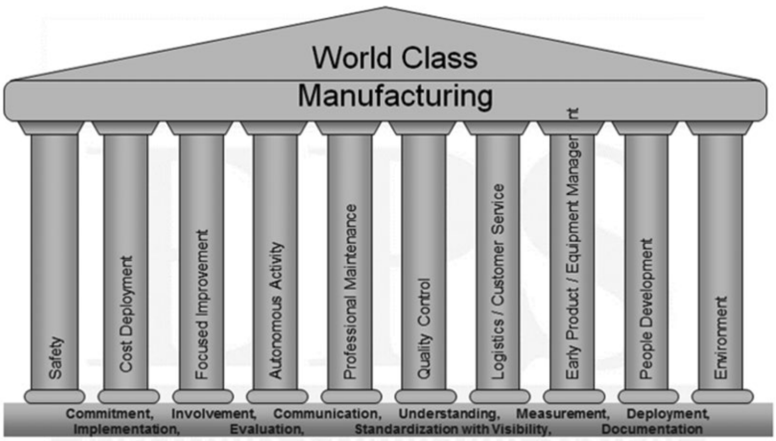


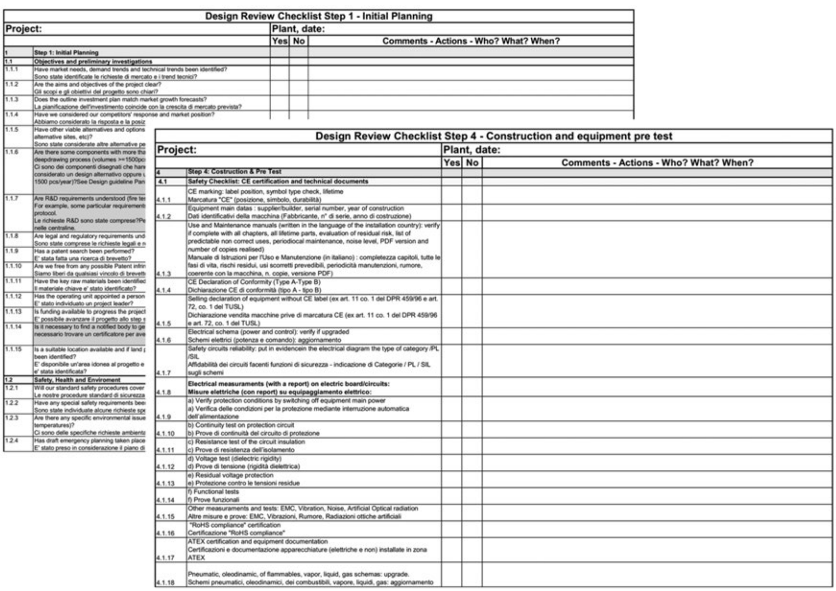
Figure 1: World Class Manufacturing temple [6].

The most important difference between the WCM temple and those used in lean philosophy is the pillar of Cost deployment. Problems are identified from the point of view of cost reduction and their effect on the company’s economic performance. Starting from the results obtained from the cost analysis, a list of priority is set and the problems are addressed and resolved by the Focused Improvement pillar. Another pillar that is important in WCM is the Early Equipment/Product Management [6].

Early Equipment Management

To gain a competitive advantage over other manufacturing companies, it is necessary to increase efficiency by reducing waste. For this reason, it is important to act from the early step of design in order to decrease as much as possible the start-up time when a new equipment is installed on the shop floor. The method that allows to achieve this goal is Early Equipment Management, which is one of the ten technical pillars of WCM [6]. EEM has the aim of making competitive installations not only from the point of view of technology innovation, but also from that of continuous improvement through the

anticipations of the problems that may arise during equipment's life. All of this is possible by designing the equipment using experience gained from other similar units already installed in the shop floor observing both the phase of production start-up and that at planned capacity. The best moment to achieve excellent results is the design phase of the equipment. In fact, changes made to the equipment in the early phases are less expensive and easier to make. Usually, during the start-up, start of production and production run phases there are costs connected to inefficiency and low quality: if these are reported as a percentage of total costs, it can be seen that most of the money is spent in this period. To achieve the goals of EEM a close collaboration between different business functions is required from the early stages of the project. In the design phase the team plans the project and incorporates ideas from quality, maintenance, production, engineering, and R&D.
The main tool for applying the EEM methodology is the checklist. The team should use a different checklist for each step of the project to verify that the equipment meets the required characteristics to give the expected results. Checklists include questions that concern topics of interest about equipment and products such as places hard to inspect, safety, ergonomics thematic. After the conclusion of the project the EEM team redesigns the EEM process and checklist thanks to the experience gained in the installation of the equipment [7].



Design Review Checklist Step 1 - Initial Planning				
Project:		Plant, date:		
		Yes	No	Comments - Actions - Who? What? When?
1	**Step 1: Initial Planning**			
1.1	**Objectives and preliminary investigations**			
1.1.1	Have market needs, demand trends and technical trends been identified? Sono state identificate le richieste di mercato e i trend tecnici?			
1.1.2	Are the aims and objectives of the project clear? Gli scopi e gli obiettivi del progetto sono chiari?			
1.1.3	Does the outline investment plan match market growth forecasts? La pianificazione dell'investimento coincide con la crescita di mercato prevista?			
1.1.4	Have we considered our competitors' response and market position? Abbiamo considerato la risposta e la posiz			
1.1.5	Have other viable alternatives and options alternative sites, etc)? Sono state considerate altre alternative pe			
1.1.6	Are there some components with more tha deepdrawing process (volumes >=1500pc Ci sono dei componenti disegnati che han considerato un design alternativo oppure u 1500 pcs/year)?See Design guideline Pan			
1.1.7	Are R&D requirements understood (fire te For example, some particular requirement protocol. Le richieste R&D sono state comprese?Pe nelle centraline.			
1.1.8	Are legal and regulatory requirements und Sono state comprese le richieste legali e n			
1.1.9	Has a patent search been performed? E' stata fatta una ricerca di brevetto?			
1.1.10	Are we free from any possible Patent infrin Siamo liberi da qualsiasi vincolo di brevett			
1.1.11	Have the key raw materials been identified Il materiale chiave e' stato identificato?			
1.1.12	Has the operating unit appointed a person E' stato individuato un project leader?			
1.1.13	Is funding available to progress the project E' possibile avanzare il progetto allo step s			
1.1.14	Is it necessary to find a notified body to ge necessario trovare un certificatore per ave			
1.1.15	Is a suitable location available and if land p been identified? E' disponibile un'area idonea al progetto e e' stata identificata?			
1.2	**Safety, Health and Enviroment**			
1.2.1	Will our standard safety procedures cover Le nostre procedure standard di sicurezza			
1.2.2	Have any special safety requirements bee Sono state individuate alcune richieste spe			
1.2.3	Are there any specific environmental issue temperatures)? Ci sono delle specifiche richieste ambienta			
1.2.4	Has draft emergency planning taken place E' stato preso in considerazione il piano di			

Design Review Checklist Step 4 - Construction and equipment pre test				
Project:		Plant, date:		
		Yes	No	Comments - Actions - Who? What? When?
4	**Step 4: Costruction & Pre Test**			
4.1	**Safety Checklist: CE certification and technical documents**			
4.1.1	CE marking: label position, symbol type check, lifetime Marcatura "CE" (posizione, simbolo, durabilità)			
4.1.2	Equipment main datas : supplier/builder, serial number, year of construction Dati identificativi della macchina (Fabbricante, n° di serie, anno di costruzione)			
4.1.3	Use and Maintenance manuals (written in the language of the installation country): verify if complete with all chapters, all lifetime parts, evaluation of residual risk, list of predictable non correct uses, periodiocal maintenance, noise level, PDF version and number of copies realised) Manuale di Istruzioni per l'Uso e Manutenzione (in italiano) : completezza capitoli, tutte le fasi di vita, rischi residui, usi scorretti prevedibili, periodicità manutenzioni, rumore, coerente con la macchina, n. copie, versione PDF)			
4.1.4	CE Declaration of Conformity (Type A-Type B) Dichiarazione CE di conformità (tipo A - tipo B)			
4.1.5	Selling declaration of equipment without CE label (ex art. 11 co. 1 del DPR 459/96 e art. 72, co. 1 del TUSL) Dichiarazione vendita macchine prive di marcatura CE (ex art. 11 co. 1 del DPR 459/96 e art. 72, co. 1 del TUSL)			
4.1.6	Electrical schema (power and control): verify if upgraded Schemi elettrici (potenza e comando): aggiornamento			
4.1.7	Safety circuits reliability: put in evidencein the electrical diagram the type of category /PL /SIL Affidabilità dei circuiti facenti funzioni di sicurezza - indicazione di Categorie / PL / SIL sugli schemi			
4.1.8	**Electrical measuraments (with a report) on electric board/circuits:** **Misure elettriche (con report) su equipaggiamento elettrico:**			
4.1.9	a) Verify protection conditions by switching off equipment main power a) Verifica delle condizioni per la protezione mediante interruzione automatica dell'alimentazione			
4.1.10	b) Continuity test on protection circuit b) Prove di continuità del circuito di protezione			
4.1.11	c) Resistance test of the circuit insulation c) Prove di resistenza dell'isolamento			
4.1.12	d) Voltage test (dielectric rigidity) d) Prove di tensione (rigidità dielettrica)			
4.1.13	e) Residual voltage protection e) Protezione contro le tensioni residue			
4.1.14	f) Functional tests f) Prove funzionali			
4.1.15	Other measuraments and tests: EMC, Vibration, Noise, Artificial Optical radiation Altre misure e prove: EMC, Vibrazioni, Rumore, Radiazioni ottiche artificiali			
4.1.16	"RoHS compliance" certification Certificazione "RoHS compliance"			
4.1.17	ATEX certification and equipment documentation Certificazioni e documentazione apparecchiature (elettriche e non) installate in zona ATEX			
4.1.18	Pneumatic, oleodinamic, of flammables, vapor, liquid, gas schemas: upgrade. Schemi pneumatici, oleodinamici, dei combustibili, vapore, liquidi, gas: aggiornamento			

Figure 2: Example of checklist used in Electrolux Professional.

Another tool that can be used in the design phase is poka yoke. It is a quality assurance technique introduced by Toyota manufacturing engineer S. Shingo in 1961 and it has the aim to eliminate defect in a product by preventing problems in the process and equipment, as early as possible [8]. At each stage of the product life cycle and in each process, there is a possibility of errors that cause defects in the final products and, as a result, customer dissatisfaction. The technique starts by analyzing the process looking for the parts that can cause problems. It can happen that during the manufacturing process different components are assembled in the wrong way without the worker being aware of it. The components can be modified to avoid this error and this technique is very cheap if it is applied in the design phase [9].
All the EEM techniques presented in the literature can be applied only before the installation of a new equipment. Nevertheless, the next installation phase also influences the ramp up curve of production, but there is presently a lack of information about tools to be used in this step. This paper proposes an instructional program to help workers in the first phase of production, when they do not have sufficient knowledge of the process and equipment.

2.2 Work instruction systems for assembly

When a new model of a product is being launched, there is a lack of training system. Training is critical to reduce the start-up time for a new equipment and problems of quality in this phase. Assembly times of workers can be improved by repeating the same processes, but in industries where product mixes and production volumes vary in a short period of time, it is more difficult to learn well the assembly procedures. Learning curves show that a worker is trained by repeating the same tasks [10]. According to these curves, it is important that the assembly times of first products should be reduced to increase the productivity because in this phase the worker does not have adequate training to carry out assembly operations in a short time. In order to reduce the learning time, it is necessary to introduce tools that allow a quick understanding of the assembly processes and the reduction of the assembly times of products. Different studies focused on this topic and a tool that can be used is video instructions for workers.
Usually, the information on job content and operations are typified by assembly worksheet. However, these documents are not particularly meaningful for workers. Volkswagen implemented a multimedia system in which all the knowledge about assembly procedures can be stored. They could be in the form of text, pictures or video. The multimedia system was used with good results to store and present the information necessary for the production in the form of operation descriptions and drawings. The evaluation results were positive with a learning effect clearly demonstrated [11]. Also in other types of industries good results can be found. For example, in a cellular manufacturing a work instruction system for untrained workers reduced the assembly times of the first products without repeating the same assembly processes. In this case, the workers received the information through a touch screen monitor. The results were that the assembly times could be decreased

from even the first product [12]. Many different systems can be used to provide workers with the information they need; a classification of these can be found in Hinrichsen et al. [13]. At a first instance, the assistance systems can be divided between physical and informational. Informational systems are made to avoid uncertainties and mental stress among workers. All these systems can be further divided into stationary systems, mobile assistance systems, hand devices, and wearables. Another classification can be made according to the type of information output and control input to the system [13]. According to Watson et al. [14] the best way to display information for workers is by dynamic instructions with animations. Their findings reveal that when animation is used to portray instructional information for assembly, an immediate beneficial effect is observed over static information. Animations instructions can produce more consistent and free-error products for a group of untrained workers [14].

3 CASE STUDY: ELECTROLUX PROFESSIONAL

Electrolux Professional S.p.A., whose headquarter is located in Pordenone in Italy, provides products for cooking and laundry dedicated to professional users and it is part of Electrolux Group, a global leader in domestic appliances. Electrolux Professional wants to implement World Class Manufacturing inside its plants and one of the pillar to develop is Early Equipment Management (cf. Fig. 1). For this reason, the company wants to take advantage of the installation of a welding robot that uses a new technology for the company: the idea is to create a base of experience that could be exploited for the future installation of others similar systems and used for a systematic implementation of the EEM pillar. The welding equipment purchased by Electrolux Professional is made up of numerous inserts that must be fitted by the worker in different positions, depending on which version of the product must be manufactured: the position is determined by an association table that has been provided by the equipment manufacturer. The table is shown in Fig. 3.
When the assembly worker uses the association table, three different problems can occur:

- very long times for the setup of the equipment, because the worker must look for the code of the product to be manufactured and then the position of the inserts and their name;
- possibility of errors in reading the table, as it is very easy to make a mistake in reading the product line or the name and the position of the inserts;
- the table does not provide the correct assembly sequence for the inserts. If the operator misses the order of assembly, there will be welding defects and therefore production rejects.

TABELLA POSIZIONI [LATO 1]													
TIPOLOGIA PEZZO	CODICE PEZZO	C1	C2	C3	S1	S2	S3	S4	S5	S6	S7	S8	T1
22" Standard	*83065HJ*	P3	P6	P7	SI	///	///	///	///	///	P17	P10/P11	///
35" Standard	*83065NH*	P3	P8	P9	///	SI	SI	///	///	///	P17	P10/P11	///
35" DX	*83065HM*	P4	P8	P9	///	SI	SI	///	P11	P13	P19	P10	///
	83065LG	P4	P8	P9	///	SI	SI	P15	P11	P13	P19	P10	P16
	83065N3	P4	P8	P9	///	SI	SI	///	P11	P13	P19	P10	///
	83065N6	P4	P8	P9	///	SI	SI	P15	P11	P13	P19	P10	P16
35" SX	*83065JC*	P5	P8	P9	///	SI	SI	P15	P10	P12	P18	P11	P16
	83065KX	P5	P8	P9	///	SI	SI	///	P10	P12	P18	P11	///
	83065N1	P5	P8	P9	///	SI	SI	///	P10	P12	P18	P11	///
	83065N5	P5	P8	P9	///	SI	SI	P15	P10	P12	P18	P11	P16

Figure 3: Association table for the welding equipment.

In the first phase, after the installation, workers do not have enough confidence with the equipment because they do not know the name of the inserts and the positions in which they must be fitted. These problems imply production waste and a slow ramp-up, with the difficulty of achieving the stated objectives in a short time. As already mentioned, the EEM literature provides techniques that can be applied only during equipment design but, in this case, the need is to use a tool after the installation step with the purpose of reducing the production start-up time. The solution proposed in this paper is the development of a program to be installed in a PC with video instructions for the set-up of the equipment. In fact, as many authors underline in different articles, the instructional programs can improve the workers' learning curve and they have a positive impact on the early stages of production. It is also important for Electrolux Professional, a company that has a wide range of products but with lower volumes than domestic appliances, to have an instrument that can ensure a fast start up of the technological systems.
Thanks to the classification made by Hinrichsen et al. [13] it is possible to have an overview of all informatics systems to be used for the instructional programs according to the usage situation. For Electrolux application, the best system that can be chosen is an instructional program to be installed in an All-in-one PC with touch interaction. The instructional program developed by Electrolux Professional is called Electrolux Tutor.
According to Watson et al. [14], an animated video instruction can help the workers to learn better the assembly operations. Nowadays, when a new equipment is developed, the 3D CAD files are available for the customer that purchase the machinery. Therefore, it is possible to create animations and for this case Solidworks program with the motion pack is used to simulate the movement of the parts. First of all, all the components of the equipment are

paired to create the correct movement of the different parts. Then the video is created moving the camera and the components in the desired directions in the space repeating several times the movements. The interface of Solidworks motion is shown in Fig. 4.

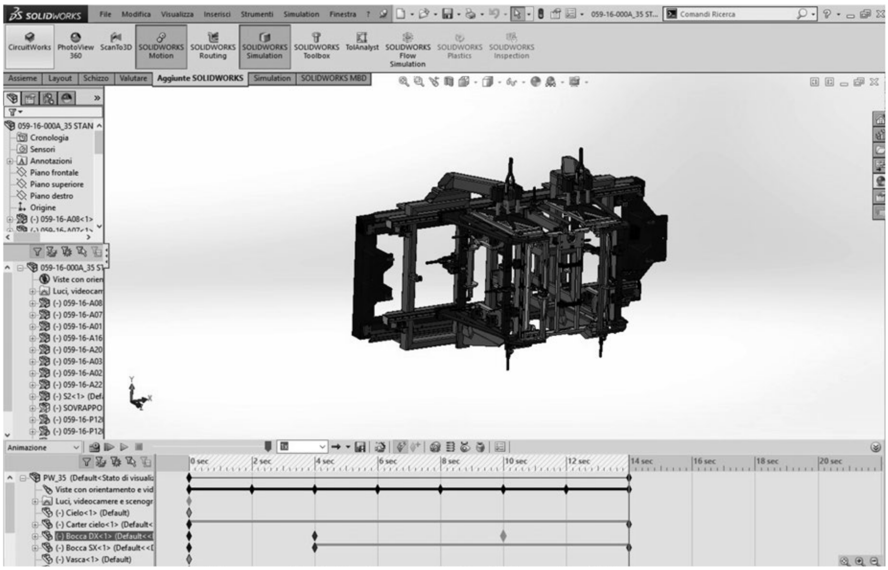


Figure 4: Interface of Solidworks Motion.

Electrolux Tutor employs two different types of input files:

- an Excel file with all the codes of the products assembled by Electrolux Professional;
- video files obtained from the 3D CAD files equipment using SolidWorks Motion.

The idea is to associate each product code to a sequence of videos with the animations of the assembly step. The videos have the description with the inserts name and with the position in which they must be fitted and they show, through the animations, the movement of the component and its location. In order to give a timing to the setup operations, the videos are repeated for a defined time based on the expected duration of the assembly. The videos with the assembly step are loaded sequentially without any interaction by the worker, who can continue the setup activity without any further time loss. If the user needs to review the previous video, a specific button must be clicked to go back to the previous step. To avoid mistakes in reading the codes of the product to be manufactured, the program can be used with a barcode gun.

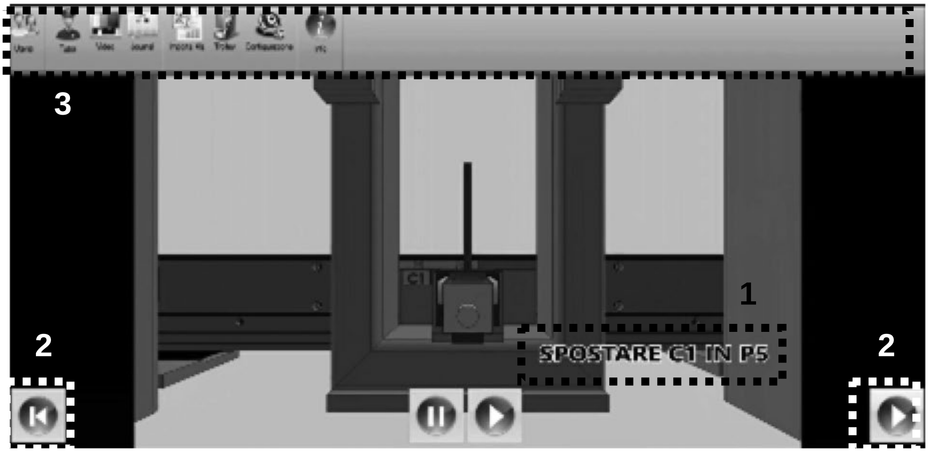


Figure 5: Screen of Electrolux Tutor with animations and instructions.

In Figure 5 a frame of the animation video is shown with the following items: a description of the assembly operation (1), command buttons to see the next step or to take back to the previous instruction (2) and an upper bar that is visible only using an administrator account (3).
It is important to develop the program from the outset so that it can be used in every area of the shop floor. For this reason, after the installation of the program on the PC, it must be assigned to a workstation in a production line. Since the codes used for the reading with the barcode gun is what identifies the finished products, the program association with the workstation is also useful because it allows to know which component of the selected machine must be assembled. In this way, Electrolux Tutor selects from the Excel input file the code and shows:

- the instruction video if, for a finished product, it is possible to produce only one code in that workplace;
- all the codes that can be assembled in that workstation for the selected finished product.

In Fig. 6, the operating principle of Electrolux Tutor is summarized.

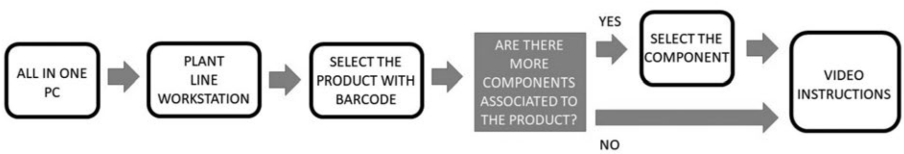


Figure 6: Electrolux Tutor operating diagram.

In order to estimate the performance of this program two indices have been defined:

- Velocity Index (VI), which allows evaluating the reduction of the time to set-up the equipment, defined as:

$$VI = \frac{Setup\ time\ without\ E.T. - Setup\ time\ with\ E.T.}{Setup\ time\ without\ Electrolux\ Tutor} \cdot 100 \quad (1)$$

- Quality Index (QI) to evaluate the rise of production, defined as:

$$QI = \frac{Nr\ wrong\ assembled\ products}{Nr\ assembled\ products} \cdot 100 \quad (2)$$

After a month of production using Electrolux Tutor, excellent results were achieved. The quality index is 2.2% that, compared with 8.3% when Electrolux Tutor was not used, is a great result that allows to reduce waste. In addition, the velocity index, which is important to understand how much the program has improved the ramp up of the production, gives a positive result. It is 18.8% and represents a huge improvement in the assembly time: the use of Electrolux Tutor allowed a reduction of about the 20% of setup time.

4 CONCLUSION AND OUTLOOK

Electrolux Tutor is a program for PC that enables a faster ramp up of the production when a company wants to manufacture a new product. It contains instructional videos with animations and can be useful on one hand to set up a technological equipment and, on the other, as a training system for the assembling of the components that make up a product. The program was created for a specific situation, but it can also fill a gap in the present literature on EEM: in fact, all the tools that are presented for implementing the pillar of EEM can be used only in the phases before the installation of a new equipment. Electrolux Tutor is a system that allows to start the production in the shortest possible time. The instructional program was installed in an All-in-one PC in the technological area near a new welding robot. With the installation of this program in the welding area, workers can fit inserts in the right positions in less time and waste due to because welding defects are reduced. Thanks to these good results, Electrolux Tutor can be expanded, in the future, in other areas inside the shop floor as a new instrument to achieve Early Equipment Management's main goals.

REFERENCES

[1] Ketter, S. (2010), Presentation of WCM results in FIAT.

[2] Arsovski, S., Dokic, I., Pesic S. (2011) Quality in World Class Manufacturing, International Journal for Quality Research, Vol. 5, No. 4.

[3] Flynn, B., Schroeder, G., Flynn, E. (1999) World Class Manufacturing: an investigation of Hayes and Wheelwright's foundation, Journal of Operations Management, 17, 249-269.

[4] Chiarini, A., Vagnoni, E. (2015) World-class manufacturing by Fiat. Comparison with Toyota Production System from a Strategic Management, Management accounting, Operations management and Performance measurements dimension, International Journal of Production Research, 53:2, 590-606.

[5] Chiarini, A. (2013) Relationship between Total Quality Management and Six Sigma inside European Manufacturing Companies: a dedicated survey, International Journal of Productivity and Quality Management, Vol. 11, 179-194.

[6] De Felice, F., Petrillo, A., Monfreda, S. (2013) Improving Operations Performance with World Class Manufacturing Technique: A Case in Automotice Industry, Operations Management, 1, 1-30.

[7] Schlie, M. (2007) Early Equipment Management, Engineering Management Field Project, 1-62.

[8] Robinson, H. (1997) Using Poka-Yoke techniques for early defect detection, Sixth International Conference on Software Testing Analysis and Review, 134-145.

[9] Dudek-Burlikowska, M., Szewieczek, D. (2009) The Poka-Yoke method as an improving quality tool of operations in the process, Journal of Achievements in Materials and Manufacturing Engineering, 36.1, 95-102.

[10] Biskup, D. (1999) Single-machine scheduling with learning considerations, European Journal of Operational Research, Vol. 115, 173-178.

[11] Dencker, B., Balzer, H.-J., Theuerkauf, W. E., Schweres, M. (1997) Using a production-integrated video learning system (PLV) in the assembly sector of the car manufacturing industry, International Journal of Industrial Ergonomics, 23, 525-537.

[12] Tanimizu, Y., Ishii, S., Yokotani, T. (2014) A study on development of a work instruction system for assembly cells based on analysis of learning processes, Journal of Advanced Mechanical Design, Systems, and Manufacturing, Vol. 8, No.4, 1-10.

[13] Hinrichsen, S., Riediger, D., Unrau, A. (2016) Assistance systems in manual assembly, 6th International Conference on Production Engineering and Management, 3-14.

[14] Watson, G., Butterfield, J., Curran, R., Craig, C. (2009) Do dynamic work instructions provide an advantage over static instructions in a small scale assembly task?, Learning and Instruction, 20, 84-93.

SESSION E
Technology and Business for Circular Economy and Sustainable Production

SUSTAINABLE MANAGEMENT OF BIOGAS PRODUCED WITH AN ANAEROBIC DIGESTION PLANT

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Abstract
There are several ways to use biogas from anaerobic digestion, in addition to the traditional use in cogeneration and trigeneration plants; there is also the possibility to purify biogas by using an upgrading plant and to inject biomethane into the gas network SNAM.
This paper analyses technical, economic and environmental feasibility among four alternative uses of biogas produced in an anaerobic digestion plant fed by zootechnical wastes eventually integrated with corn silage:

1. a cogeneration plant producing electrical power to satisfy the company needs and to sell to the power grid if exceeding and using the heat only to warm-up the digester and the post-digester;
2. a cogeneration plant producing electrical power to satisfy the company needs and to sell to the electrical grid if exceeding and using the heat to warm-up the digester and the post-digester and to feed a dryer for reducing cereals moisture to optimal conditions for their storage;
3. a trigeneration plant producing electrical power to satisfy the company needs and to sell to the electrical grid if exceeding and using the heat to warm-up the digester and the post-digester and for air-conditioning the company;
4. a regenerative water scrubbing up-grading plant and injecting biomethane into the gas network SNAM.

The results of this analysis enable to make a choice not only technologically developed but also economically and environmentally sustainable; it strictly binds to a plant fed by renewable energy sources as the anaerobic digestion is.

Keywords:
Biogas, Management, Sustainability

1 INTRODUCTION

The continuous growth of energy needs and the ability to realize localized eco-sustainable generation plants has led to the creation of many anaerobic digestion systems for wastewater in recent decades. Production of waste biogas from scraps of productive activities, whose costs are low or nil, has taken on a growing role in the national energy market because it is a source of renewable energy, hence subject to incentives. It is widespread in farms, since it integrates with the primary production sector (agriculture and breeding), enabling the company's energy needs to be met and, in many cases, a further revenue due to the production of energy surplus and its mode of employment. The biogas produced by anaerobic digestion can have different possible uses; in Italy, it is used almost exclusively in cogeneration or trigeneration. In other countries such as Germany and Sweden, biomethane purification is used, an alternative that should be taken into account in Italy, considering that the technology for this process has reached a sufficient degree of maturation and that the Italian regulatory and legislative framework considers this opportunity. A biogas system should integrate a traditional anaerobic digestion plant which is why this article will present the technical, economic and environmental feasibility of different alternatives, besides cogeneration or trigeneration, as the possibility of using an upgrading plant to purify biogas and enter biomethane into the methane gas network.

2 DESCRIPTION OF ANAEROBIC DIGESTING SYSTEM

The anaerobic digestion plant is a traditional one, which operates in mesophilic conditions (temperature around 40°C) and is fed with animal waste from poultry and fattening pigs, possibly integrated with maize silage. The digester provides a flow rate of about 3,400 Nm^3/day of biogas with a percentage of methane ranging from 51 to 54% in volume. The plant consists of (Fig. 1) [1]:

a) biomass load systems, through two modes:
   - introduction into an underground cement pre-tank (8 m diameter and 3.5 m high) for non-shovellable biomass (pig effluent);
   - introduction with a loading hopper, powered by a conveyor belt, for solid biomass (manure and silage);

b) digester and post-digester with a cylindrical shape, having a volume of 1,665 m^3 and 2,814 m^3 respectively, 20 m and 26 m in diameter, both the same height 6 m, with an operating temperature of 42°C;

c) technical room, where are housed the machines used for the anaerobic digestion process or for preliminary operations (lobe pump for biomass handling, shredder for smudging solid biomass and facilitating bacterial action at the beginning of the digester operation, pumps for the reactor tank mixers and the air compressor needed for the desulphurization process in situ). There are also various types of measurement devices (flow meters, temperature meters, etc.);

d) storage system with gasometric covers for both the digester and the dome post-digester.

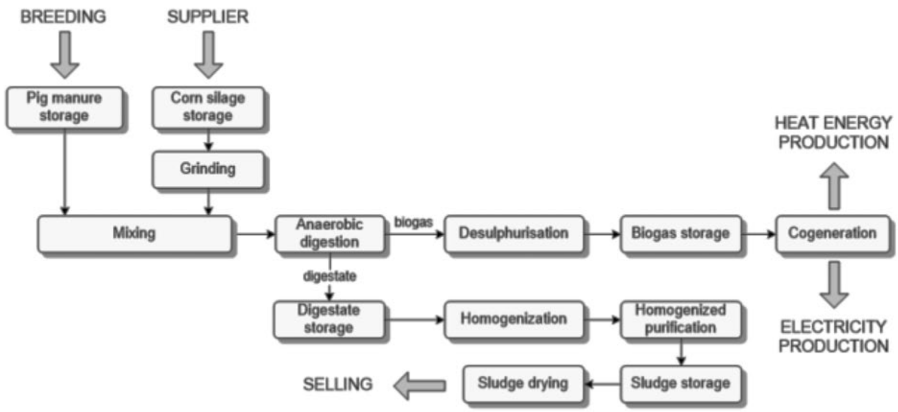

Figure 1: Anaerobic digestion diagram.

It is in tarpaulin (parafilm), which allows the accumulation of gas, with double variable membrane volume: the internal one is under pressure from the biogas, the external one by a compressor. Biogas is at 42°C and at a slightly higher pressure than atmospheric pressure (1.1 bar). Within the cover of the post-digester is placed a plastic mesh network that acts as a support for bacteria that perform biological desulphurization in situ; the air required by the process is blown by a compressor.
Biogas from the methanogenesis process has a chemical composition and chemical-physical properties (Tab. 1), which make it unsuitable both for sale in the methane gas network and for energy use unless it is subjected to appropriate treatments. If the biogas has to enter into the gas grid, it is necessary to purify it to obtain a chemical composition and chemical-physical properties defined by the network operator. If gas respects these parameters, SNAM defines it biomethane and it has features close to natural gas. The treatments required are [2]:

- removal of unwanted components such as H_2S, ammonia, micropollutants, solid particulate matter and moisture;
- improvement of physical-chemical properties of the gas by eliminating the CO_2;
- conditioning, which includes gas odorization for safety reasons and the possible addition of propane to increase its calorific value.

In energy conversion systems, such as cogeneration or trigeneration, the biogas is subjected to treatments, which can be classified into [2]:

- primary removal systems, which are designed to separate biogas from traces of liquid and solid phases through inertial systems such as separation cyclones and filters;

Table 1: [2]

COMPONENT	*BIOGAS*	*PROPERTIES*	*BIOGAS*
CH_4	45-75% volume	Lower calorific power	23 MJ/Nm^3
CO_2	22-47% volume	Wobbe Index	27 MJ/Nm^3
O_2, H_2 e H_2O	< 1% volume	Relative density	1,2 kg/Nm^3
H_2S	1000 ppm	Minimum temperature	-
NH_3	< 100 ppm	Maximum temperature	-

- secondary removal systems, which eliminate the removal of undesirable compounds, such as sulfur compounds, halogenated compounds and siloxane. The desulphurization techniques are active carbon adsorption, chemical conversion systems and wet removal with caustic solvents. The halogenated compounds are eliminated through the passage into selective membranes, acting as a filter, or by chemical adsorption with amines. The siloxane is eliminated by cryogenic techniques or conveying them onto activated carbon filters.

Some treatments, above all the desulphurization, are common to both the use of biogas for energy purposes and to the case of biomethane purification for injecting into the net.

3 TECHNICAL, ECONOMIC AND ENVIRONMENTAL FEASIBILITY BETWEEN THE DIFFERENT ALTERNATIVES OF BIOGAS USE

3.1 Simple cogeneration plant

The system consists of an endothermic engine with a displacement of 16.6 dm^3 with 8 cylinders in line, rotational speed of 1,500 rpm and biogas consumption at nominal conditions of 142 Nm^3/h. The engine is installed in a structure that protects it against weather, working at full duty with regular maintenance every 8,700 hours (about 60 hours). The electrical efficiency of the cogenerative group is 38.1% and provides a power of 249 kW$_e$. There is a thermal recovery from the 164 kWt engine cooling system with a thermal efficiency of 25.1%. the produced electricity is 5,966 kWh/day for both self-consumption and networking. The thermal energy produced is 7,030 kWh/day, which comes from cooling the engine block through an oil-operated system with a volumetric flow rate of 10 m^3/h a thermal jump between output/input of 7°C and a thermal power of 40% given to the water-glycol system, together with the cooling of the engine block, which has a volumetric flow rate of 12.6 m^3/h and a thermal power of 164 kW with a thermal jump between output/input of 10°C (70/60°C) and a thermal output of 7,030 kWh/day, which is partially used to heat the digester and the post-digester, and the remaining portion is dissipated in the torch, either to burn gas surplus or to stop the engine for ordinary maintenance. The system envisages a series of pipelines (about one hundred meters long) that allow the flow of biogas from the gasometric covers to the cogenerative. There are accessories and gravel filters, placed in parallel, with the purpose of retaining the impurities present in the biogas, a chiller, necessary to lower the biogas temperature from 42°C to 15°C (optimal condition for engine input), and a compressor used to increase the pressure in the biogas at the motor input. The amount of heat absorbed by the digester and the post-digester varies depending on the atmospheric conditions and, in particular, the outside temperature. It is expected that during the winter season 90% of the thermal power will be used (164 kW equivalent to 3,936 kWh/day), while it will be 20% in the summer period. From the energy balance made the following data can be noted:

- daily biogas production of 3,405.24 Nm3/day, with a percentage of methane in the biogas of 55% and a biogas product value of 6,977.98 MWh/year;
- annual operating hours of the plant: 8,700 hours;
- power to heat the substrate of the digester and the digester itself at 42°C of 92.1 kW and the required thermal energy of 806.8 MWh/year;
- electricity produced by the plant: 2,741.89 MWh/year;
- electricity consumed by the company and the auxiliaries of the plant: 142.08 MWh/year;
- available electricity: 2,599.81 MWh/year.

The machinery necessaries for the plant are: cogenerative group, sound-proof container, silencer, catalyst, ventilation system with air outlet silencer, heat sink working in air excess, heat recovery system for the engine block only, cooling pumps, parallel box and power supply for auxiliary services with full enclosure container protection, automation with PLC and inverters for both engine and auxiliary services, supervisory PC, LV/MV power transformer, MV transformer shields, MV line for energy transfer from container to delivery transformer room, booth MV framework, biogas treatment system, biogas dehumidification chiller and auxiliary. The total investment is 454,000.00 €.
The annual revenue is:

- digestate spilling: 46,770.88 €/year;
- electricity sales (all-inclusive tariff): 649,950.80 €/year;
- total revenues: 696,721.68 €/year.

The annual saving is related to the electricity used by the company 0.06 €/Nm^3 for 142,082 Nm^3/year equal to 8,524.92 €/year.
The operating costs are quantifiable in:

- total cost of biomass (maize silage, glucose, barley and triticale): 142,903.50 €/year;

- total labour cost: 17.719,53 €/year;
- total cost of ordinary and extraordinary maintenance: 39,150.00 €/year;
- cost of managing the cogeneration system: 26,100.00 €/year;
- insurance (0.3% of the investment): 1,362.00 €/year;
- administration costs (0.5% of revenues) 3,236.62 €/year;
- other operating costs (digestate loading and spilling): 39.649,78 €/year;
- total operation costs: 270,121.43 €/year.

If the company invests a total capital of 454,000.00 € and considering that the company pays IRPEF (personal income tax) and IRAP (regional income tax) taxes at 27.5% and 3.9% respectively, it has a payback period of 1.6 years and a Net Present Value (NPV) of 2,683,811.08 € after 15 years.

3.2 Cogeneration plant with annex dryer for treatment of different types of agricultural crops

To integrate the simple cogeneration plant and to maximize recovered heat, two heat exchangers have to be designed: one that recovers heat from water-glycol cooling system of the engine block, which will work mostly in summer, and one that recovers heat from combustion products, which will work all year round. Combustion products develop a power of 129 kW, equal to 3,096 kWh/day, while the water-glycol used for cooling the engine block achieves a power of 164 kW, equivalent to 3,936 kWh/day. You have that:

- during the summer period the total thermal power achieved is $129 + 0{,}9 \cdot 164 = 276.6$ kW;
- during the winter the thermal power available is equal to $129 + 0{,}1 \cdot 164 = 161.8$ kW.

The project of the heat exchangers is carried out referring to the climatic zone where the anaerobic digestion plant is located:

- winter: average temperature, relative and specific humidity of ambient air 3.5°C, 75.41% and 11.6 g/kg_{AS};
- summer: average temperature, relative and specific humidity of ambient air 23.3°C, 66.76% and 11.6 g/kg_{AS}.

Using the summer data in which the average air temperature is 23°C, the first water-glycol exchanger provides a potential of 129.58 kW with an exchange surface of 97.68 m^2, a volumetric flow rate of 12,960 m^3/h (m_1 = 15,339 kg/h) and an increase in temperature between input and output from the exchanger by 29,6°C with constant humidity content. Referring to the exhaust gas flow of 1,067 m^3/h and to the gas temperature at the inlet and outlet of the second exchanger of 478°C and 180°C respectively, it would have a potential of 54.82 kW, with an exchange surface of 97.97 m^2 and a volumetric air flow rate of 298.4 m^3/h (m_2 = 739 kg/h) with an increase in temperature between input and output from the exchanger of 262°C on a constant humidity content. By placing the two heat exchangers in parallel and considering the adiabatic process, a mixture of the two quantities of air is obtained. The massive flow rate of the combustion gas cooling battery will remain constant throughout the year, while it is necessary to calculate the mass flow rate of the engine block cooling battery in the two limit cases (summer and winter). The extraction of water vapor from cereal grains drying requires a series of iterations depending on the characteristics of the mixing air and the flow rate. The drying air temperature will be 100°C with a mass flow of about 15,000 kg/h. The required mass flow rate m_1 will be 14,261 kg/h after the passage and before mixing with the capacity m_2, it must be heated to 90.4°C. The thermal power supplied is 353.5 kW in winter and 153.8 kW in summer. The drying plant will be designed considering the corn, as the other cereals have a lower water content and/or the specific surface is higher [3] and will operate between June and October, close to the summer air characteristics. In addition to corn, other cultures, such as vineyard barley, some varieties of tomato and leguminous seeds, may be dried. Considering that the productivity of the farm is 2,000 tons/year of corn and that the drying plant can work on behalf of third parties, a treatment potential of 55 tons/day (2,291.67 kg/h) of dry product can be estimated. For mass balance it has been assumed:

- adiabatic drying process and equivalent to a linear process of 1 hour;
- temperature of drying air: 100°C;
- specific humidity of drying air: 11.6 g/kg_{AS};
- relative humidity of the air at the exit of the dryer: 90%;
- initial and final grain moisture of 28% and 16%, required for the Dry aeration process, which allows a contraction of both stress cracks (7.4%) and the percentage of broken grains (6.7%) [3] and that involves in the case under consideration a mass of water removed of 381.95 kg_{H2O}.

The mass flow of dry air at the entrance is therefore of 14,747.1 kg_{AS}/h, corresponding to a volumetric flow of 15,853.13 m^3/h. Referring to an operating hour, neglecting the heat loss in the dryer, the energy balance shows that the heat required for the actual drying of the cereal (368.78 kW) is the sum of three contributions:

- sensitive heat needed to heat the water from the initial solid temperature to the wet bulb temperature at which evaporation occurs (35.53 kW);
- latent heat to evaporate water (241.05 kW);
- sensitive heat needed to heat the dry solid from the inlet temperature of 20°C to the output temperature of 60°C (92.20 kW).

The required heat is higher than what is generated by the air flow rate of 14,747.10 kg/h with a 62.5°C thermal leap. Therefore, the mass flow rate of air is increased to 20,209.70 kg/h, so that a natural gas burner is needed. By maintaining the operating conditions previously set, the temperature of the mass flow m_1 is 92.97°C, the adiabatic mixing will be followed at first and then the indirect burner will be activated. The thermal power supplied will be 259.23 kW. Given the required productivity and the amount of energy available, it was decided to use a mobile drying machine. The investment values, revenues and costs of the cogeneration system are those presented in paragraph 3.1. The investment of the drying plant is given by the sum of the cost of mobile dredging (34,533.00 €), two heat exchangers (3,000.00 €, divided into 1,000.00 € for the exchanger operating with combustion products and 2.000,00 € for the heat exchanger working with digester heaters) and two silos needed to store the processed material, such as corn, soy or other seeds (125,000.00 €). The latter, if they have a moisture content of 28%, then the drying rate will be of 292.00 €/kg and 340.00 €/kg respectively. For a four-month operating period, the drying system consumes 30 kWh of electricity per hour corresponding to 108,000 kWh/year, referring to an electricity cost of 0.050 €/kWh, a total annual cost of 5,400.00 €. Since 32.91 Nm^3/h of methane is needed, corresponding to 118,476 $Nm^3/year$, and since the cost of methane is 0.21 €/Nm^3, an annual total cost of 24,879.97 € is obtained. Since the silos depreciation coefficient is 8% and the coefficient of amortization of the cereal treatment machinery is 12.5%, it is noted that the annual amortization, as sum of the two, is 12,691.62 €. The personnel cost for managing the plant could be considered null and void as the company already has its own employees who work, in rotation, every day of the week and therefore may also manage the dryer. However, it is also considered the possibility of hiring a worker at the cost (including wages, taxes and contributions) of € 2,000.00 per month. Considering the operation of the plant for only five months a year, the total cost is € 10,000.00. In a year, 3,300 tons of corn, 1,650 tons of soybean and 3,300 tons of barley beet or leguminous seeds are processed, from which an annual revenue of 262,960.00 € can be obtained. In the event that the company invests the overall capital of 616,553.00 and as a tax that the company pays are IRPEF and IRAP at a rate of 27.5% and 3.9% respectively, it has a payback period of 1.69 years and a Net Present Value of 2,659,764.92 € after 15 years.

3.3 Trigeneration plant

The combined Heating, Cooling and Power is a system for producing both electrical, thermal and refrigeration energy [4]: the heat recovered from the main engine coolant circuit is used, depending on the needs, for heating and/or cooling needs [5].

A CHCP plant is [5]:

- a prime mover (internal combustion engine with high electrical performance) connected to a generator or an alternator;
- a heat recovery system from the exhaust gas or from the first engine cooling circuit, through a heat exchanger;
- a refrigerant fluid generating system, consisting of an absorbing

machine for producing chilled water for conditioning or for industrial use.

From the energy balance made it is noted the following:

- daily biogas production 3,405.24 Nm^3/day, a percentage of methane in the biogas of 55% and an energy value of biogas produced by 6,977.98 MWh/year;
- annual operating hours of the plant: 8.700 hours;
- power to heat the substrate of the digester and the digester itself at 42°C of 92.1 kW and the required thermal energy equal to 806.8 MWh/year;
- heat energy consumed to heat poultry farm at 20°C: 240 MWh/year;
- cooler energy produced by the chiller: 151.2 MWh/year;
- electricity produced by the plant: 2,741.89 MWh/year;
- electricity consumed by the company and the plant auxiliaries: 142.08 MWh/year;
- electric energy saleable: 2,599.81 MWh/year.

The investment of the plant (cogeneration group, heat exchanger, absorption chillers, fan coils, connection to the mains and auxiliary network) is equal to 1,742,890.00 €.
Annual revenue is:

- digestate spilling: 46,770.88 €/year;
- electricity sales (all-inclusive tariff): 649,950.80 €/year;
- total revenues: 696,721.68 €/year.

Annual savings are instead:

- thermal energy for the natural gas heating system of the farm 0.27 €/Nm^3 for 22,641 Nm^3/year equal to 6,113.20 €;
- electric energy for the company 0.06 €/Nm^3 for 142,082 Nm^3/year equal to 8,524.92 €/year;
- electric energy that would use a compression chiller with EER = 1.5 equal to 2,028.96 €/year;
- total saving: 16,667.08 €/year.

The operating costs are quantifiable as:

- total cost of biomass (maize silage, glucose, barley and triticale): 142,903.50 €/year;
- total labour cost: 17,719.53 €/year;
- total cost of ordinary and extraordinary maintenance: 95,057.86 €/year;
- insurance (0.3% of the investment): 5,229.00 €/year;
- administration costs (0.5% of revenues): 3,236.62 €/year;
- other operating costs (loading and spillage of digestate) 39,649.78 €/year;
- total operating costs: 303,796.29 €/year.

If the company invests a capital of € 639,171.00 and the remaining amount of € 1,103,719.00 is covered by a 15-year bank loan with a 6% interest rate and at constant rates, and considering that the company pays IRPEF and IRAP taxes at a rate of 27.5% and 3.9%, respectively, it has a payback period slightly above 2.34 years and a Net Present Value of 2,029,487.56 € after 15 years.

3.4 Up-grading plant and immission of the biomethane in the SNAM network

There are several biomethane purification techniques, and the most advantageous choice is strictly dependent on the size of the plant and the availability of resources (water, chemicals, and heat). From a purely technical point of view, the best processes are chemical absorption [6] and cryogenic separation [2], which make it possible to obtain almost pure methane with extremely low losses; unfortunately, such techniques are on average the most expensive in terms of operating costs. To date, are chosen mostly chemical and physical absorption [6] and Pressure Swing Adsorption (PSA) [2] [6] [7], which have achieved good technological maturation and discreet commercial diffusion; on the other hand, they will probably be replaced by cheaper processes, as the membrane one, in the near future when technological development will increase their efficiency, especially for small-scale plants. It has been planned an anaerobic digestion system with a biogas depuration system with regenerative scrubbing water and the introduction of biomethane into the SNAM network. From the energy balance made it is noted:

- daily biogas production 3,405.24 Nm^3/day, a percentage of methane contained in the biogas of the 55%;
- biomethane losses during the upgrading: 3%;
- operating hours of the plant: 8,700 hours;
- amount of biomethane sold 1,816 Nm^3/h and 658,300 Nm^3/year with a calorific power of 10.6 MWh/Nm^3 and a biomethane energy value of 6,977.98 MWh/year;
- power to heat the substrate of the digester and the digester itself at 42°C of 92.1 kW and the required thermal energy equal to 806.8 MWh/year;
- thermal energy consumed by the upgrading plant: 370.32 MWh/year;
- thermal energy consumed by the air conditioning unit: 41.48 MWh/year.

The investment of the plant (design, installation, electrical and plumbing systems, civil and auxiliary works) is equal to 2,335,000.00 €.
Annual revenue was derived using the procedure without destination of use with fixed price withdrawals, better than the other two possibilities (without destination use with incentives modulated on the monthly price or intended for transport sector use) and can be quantified in:

- digestate spilling: 46,770.88 €/year;
- biomethane sales: 687,771.24 €/year;

- total revenues: 734,542.12 €/year.

The operating costs are quantifiable as:

- total cost of biomass (maize silage, glucose, barley and triticale): 142,903.50 €/year;
- total labour cost (pre-tank loading, plant control, ordinary cleaning, emergency intervention, remote monitoring): 21,585.61 €/year;
- total cost of ordinary and extraordinary maintenance: 43,877.43 €/year;
- insurance (0,3% of investment): 7,005.00 €/year;
- administration costs (0.5% of revenues): 3,672.71 €/year;
- costs of water, thermal and electric energy: 46,484.49 €/year;
- other operating costs (loading and spillage of digestate): 39,649.78 €/year;
- total operating costs: 298,173.54 €/year.

If the company invests a capital of € 639,171.00 and the remaining amount, equal to € 1,695,829.00, is covered by a 15-year bank loan with a 6% interest rate and at constant rates, it has a payback period slightly above 2.21 years and a Net Present Value of 2,004,376.79 € after 15 years.

3.5 Economic analysis of solutions

In the economic analysis, it was assumed that the incentive scheme for biogas production will remain unchanged throughout the investment period (15 years); this is an ideal hypothesis, given the uncertainty of the economic situation and the high number of legislative changes in recent years, aimed at reducing the incentive component. A careful analysis of the economic results presented for the individual solutions analyzed allows to detect that (Fig. 2):

- the trigeneration plant and the upgrading plant with direct sale of biomethane to the SNAM network are not as profitable as the other two solutions, as they have a higher payback period and an NPV lower than 15 years;
- the cogeneration plant with dryer is preferable to the simple cogeneration one because, although it has a slightly higher payback period or an NPV slightly lower than 15 years, the useful life of the dryer is much higher than 15 years and therefore the economic advantage is achievable even beyond this period. Moreover, if the dryer is used for more than 5 months every year by exploiting other agricultural crops (e.g. greenhouse tomato), the benefit would be much higher.

4 ENVIRONMENTAL SUSTAINABILITY

The realization of an anaerobic digestion plant with zootechnical waste with the production of biogas offers a significant environmental advantage over the traditional plants for the production of energy from fossil source. In particular, the carbon dioxide emission differential has been assessed in the solution for the cogeneration plant associated with the drier for the treatment of different types of agricultural crops, both when using biogas integrated with methane, and when using methane for both plant systems. In the first case, carbon dioxide is emitted only for the integration of the thermal power required by the dryer by activating a direct fire burner. In this case, methane consumption is 624 Nm^3/day, corresponding to a carbon dioxide emission of 1,716 Nm^3/day.

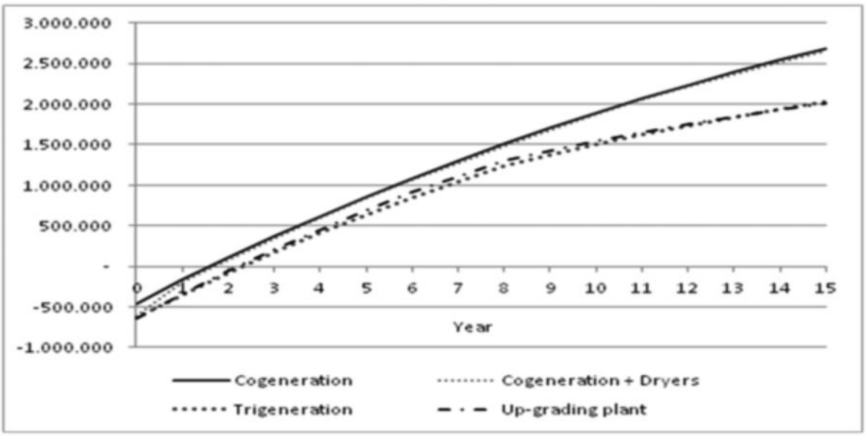

Figure 2: NPV at the end of 15 years for the different solutions analysed.

When, on the other hand, both the cogenerator and the integration energy of the dryer are fed with methane, there is a consumption of methane from fossil origin of 1.874,4 Nm^3/day and 624 Nm^3/day. This corresponds to an overall carbon dioxide emission of 6,870.6 Nm^3/day. The positive balance of the plant powered by renewable energy sources is therefore 5,154.6 Nm^3/day.

5 CONCLUSION

The biogas produced by an anaerobic digestion plant powered by zootechnical waste, possibly integrated with maize silage, must be used with energy systems that will convert the energy potential into electrical and thermal energy. To this end, the paper analyses the technical feasibility of different technologically mature alternatives, which then allow to choose the best through an economic analysis, which also corresponds to the one that is more environmentally sustainable. This allows a better management of the energy service in an agricultural business that can be extended to other similar realities, gaining obvious economic-environmental benefits.

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REFERENCES

[1] Di Bernardo, E., Pozzetto, D., Rocco S. (2017) An Innovative Process For The Integrated Fuor Phase Anaerobic Digestion System.

[2] Canziani, R., Malpei, F., Piccinini, S., Vismara, R. (2011) Biogas da agrozootecnica e agroindustria, Palermo.

[3] AA.VV. (2001) Problemi di essiccazione del mais e suoi prodotti – Heated air drying of corn and its products" di Tecnica Molitoria.

[4] Caputo, P. (2011) Impianti a biomassa: dal riscaldamento alla trigenerazione, Edizioni Ambiente, Città di Castello.

[5] Padoano, E., Pozzetto, D. (2013) Impianti speciali, Goliardica Editrice, Bagnaria Arsa (UD).

[6] Ryckebosch, E., Drouillon, M., Vervaeren, H. (2011) Techniques for transformation of biogas to biomethane.

[7] Sunn, Q., Li, H., Yan, J., Liu, L., Yu, Z., Yu, X. (2015) Selection of Appropriate Biogas Upgrading Technology – A Review of Biogas Cleaning, Upgrading and Utilisation.

AN ERGONOMIC PROJECT TO INCREASE FACTORY EFFICIENCY

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Abstract
Ergonomics uses objective indicators to measure the usability of a production process. Achievement of the set goals is calculated by means of effectiveness, efficiency, and satisfaction. It has been found that the driver which helps to improve the output of every single elementary production unit (ETU) inside the production plant is "Efficiency", that is, the diminishing of the effort that every single operator must perform in order to carry out his task. Reducing this effort by means of movements specially studied as a result of objective measures of field strength, we will improve both the effectiveness and satisfaction of the worker in doing his job. By adding all the improvements that are made to the individual ETUs, through these economies in the efforts, we will be able to increase the OEE of the entire factory.

Keywords:
Ergonomics, Electromyography, OEE, Efficiency, Usability, Lean

1 INTRODUCTION

Ergonomics (or human factors), as defined by the International Ergonomics Association (Fig. 1) is “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance”. [1] The etymology of the word Ergonomics derives from two terms of ancient Greek: “Ergo” (from Greek εργον), which means "work" and “nomics” (from Greek νομοζ), which means "rule, law". The International Ergonomics Association [2] subdivides into three sub-funds the application domains of specialization within the discipline of ergonomics, Physical Ergonomics, Cognitive Ergonomics and Organizational Ergonomics. We will refer to the last sector. The most used test in Ergonomics is Usability, which is a technique utilized in user-centered interaction design to evaluate, in this case, the process of production. Usability testing focuses on measuring a human-made capacity to meet specified intended purpose. The purpose of this work is to analyze worker activity, measure their performance, and minimize their efforts in order to achieve better quality of work and more efficient production.

Figure 1: The IEA's Logo

2 THE ORGANIZATIOPNAL STRUCTURE OF THE PRODUCTION SYSTEM DURING THE YEARS

The first industrial revolution brought to the pursuit of economic efficiency and in business logic, the work factor plays a very special role. This factor has evolved over time, especially in relation to the different and greater importance that human resources have taken on the enterprise. Work inside the big factories during the first decades of the twentieth century was immortalized in the images of "Modern Times" (Fig. 2), the film where Charlot, as a worker of the assembly line, repeats repetitively the same operations with automated gestures, as a puppet, screw a piece, press a button, pull a lever. That was the triumph of the Scientific Organization of Work; the tasks were split into so many small operations, each of the duration of a few seconds, entrusted to workers who repeat them uninterrupted hundreds or thousands of times a day.

Figure 2: Charlie Chaplin in "Modern Times".

But let's sum up three, among the organizational models of enterprise which have been implemented in the course of the years.

2.1 Taylorism

First, we must consider the theories of Frederick Taylor, known as "Taylorism" [3] and, afterward, the continuation of studies regarding the "scientific management", all oriented to the factory and not to man. The main scope of these theories is to analyze and to synthesize workflows, improving economic efficiency, but without taking due consideration of the human factor, which is badly adapted to monotonous and repetitive work. (Fig. 3) So, if on the one hand, production seems to enhance, on the other hand, accidents and diseases are increased, thus causing damage to the factory and also to the business itself.

Figure 3: The Ford “T” Factory.

2.2 The Olivetti’s and Volvo’s production isles

At the beginning of the seventies the factory of typewriters Olivetti studied and implemented a new model of work organization. The new organizational form led to the creation of the so called "Integrated Mounting Units" (IMUs), small structures that had the task and responsibility to realize a part of the machine or the whole machine (depending on the complexity of the product), complete with all its demanded performance, tested and then sold to the customer. [4] Each IMU was formed by a working group (typically from 10 to 30 workers) which worked independently in a defined area of the plant ("mounting island"), also with responsibility regarding the final quality. The same assembly mode, always at the beginning of the seventies, was experimented in the automotive industry, by Volvo, at its Kalmar (Fig. 4) and Udevalla plants. Skilled workers left the traditional assembly line and, gathered in teams, built entire individual vehicles from the ground up. In other words, the plant design was conspicuously different from standard car plants and, instead of one long line, a multitude of small parallel teams built complete cars. With a work content of several hours they built cars, in real "production islands", according to customer order, with a short delivery time, thus avoiding stocks, anticipating, therefore, the “just in time”. [5]

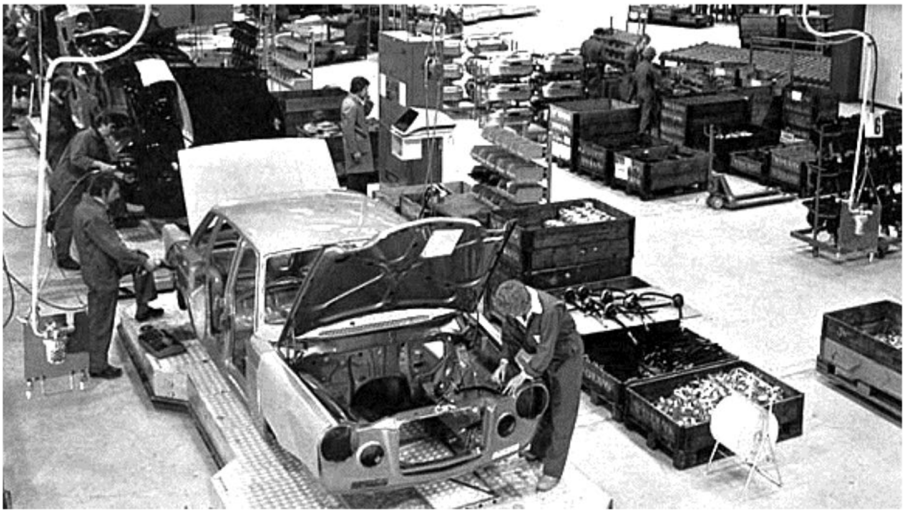

Figure 4: A Volvo’s Isle of Production at Kalmar Plant.

2.3 The FCA’s ETU

A new production strategy, the WCM (World Class Manufacturing) [6], developed in the USA in the late 1990s, integrates into the Total Maintenance Productivity (TPM) methodology, both the Lean Manufacturing and the Total Quality Management logics. Fiat Chrysler Automobiles has acquired the most innovative and ingenious best Practices born from WCM and continuously studies new application. The main innovation that FCA has developed, is the so called ETU (Elementary Technology Unit) [7], i.e. an autonomous and independent production cell, controlled by its team leader (Fig. 5). Also here the rigidly vertical structure of the traditional plant is replaced by decentralization. Each ETU is a true micro-enterprise, and the ETU leader is like a small businessman with remarkable management autonomy, who decides on production lines, designing and directing changes deemed necessary from time to time. So, all the factory has become an Integration Platform, by means of the power of collaboration.

Figure 5: An ETU at the Ferrari Factory.

3 USING THE ERGONOMIC DESIGN, USABILITY

We now consider to use the methodologies of Ergonomic Design to carry out comparative objective evaluations in each ETU. In this case we are supported by a specific ISO standard, the ISO/DIS 9241-11.2 [8], which provides us with the guidelines for measuring the usability of a production process. Usability means making products and systems easier to use and matching them more closely to user needs and requirements. This international standard provides guidance on usability and defines it as: "*The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" [9]. The above-described ISO standard, specifies the quantification of usability, which is implemented through “effectiveness”, “efficiency” and “satisfaction” measurements, that are defined as follows:

- Effectiveness, i. e. accuracy and completeness with which users achieve specified goals.
- Efficiency, i. e. resources used in relation to the results achieved.
- Satisfaction, i. e. person's perceptions and responses that result from the use of a system, product or service.

In our case, attention will focus on efficiency, that is, on economizing work effort resources, to speed up production (effectiveness) and to ensure greater satisfaction by the operator. By implementing a saving in the effort of the worker we will achieve very interesting results.

4 OEE, FOR THE CONTROL AND IMPROVEMENT OF PRODUCTION EFFICIENCY

In order to increase productivity and reduce costs, it is essential to have an effective system for measuring, controlling and improving the efficiency of production, that is the OEE (Overall Equipment Effectiveness) method. Effectiveness is the relation between what theoretically could be produced at the end of a process and what actually came out or was produced at the end of the process. Therefore, basically OEE is Effectiveness, i.e. the rate between what a machine theoretically could produce and what it actually did [10]. Two are the ways proposed to calculate OEE:

a) the easiest is the ratio of Fully Productive Time to Planned Production Time [11]. Fully Productive Time is just another way of saying manufacturing only Good Parts as fast as possible (Ideal Cycle Time) with no Stop Time (Fig. 6).

$$\mathrm{OEE} = \frac{\mathrm{output}}{\mathrm{input}} = \sum_{i=1}^{n} \frac{\textit{Standard Working Time X Number of Good Parts}}{\textit{Planned Production Time}}$$

$$i = \textit{items of the production mix}$$

Figure 6: A simple calculation of OEE.

b) a more exhaustive calculation is based on the three OEE Factors: Availability, Performance, and Quality, using the following formula (Fig. 7).

Figure 7: The preferred formula to calculate OEE.

Availability takes into account all events that slow down planned production, performance considers anything that constrains the manufacturing process to run at less than the maximum possible speed and quality is careful to manufactured parts that do not meet quality standards (Fig. 8). It is important to consider the fact that the result will be the same in both ways of calculation. Then, if we go to analyze the two formulas we will see that the driving factor is the amount of resources, in other words the efforts of workers.

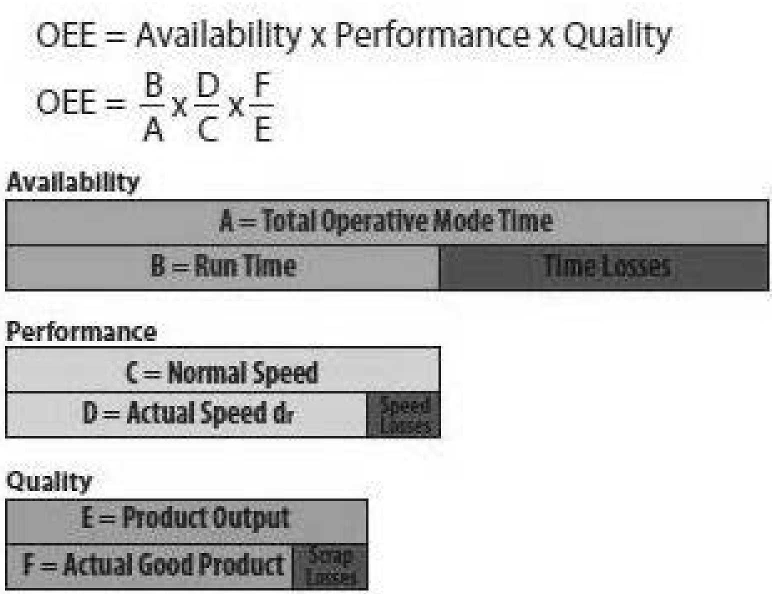

Figure 8: An overview of the elements of OEE and how they interrelate [10].

5 MEASURING EFFORTS OF WORKERS INSIDE ETUs

The movement in the human body is determined by the action exerted by the muscles on the bone levers, so for the knowledge of human motion, a great scientific speculation was devoted to the study of the structure and functioning of the muscular tissue. In order to understand the action of muscular force (i. e. effort) and the phenomena related to the methodology of its performance, it is necessary to understand exactly how a muscle works.

5.1 Muscle physiology

It should be assumed, however, that from the cellular level to that of activation, all phenomena related to the muscle are not yet well-known, so in the field of biological research on the muscular system, we adopt some models of operation. The most accredited and last-in-time model is that one related to the muscle functional unit called "sarcomere", within which the two specific elements and protagonists of the contraction are contained: myosin and actin [12]**.**

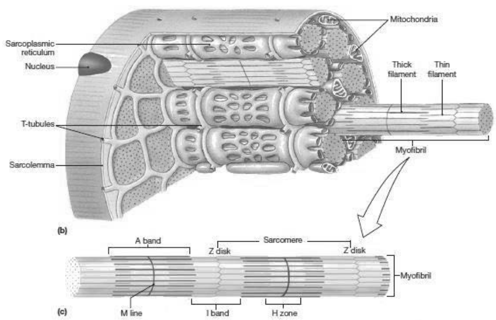

Figure 9: The muscle cell in its structural units.

In the locomotor system, the main function of muscle is to create tension (effort), which, through biomechanical manifestation, is transformed into Force. A concentric or eccentric activated muscle varies its length (l) in a time (t), so we must think of muscle as a biomechanical element capable of developing Strength in relation to the shortening speed, “$v = \Delta l/\Delta t$”. In these terms, then, the fundamental function of a muscle, becomes that of developing together, strength and speed. In 1938, Arcibald V. Hill received the Nobel Prize for Physiology for explaining the relationship between the two physical quantities developed by muscle, namely Strength and Shortening Speed [13].

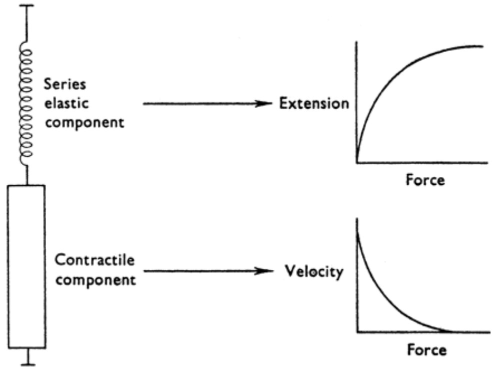

Figure 10: Hill's 2-compartment model of contracting muscle, showing the "series elastic" and contractile components. The force-velocity curve defines the properties of the contractile component, whereas the force-extension curve defines the properties of the series elastic component.

All this supports our design idea, based on the measurement of force/effort (efficiency) in individual ETUs.

5.2 Measuring the muscle effort with EMG

Electromyography (EMG) refers to a diagnostic, functional type of recording and analysis of the myoelectric signal, that is, of the electric bio-potential activity produced by skeletal muscles. EMG is performed using an instrument called "Electromyograph" to produce a record called an electromyogram [14]. Depending on how the signal is recorded, in general, it is referred to as surface electromyography (sEMG) or "needle" Electromyograph, also called nENG. The sEMG involves taking the signal via electrodes placed on the skin (superficial electrodes), while nEMG involves the use of subcutaneous needles placed in direct contact with the muscle of interest. The recorded potentials will then highlight a group of motor units and their conduction speed with superficial electrodes, while with needle electrodes it is possible to analyze a single motor unit. Since our research scope does apply to muscle bundles and not to single muscle, we will use sEMG instrumentation.

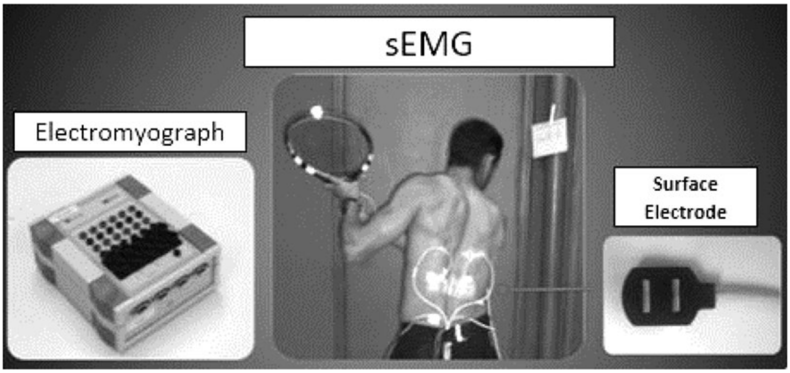

Figure 11: The sEMG's diagnostic investigation.

The problem, in the use of EMG, is the immediate understanding of the result. Indeed, EMGs on the market display only "wave trains" of electrical current emitted by the muscles in action (Fig. 12).

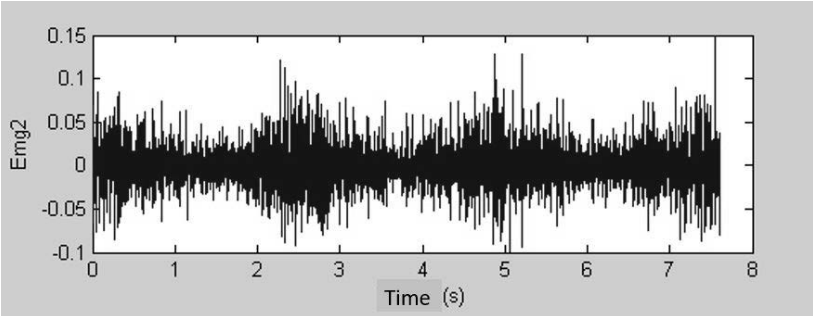

Figure 12: The visual response of a typical sEMG.

In our case, however, we will use a software that transforms the display of wave trains into circular charts (pie charts), in which the maximum effort of antagonist muscles can immediately be identified (Fig. 13). It will then be easy to suggest other types of movements to achieve the same result in the manual operation that worker must perform. And this with the least possible effort.

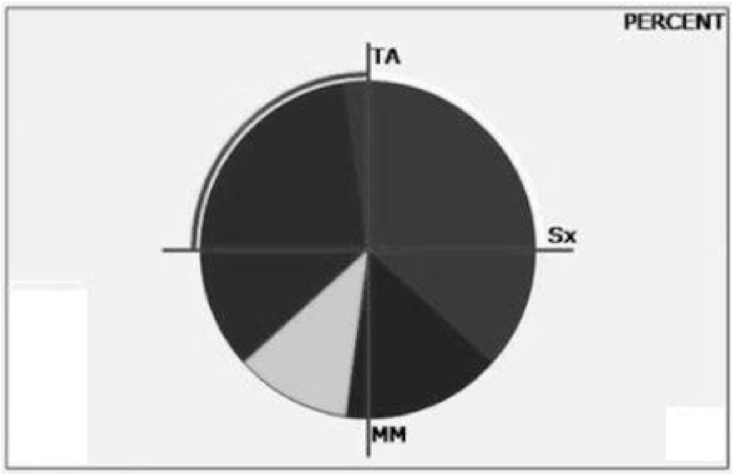

Figure 13: Our sEMG's Pie chart intuitive interface.

6 METHODOLOGY USED

The Fordist model, in order to increase efficiency, required to replace the plant layout, based on the grouping of functionally similar machines, with a sequential flow-based layout, by placing the machines in the order of the operations they allowed, so to not be obliged to carry the batches from one department to another. This organization system allowed an extraordinary increase in labor productivity because the total familiarity with a single operation allowed the workers to execute it more quickly. Unfortunately, as already stated above, it also represented the cause of an increase in serious accidents. Our model, on the contrary, is completely opposed. Obeying the principles of the Ergonomic project must be the machine to submit to needs of man and not vice versa. For this reason, the effort of the worker in the ETU must be reduced as much as possible. Here is our idea, measuring the effort in the different cases of movement to reach the same result and choose the movement that requires the least effort. And this analysis will be implemented in all ETUs of the plant. Measurements will be facilitated by the very intuitive interface used, utilizing the proposed GUI equipped sEMG. In field trials we use the Miller's TOTE (Test - Operate - Test - Exit) iterative problem-solving strategy based on feedback loops [15].

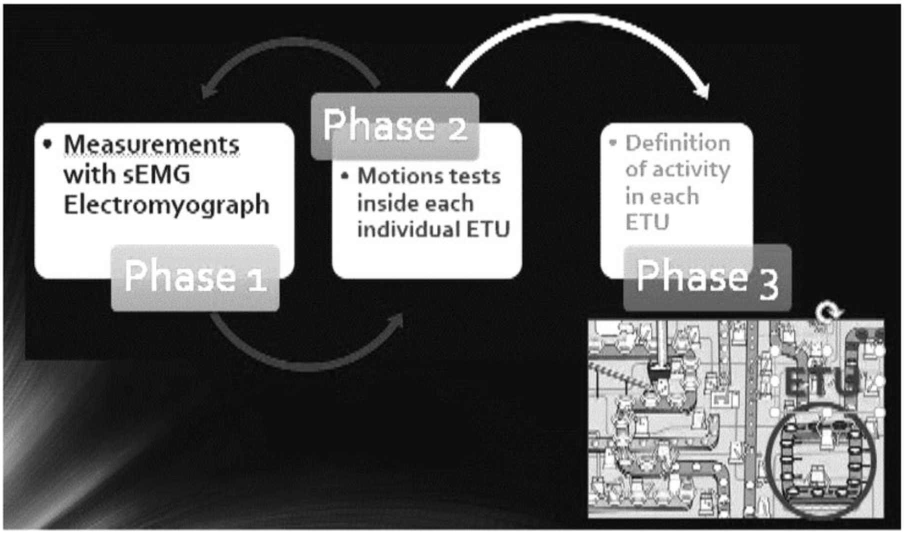

Figure 14: Our tests methodology, based on Miller's "TOTE" operative strategy.

So, we will reach the following proposed goals:

- to reduce the worker’s efforts throughout the production chain (Efficiency);
- to make manual operations less difficult, also increasing the execution rate (Effectiveness);
- to let that the executed work inside the ETUs can be perceived as more enjoyable (Satisfaction).

These results, subsequent to the use of the ergonomic design methodologies, will contribute both to the increase in the factory output (OEE from 50/65% towards 70/85%), and to the respect of workers' needs.

7 CONCLUSIONS

With this project we have two goals: to improve the quality of work and to increase the OEE and all this, trying to reduce the efforts made by the workers in their manual activity. This because, in our opinion, everything winds about working efficiency. We then analyzed the new logistics model of the factory, which now includes its subdivision into ETUs. The tests will then be made into individual ETUs, using a sEMG, equipped with an immediately intuitive graphical user interface. This will make it possible to choose those specific movements with less muscle energy dispersion, which will also result in faster work execution, with greater satisfaction from workers. Finally, making the summation of the enhancement results achieved in all ETUs, we will get a percentage improvement of the plant's OEE.

REFERENCES

[1] IEA International Ergonomics Association (2017) http://www.iea.cc/whats/index.htm/.
[2] IEA International Ergonomics Association (2017) http://www.iea.cc/.
[3] Taylor, F. W. (1911) The Principles of Scientific Management, Harper & Brothers, New York, NY, USA and London, UK.
[4] Boffo, V. (2012) A glance at work. Educational Perspectives, Firenze University Press, Florence, Italy, page 29.
[5] Engström, T., Jonsson, D., Medbo, L. (1998) The Volvo Uddevalla plant and interpretations of industrial design processes, MCB University Press Ltd., Bingley, WEST YORKSHIRE, UK.
[6] Olofsson, O. (2016) Succeeding with Standardized Work, WCM Consulting AB, Vaxholm, Sweden.
[7] FCA Group Fiat Chrysler Automobiles (2017) https://www.fcagroup.com/plants/en-us/melfi/the_plant/Pages/default.aspx#.
[8] ISO/DIS 9241-11.2 (2017) Ergonomics of human-system interaction - Part. 11: Usability.
[9] ISO 9241-210:2010, 2.13 (2017).
[10] Zepf, P.J. (2013) How to calculate overall equipment effectiveness: A practical guide, Packaging Machinery Automation Playbook, https://www.automationworld.com/article/topics/oee/how-calculate-overall-equipment-effectiveness-practical-guide.
[11] OEE (2017) Calculate OEE, http://www.oee.com/calculating-oee.html.
[12] Riddle DL, Blumenthal T, Meyer BJ, et al. (1997), Cold Spring Harbor Laboratory Press, New York, USA.
[13] http://jap.physiology.org/content/93/5/1567.
[14] Kamen, G. (2004), Electromyographic Kinesiology. In Robertson, DGE et al. Research Methods in Biomechanics, Human Kinetics Publ., Champaign, IL, USA.
[15] Miller G. A., Galanter E., Karl H. Pribram K. H. (1960), Plans and the Structure of Behavior, Henry Holt and company, New Yor, USA.

SESSION F
Wood Processing Technologies and Furniture Production

PREPARATION OF PRODUCTION AND MANUFACTURING DOCUMENTATION FOR DESIGN UPHOLSTERED SOFA

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Abstract
The objective of the paper is to demonstrate new trends in living room furniture, together with a design of an experimental construction of a lounge suite manufactured with current technology, using solid wood, composites, and upholstery. The design of the construction refers to current material possibilities, style and EU testing standards. The lounge suite presented in this paper resulted from a long shape, required properties of the furniture (safety, strength, durability, and stability) and assembly that allowed safe transport. The aim was to produce a simple and functional product of an interesting shape which meets ergonomic and safety EU standard requirements for upholstered furniture.

Keywords:
Furniture, Design, Construction

1 SOFA DESIGN

Design of this upholstered sofa links historically proven facts with the current trend. Visually, there is a link in permeation of matter and subtitle look, which has been created by stylish thin wooden legs. The design of the sofa comes from classical construction and craft processing while following basic rules concerning ergonomics and typology that are being laid upon upholstered furniture. This article shows the whole process starting with the original thought up to testing in a furniture testing room. During the process, the author of this design was developing the final shape using visualizations. First visualizations were followed by creating a reduction model. Shape proving of an upholstered sofa led to more exact construction solutions and a realization of the final prototype and testing in the furniture testing room.
Final appearance of the new sofa is shown in Figure 1. There are three shape variations of appearance of this upholstered sofa. The first option shows a fully upholstered variation of the seat. The second and third option use decorative wooden component which is placed to the front side of the seat.

Figure 1: Three basic variations of SOFA design.

1.1 Model production

A sofa model, using reduction 1:10, was created to check the outer relations and proportions. The model itself was made by a 3D printing machine. The sofa model draft intended for printing was made based on visual documentation in 3D MAX Studio. After finishing, the model was exported as STL. Before printing, the model was opened in a program called Slic3r Prusa Edition 1.33.8 for making final corrections (settings of material, printing quality, thickness of printed layer). The printing itself was made on a PRUSA 3D i3MK2 printer using PLA material with applying a temperature of 215°C. Printed 3D model is shown in Figure 2.

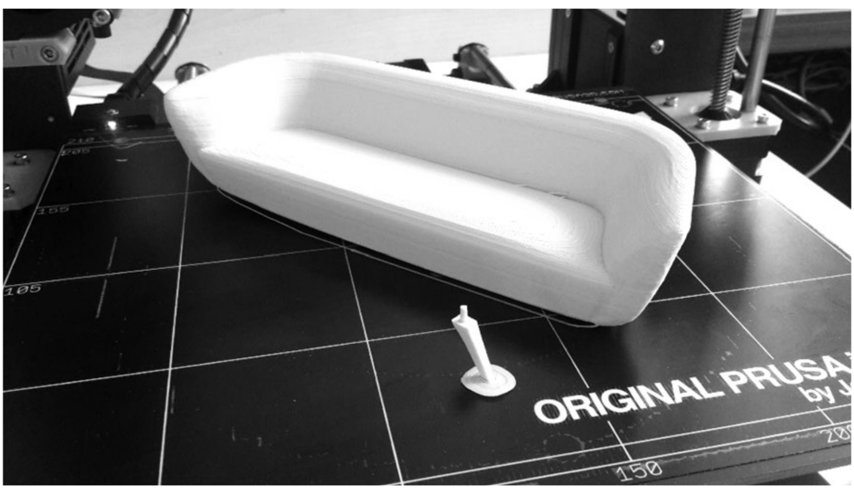

Figure 2: SOFA model printed by 3D printing machine.

The final appearance of the designed Sofa is shown in Figure 3. We used the variation of a fully upholstered seating. Visualization was created in 3D MAX Studio 2016.

Figure 3: Sofa final look visualization.

2 TECHNICAL DESCRIPTION OF THE CONSTRUCTION

A supporting frame construction is determined by its shape which brings a certain way of covering the sofa by textile material. The supporting frame is composed out of four assembly units (2 armrests [A], 1 backrest [B] and one seat frame [C]). These parts are put together using screws and T-nuts M8 after being upholstered. See the following pictures (Figure 4 - 6).

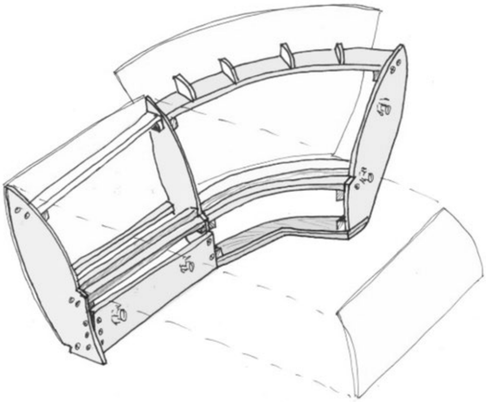

Figure 4: Supporting frame, assembling unit [A]: Armrest.

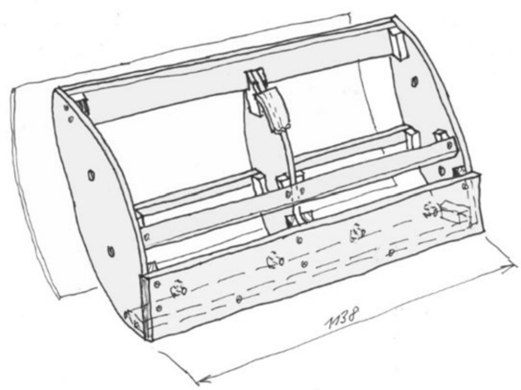

Figure 5: Supporting frame, assembling unit [B]: Backrest.

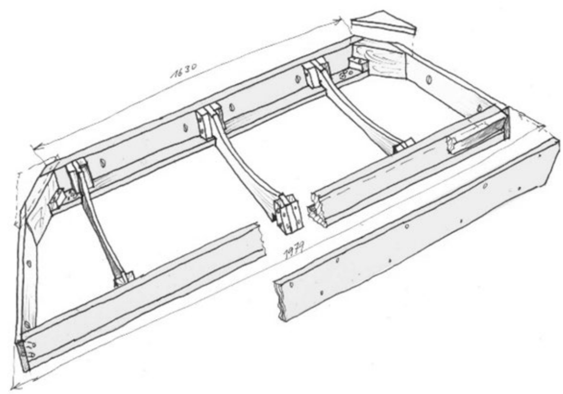

Figure 6: Supporting frame, assembling unit [C]: Seat frame.

2.1 Supporting frame material

Rails and support blocks are made of hard solid wood (beech), other rails are made of hard coniferous wood (spruce). Vertical and shape units which are not suitable for solid wood because of size are made of 15 mm wide birch plywood. The strained parts are doubled and have 30 mm width. Fillings are made of hard 3 mm thick fiber board and of 2,2 mm thick cardboard.

2.2 Construction of assembling units

Supporting frame of the armrests [A].
Connecting of parts is made by screws ø 4,5 mm or staples and supporting blocks, all connections are glued by PVAc on the whole surface. The fillings are glued and fastened on the peripheries by staples. The supporting frame of the armrests is divided into two parts depending on the shape, front linear and back, which is round and spreads out behind the seat up to the backrest part. Upholstery is made from foam and a wadding made of fiber.

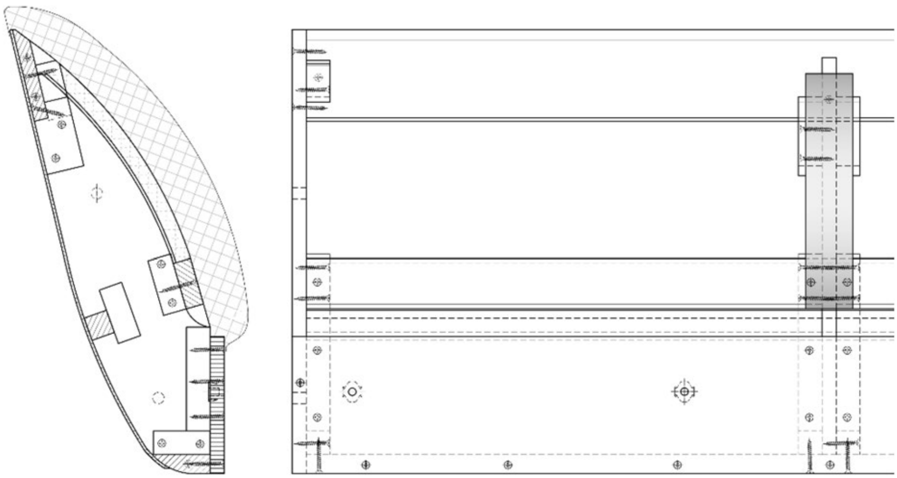

Figure 7: Technical drawing of the supporting frame of the backrest [B].

Supporting frame of the backrest [B].
Similarly to the armrests, the connecting of backrest components is made by screws ø 4,5 mm or staples and support blocks, all connection parts are glued with PVAc on the whole surface. The middle part is smaller on the front side than the side parts, to make it softer by inserting foam. Springing of the backrest surface is made by horizontal springing straps and 2 layers of foam with the fiber wadding under covering, the back filling of the backrest is being placed after firming to the upholstered armrests. Covering is stitched invisibly.

Seat frame [C].
The seat frame is in shape of irregular hexagon, horizontal rails and support blocks are made of hard wood (beech), the back sidelong part is made of coniferous wood on the peripheries (spruce), side parts, crossbars and front seating skew part are made of 15 mm thick birch plywood. The connection of front rails and side parts is made thanks to wooden dowels ø 10 mm, which go through the whole thickness of the side parts where the screw is in

between. The other connections are made by screws and support blocks. There are wooden screw legs fastened to the lower rails by allen screws screwed to stop nuts and wooden pegs ø 10 mm glued to the leg. There are holes ø 12 mm made on the side and back part for screws, for connection with the armrests and the back rest. Springing of the seat is made by zig-zag springs, where is sandwich from polyurethane foam and a fiber wadding under the covering.

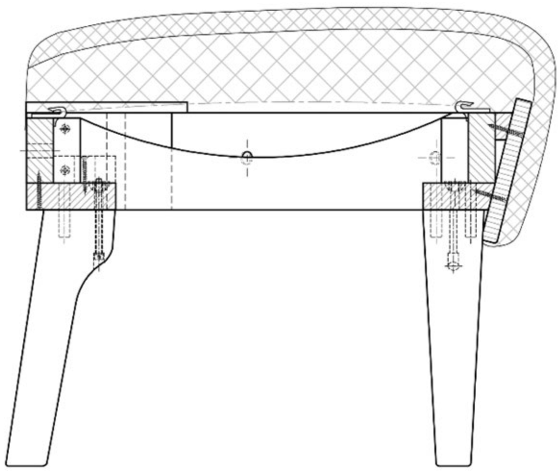

Figure 8: Technical drawing of the seat frame [C].

3 PROTOTYPE MANUFACTURING

While working on the solution, it was managed to create two prototypes of the Sofa. The construction is described in the paragraph named Supporting frame material. The Sofa construction was made in practical workrooms of the Mendel University. The supporting frame for upholstery can be seen in Figure 9. Upholstered parts were made in cooperation with the upholstery Karel Malý. We used classical modern materials. There is 3 mm thick fiberboard and 2, 2 mm thick cardboard used for the filling. Covering textile is used in two colorful variations. When creating the prototype, the following type of covering textile was used, which has high resistance to scuff marks. The covering material has commercial name BORA TERRA 25 and 28, Damask, made from 100% PES (polyester), weight: 330 g/m², resistance 100.000 ot.MD (EN ISO 12947), permanence on light: 5 (EN ISO 105-B02), endurance against humidity/dryness: 5/5 (EN ISO 105-X12), width 140 cm, hard to ignite: BS 5852.

Figure 9: Supporting frame prototype.

4 TESTS AND REQUIREMENTS FOR STRENGTH AND SAFETY

The designed sofa meets the upholstered furniture requirements stated in European standards EN 16139 Furniture - strength, durability and safety requirements for non-domestic seating.
If the requirements of these standards are met, it is probable that it will meet also requirements of domestic usage, EN12520 Furniture - strength, durability, and safety requirements for domestic seating, because the requirements of EN 16139 are generally higher than EN 12520.

4.1 Stability

The standard above states in general that the seating furniture must not be overturned in these situations:

- while there is loading on the front edge of the seat surface in median plane;
- while loading the seat surface led over the front corner;
- while tilting to the side;
- while leaning on the backrest;
- while sitting on the front side of the seat.

Requirements for stability are met if the furniture is not overturned during tests demanded by the standards EN 16139. The tests are being carried out due to EN 1728 Furniture-Seating-Test methods for the determination of strength and durability while using loadings stated in EN1613, level of test severity is in relation to applications and it determines 2 levels of usage and extreme usage.

Figure 10: Prototype of yellow variation of the sofa, legs: American walnut.

5 CONCLUSION

Usage of the solution results of this project can be found at various levels. In theoretical level: the product represents nowadays a trend in the field of upholstery furniture which is based on functionality and comfort.
It was managed to create final design of the new seating component. There has been detailed drawing documentation made for the designed seating part containing visual processing. Before the actual manufacturing, a reduced 3D model has been printed to certify outer relations. The manufacturing was divided into two phases. In the first phase, supporting frame and all wooden legs were made. The final look of the sofa was made in the second phase in which the whole supporting frame was upholstered. This prototype had been tested repeatedly so that all strength and safety demands linked to this type of furniture were certified. The product described was designed in a way to meet all needs of public areas in general use and to meet all European standards for this type of furniture. Two experimental prototypes were made.

ACKNOWLEDGMENTS
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REFERENCES

[1] EN 12520 (2016) Furniture - Strength, durability and safety - Requirements for domestic seating.
[2] EN 16139 (2013) Furniture - Strength, durability and safety - Requirements for non-domestic seating.

[3] EN 1728 (2013) Furniture - Seating - Test methods for the determination of strength and durability.

[4] Tauber, J., Šimek, M., Holous, Z., Svoboda, J. (2016) New Trends in Upholstered Furniture. In The Path Forward for Wood Products: A Global Perspective: Proceedings of Scientific Papers. Zagreb: WoodEMA, i. a., pp. 35-41. ISBN 978-0-692-76612-5.

INFLUENCE OF GEOMETRICAL AND TECHNOLOGICAL PARAMETERS ON THE CUT QUALITY WHEN CUTTING MELAMINE FACED CHIPBOARD

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Abstract
The influence of tooth shape, feed per tooth and the saw blade height on the cut quality of melamine faced chipboard was analyzed in the work. Three most common tooth shapes of circular saw blades were taken; alternative top bevel teeth (WZ), square/trapezoidal teeth (FZ/TR) and hollow face/inverted V teeth (HZ/DZ). Melamine faced chipboard with the thickness of 18 mm was cut without scoring blade, with the height of the saw blade being 10, 20, 30 and 40 mm above the workpiece. After each cut, the profile of the edge on the panel's top and bottom side was measured, and the R_a, R_z and R_v parameters were calculated. It was established that the best quality on the top side is obtained by cutting with square/trapezoidal teeth (FZ/TR), while the best quality on the bottom side was produced by cutting with hollow face/inverted V teeth (HZ/DZ).

Keywords:
Circular saw blade, Tooth shape, Cut quality, Melamine faced chipboard

1 INTRODUCTION

With the quality of wood machined surface have already dealt many authors. Some of them have researched the influence of machining parameters on the surface quality in milling [1] [2], while others in wood cutting [3] [4] where the circular saw blade is one of the basic woodworking tools. When cutting wood and wood composites, we want the quality of the cut to be as good as possible especially in the case of the final cut. The quality of cutting can be influenced by many types of tooth shapes, where one type of tooth shape is more suitable for a particular type of material, while other types of materials favor other types of tooth shapes. The quality of cutting can also be influenced by using a scoring saw blade, especially when cutting melamine faced chipboard, where the scoring saw blade cuts a plate on the underside a few millimeter deep where the cutting width is 0.1 to 0.2 mm greater on each side than the cutting width of the main saw blade. In such a way, a good quality edge on the upper side as well as on the bottom side of the melamine faced chipboard is produced. But in some cases, it is not possible to use a scoring saw or the

scoring saw blade is not available. In this case, it is necessary to consider carefully which type of tooth shape should be used.
The purpose of this experiment is therefore to determine the optimum type of tooth shape and technological parameters to be applied when cutting the melamine faced chipboard without a scoring saw blade.

2 MATERIALS AND METHODS

Three circular saw blades with the diameter of 300 mm, produced by Leitz, were tested. The first saw blade had alternative top bevel teeth (WZ), the second square/trapezoidal teeth (FZ/TR) and the third hollow face/inverted V teeth (HZ/DZ), as shown in Fig. 1. The circular saw blade with alternative top bevel teeth (WZ) is a multi purpose saw blade, economical to purchase and maintain. It is perfect for chipboard, veneered chipboard, solid wood and plywood cutting. The circular saw blade with square/trapezoidal teeth (FZ/TR) is used for cutting plastic and foil coated wood derived materials, and is also suitable for cutting without scoring saw. The third saw blade with hollow face/inverted V teeth (HZ/DZ) is intended for high cutting quality of plastic coated materials, with high upper and lower edge quality, on machines without scoring saw. The saw blades with WZ and FZ/TZ tooth shape had 96 teeth, and the blade with HZ/DZ tooth shape had 60 teeth. All blades had 10° tooth rake angle and were freshly sharpened.
Cutting was performed on the SCM sliding table saw with the attached feeding device MAGGI STEFF 2048 with adjustable feeding speed.
Melamine faced chipboard with the thickness of 18 mm was cut without scoring blade, with the height of the saw blade being 10, 20, 30 and 40 mm above the workpiece, and the length of specimen amounted to 750 mm. The circular saw blades rotated with the rotation speed of 4000 rpm. Since the saw blade producer recommends the feed per tooth from 0.03 mm to 0.1 mm, the feeding speed used was 6.5 m/min and 13 m/min for the saw blades with WZ and FZ/TR teeth and 4 m/min and 8 m/min for the saw blade with HZ/DZ teeth. At such feeding speed, the feed per tooth amounted to 0.017 mm and 0.034 mm, respectively.

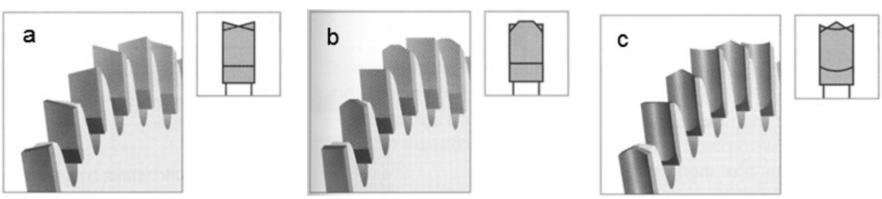

Figure 1: Circular saw blade teeth shapes. a - alternative top bevel teeth (WZ); b - square/trapezoidal teeth (FZ/TR); c - hollow face/inverted V teeth (HZ/DZ) [5].

For each combination of saw blade height, the feed per tooth and tooth shape, and the edge quality on the upper and lower side of the specimen were measured using a specifically designed measuring device made from steel sheet with a sharp edge that slides along the edge of the specimen where the oscillation was measured with an inductive displacement sensor, type CARLO GAVAZZI IA12ASC05AK-K, as shown in Fig. 2. The data were acquired at with the sampling frequency of 2 kHz by means of a data acquisition card NI6351 and LabView software manufactured by National Instruments, where the feeding speed amounted 4 m/min. In this combination, the value was recorded at every 0.033 mm.

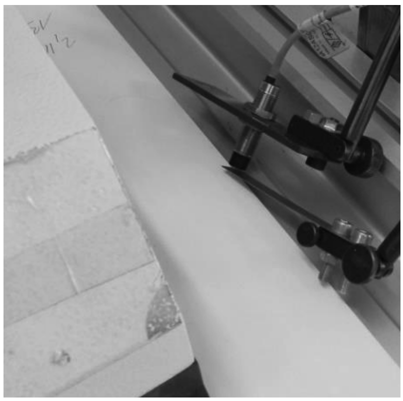

Figure 2: Experimental roughness measuring system.

Since the edge was not perfectly straight, the waviness and form was removed, where cubic spline was applied (eq 1) [6]

$$p\sum_{i=0}^{n-1} w_i \left(y_i - f(x_i)\right)^2 + (1-p)\int_{x_0}^{x_{n-1}} \lambda(x)\left(f''(x)\right)^2 dx \qquad (1)$$

where *p* is balance parameter, w_i is the i^{th} element of weight, y_i is the i^{th} measurement, x^i is the i^{th} position, *f''(x)* is the second order derivative of the cubic spline function, and λ^i is the i^{th} element of smoothness. For fitting 0.0003, 1e-5 and 1 was used for weight, balance parameter and smoothness, respectively.

To obtain the roughness curve, the shape curve was deducted from the measurement curve and the following surface parameters were calculated (Fig. 3):

- R_a – arithmetic mean of all deviations from the center line over the sampling path:

$$R_a = \frac{1}{l}\int_0^l |Z(x)|dx \tag{2}$$

- R_z – ten point height – average distance between the five highest peaks and five deepest valleys within the sampling length:

$$R_z = \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_5}{5} \tag{3}$$

- R_v - maximum valley of the profile:

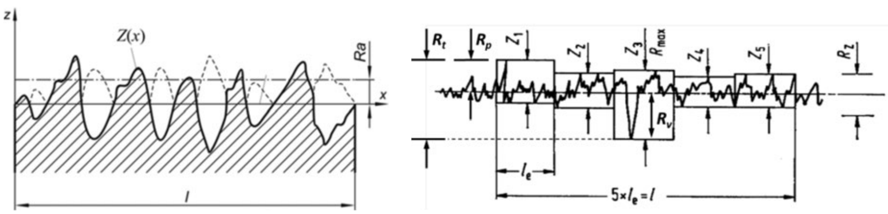

Figure 3: Profile roughness parameters R_a, R_z and Rt [7].

3 RESULTS AND DISCUSSION

Fig. 4 shows the profile of the bottom edge of the plate for the circular saw blade with alternating tooth (WZ) where the height of the saw blade was 20 mm above the workpiece, and the feeding per the tooth was 0.034 mm along with the shape curve, while Fig. 5 shows the roughness for the same measurement section.

Fig. 4 nicely shows a shape where it fluctuates by about 0.1 mm over the length of 100 mm. The fluctuation does not pose any problem for the product, but it could be a big problem for calculating the parameters unless the shape curve is subtracted from the measurements.

Fig. 6 shows the photograph of the edge of the specimen along with the measurements where the correlation between the measurements and the edge quality is shown nicely.

Fig. 7 shows R_a values for all cutting combinations. When the saw height is increased from 10 mm to 20 mm, the values on the upper side of the panel decrease for all circular saw blades. With further increase of the saw blade height, the values further decrease only slightly. It is clear from the graph that the saw blade with WZ teeth at the smallest height had far the worst values, while at bigger heights it is worse by only a small amount.

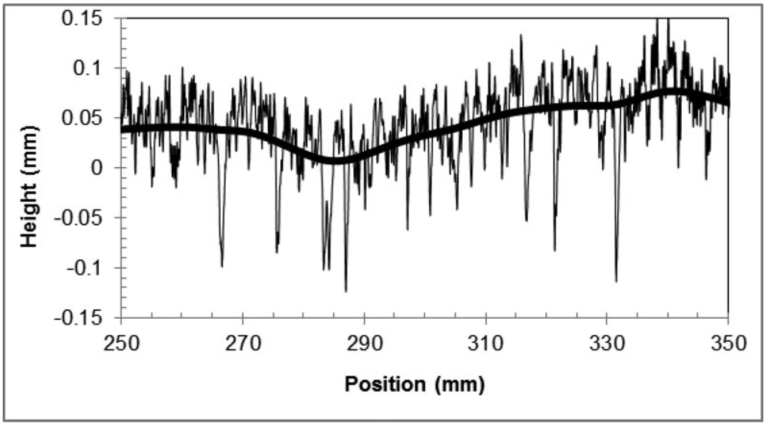

Figure 4: Profile measurement.

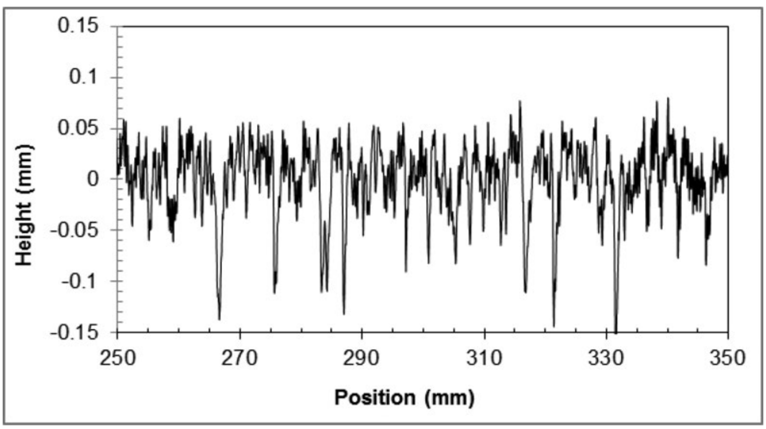

Figure 5: Roughness profile.

It is also evident from Fig. 7 that with a larger feed per tooth e_{z2}, the quality is better than the quality obtained with a smaller feed per tooth e_{z1} for all saw blades. The R_a's analysis for the upper side of the panel shows that sawing with FZ/TR tooth shape produces the best quality regardless of the height of the saw blade above the workpiece, and that sawing at the height of 30 mm above the workpiece gives the best results. Similar findings are obtained in the analysis of R_z and R_v.

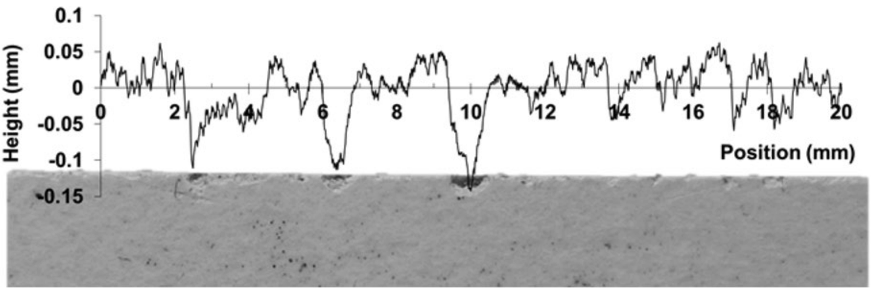

Figure 6: The board edge.

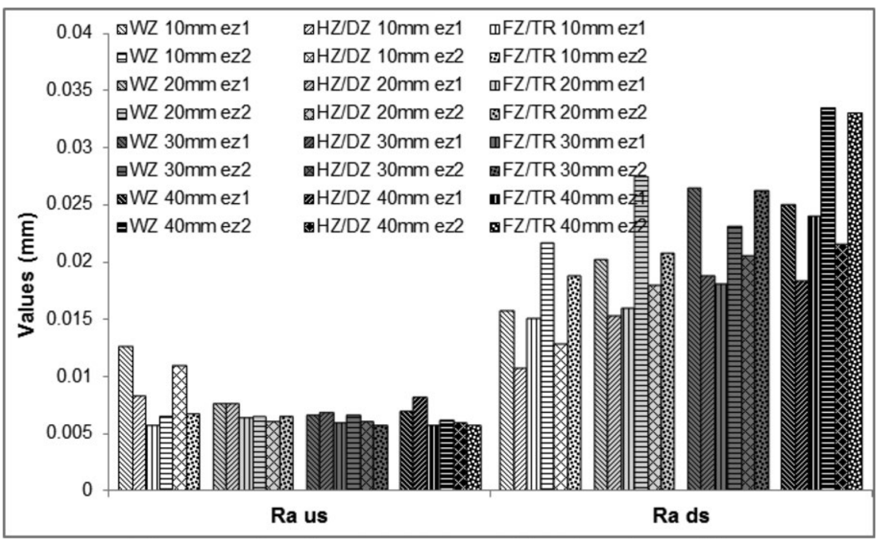

Figure 7: R_a values; us - upper side, ds - down side.

When analyzing the quality of the lower edge, the situation is completely different. It can be seen from all the parameters that the quality on the underside of the plate is decreasing with increasing height of the circular saw blade above the workpiece, for all teeth shapes as well as for both feeds per tooth. It is also evident that sawing with HZ/DZ tooth shape produces the best quality in comparison with the other tooth shapes in all conditions, and that the quality of the edge is the best at the smallest height of the saw blade above the workpiece and with the smallest feed per tooth e_{z1}. The figures also show that the quality of the bottom edge is worse than the quality of the upper side edge in all cases, regardless of the type of saw blade and other parameters.

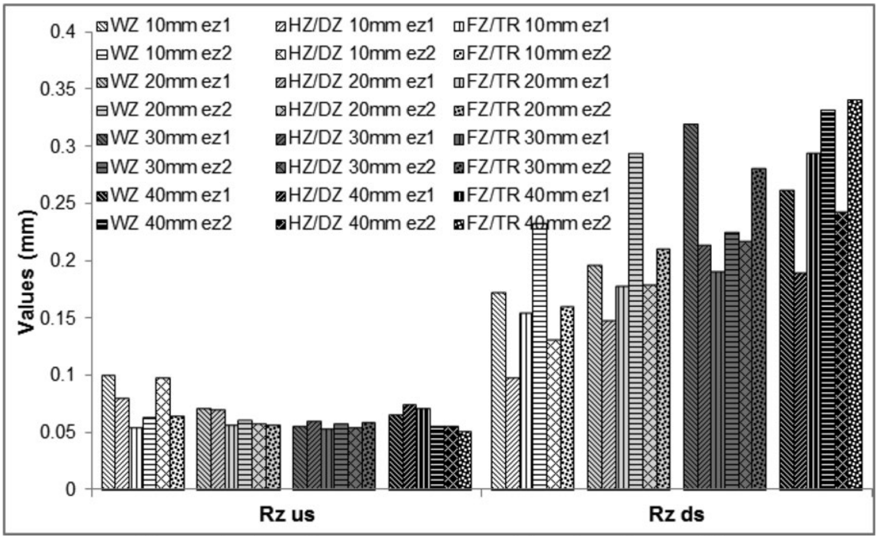

Figure 8: R_z values; us - upper side, ds - down side.

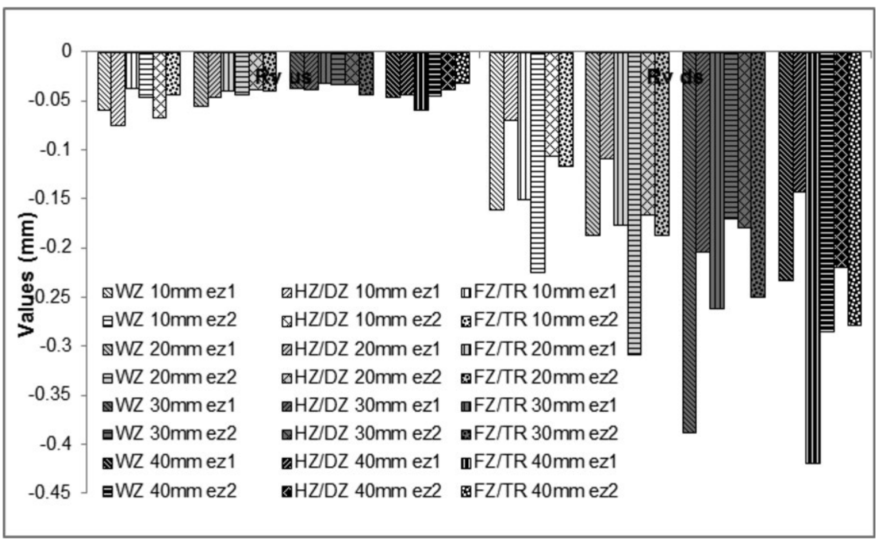

Figure 9: R_v values; us - upper side, ds - down side.

4 CONCLUSIONS

The analysis of melamine faced chipboard cutting with various tooth shapes, heights of saw blades above workpiece and feeds per tooth confirmed the manufacturer's claims that cutting with the saw blade with HZ/DZ tooth shape without scoring saw blade is the optimum choice when cutting at the height of 10 mm above the workpiece. Using the saw blade with the mentioned tooth shape produces the best edge quality on the underside of the panel. But when cutting the melamine faced chipboard with a scoring saw blade the situation is slightly different. In this case, the experiment showed that the quality of the upper side edge is the best when cutting with FZ/TR tooth shape, regardless of other parameters.

ACKNOWLEDGMENT
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REFERENCES

[1] Roel, P. D. D., Cleber, M. S. A., Vieira, H. A. V. (2015) The quality of MDF workpieces machined in CNC milling machine in cutting speeds, feedrate, and depth of cut, Meccanica, 50: 2899-2906.
[2] Szwajka, K., Trzepiecinski, T. (2016) Effect of tool material on tool wear and delamination during machining of particleboard, Journal Of Wood Science, 62: 305-315.
[3] Kminiak, R., Gasparik, M., Kvietkova, M. (2015) The Dependence of Surface Quality on Tool Wear of Circular Saw Blades during Transversal Sawing of Beech Wood, Bioresources, 10: 7123-7135.
[4] Hernandez, R. E., Llave, A. M., Koubaa, A. (2014) Effects of cutting parameters on cutting forces and surface quality of black spruce cants, European Journal Of Wood And Wood Products, 72: 107-116.
[5] http://lexicon.leitz.org/index.
[6] https://en.wikipedia.org/wiki/Spline_(mathematics).
[7] https://in.misumi-ec.com/contents/tech/press/20.html.

AUTONOMOUS SANDING PROCESSES – AN OVERVIEW OVER ANALYTICAL, EXPERIMENTAL AND FUZZY CONTROL PROCESS MODELS

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Abstract
Sanding is an important step in the process chain of surface coating in the furniture industry. Today, highly sophisticated machines are used which machine the wooden surfaces with different sanding processes while the workpiece is passing through the machine. The steps how the machine and the sub processes are set up and controlled today are, in contrast, completely manual and need a specialist with high expertise. The inhomogeneous material, the roughly determined and difficult to measure specifications and quality issues as well as the type of process are the reasons. In most cases where sanding process is used a high number of input parameters, which are also interdependent, affect numerous quality characteristics.

Keywords:
Sanding, Autonomous processes, Process models

1 INTRODUCTION

Compared to other woodworking processes like routing or molding, sanding is quite complex. The desired output is often difficult to define and the success of the process is only obvious after coating or laminating. The tools used are geometrically undefined and can change in a wide range by a couple of non-standardized factors. The machines can also be configured with different aggregates to cover a broad range of applications, but once installed are not able to be reconfigured to an optimized solution. Each process on these aggregates can be not only influenced by selecting different tools/belts but also by changing the specific equipment of the aggregates and determines the machine setup parameters like feed speed, cutting speed, and infeed or pressure. Some of the machine parameters cannot be influenced, like the oscillating frequency of the wide belt.
Sanding processes therefore must be configured, setup, optimized, monitored and controlled by specialists. This is in contrast to the low added value the process brings to the workpiece. Sanding is just the preparation for a subsequent finishing process, which adds the highest value to the workpiece. Workpieces out of wood and wood based materials often create their specific

value for the customer by the appearance. So finishing is important but if sanding could be avoided nobody would care.
This situation in both industrialized and emerging countries enforces the use of more intelligent machines to support barely skilled and trained machine operators instead of specialists. The next generation of machine control systems must be able to perform some of the needed tasks autonomously. This paper will systemize the needs and give an overview of possible solutions for such systems.

2 AIM OF THE PAPER

In the past several attempts have been made to replace the expertise of the operator by a more or less autonomous machine control. Scientists have developed or enhanced some process models explaining the interactions of all process parameters. This paper resumes shortly the state of the art and focuses on process models, which might be used in a machine control system, able to set up and control a machine consisting out of several sanding aggregates. During sanding the wear of the abrasive must be monitored and compensated by certain strategies.

3 METHODOLOGY

An incomplete process model for sanding with constant pressure has been developed by Riegel [1]. It explains the influence of high numbers of input parameters but not all which are necessary. Schneider and Riegel [2] and Kortüm and Riegel [3] show how sequential process might be set up by a nowadays called Cyber Physical System. Licher [4] introduced Fuzzy Control an adaptive control systems in woodworking processes in 1993. Saloni [5] enlarged the sensor techniques of a sanding machine and showed that an adaptive control is possible. Recently experiments have been made to describe the wear of an abrasives at HS-OWL by a model with discrete and fuzzy inputs. These are modules which could be used for an autonomous overall control of a sanding machine. The experimental results of the wear out tests will be shown. The systematical approach will be explained.

4 SANDING PROCESSES

There are different concepts to run a sanding process. If the surface of the rough workpiece is uneven or very high stock removal rates are needed calibrating procedures are made use of. In multiple cutting procedures e.g. to produce glue boards these are the first steps. In the contact zone, the support of the abrasive is very rigid and the workpiece must pass a predetermined gap between the tool and the machine table or moving carpet. Sanding with constant pressure is in contrast used to reduce the roughness, sometimes also the waviness of the workpiece surface.
The cutting direction and so the orientation of the running belt can be in the direction of the feed speed, the direction of the moving carpet, across or rarely in other angles. If solid wood is sanded the feed speed is oriented normally along the grain.
The contact zone can be flat, cylindrical or profiled. The tool or in most cases the supporting element of the abrasive is respectively formed.
The grit size of the abrasive plays a great role for the finish operation. Depending on the needed roughness or the wood species fine grains are used (FEPA P120 P220). With fine grain the cutting roughness is compared to the grain of the wooden surface not visible but the stock removal rate is very low. To get the needed amount multiple cutting processes with aggregates equipped with subsequently rising grit sizes (e.g. P80 – P100 – P120 – P180) are used, in practice some grit numbers get skipped – P80 -> P120, most operators do not know which can be skipped and which cannot be skipped (Fig. 1).

FEPA	P12	P16	P20	P24	P30	P36	P40	P50	P60	P80	P100	P120	P150	P180	P220
µm	1815	1324	1000	764	642	538	425	336	269	201	162	125	100	82	68
ANSI	12	16	20	24	30	36	40	50	60	80	100	120	150	180	220
GOST	160	125	100	80	63	50	40	32	25	16	12	10	8	6	5

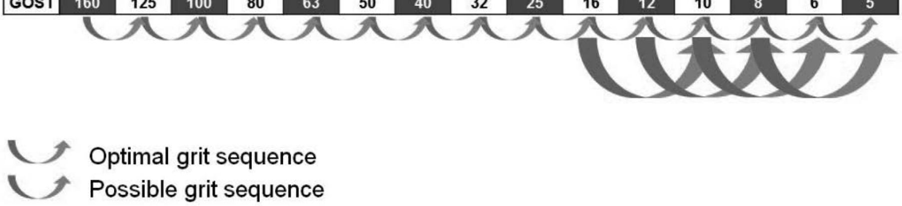

Figure 1: Possible grit sequences.

5 TASKS FOR AUTONOMOUS SANDING

As already pointed out different tasks are needed to determine how a workpiece should be sanded completely. All these tasks are today performed by specialists, well trained or experienced operators. A wide knowledge and intuition are needed to consider all possible influences on the desired process. The situation is getting even worse thus the output of the desired process cannot be precisely defined by the customer. Most likely only in combination with a later coating the sanded surfaces can be evaluated properly. In the meantime, there are certain standards (e.g. VDI 3413 and VDI 3414) supporting the necessary decisions, but due to the high number of attributive quality characteristics and the not yet existing measuring techniques and devices for these characteristics the decisions must be made with cloudy, fuzzy values and logics.

5.1 Configuration

One of the most difficult tasks in autonomous sanding is, which aggregates should be combined to fulfill the surface specification for later coating. Today sales engineers or product managers use their knowledge to configure the sanding head setup. Only in few cases production specialist of the customer are well educated and deeply involved enough to take part in the decision. In most purchasing cases a possible configuration is tested in a demo center of the machine builder. The specific know-how is rarely stored in a database. A classification of use cases with a clear definition of the workpiece quality would be needed but seems to be too difficult at the moment.

5.2 Split of cuts

If the stock removal rate is too high for one sanding operation, the process must be split into sub processes. Also here the know-how of the sales engineers, product managers and application engineers of the machine builder plays the dominating role. In few cases it was possible to predict the needed stock removal rate using the output of preceding process [2] used the pitch of a molding process as input for an experimental, analytical process model of sanding. With a clearer description of the workpiece roughness to be removed by the sanding process and related experimental data [6], this task might be solved in interaction with an expert by algorithms. The output of such algorithms would be in any case only a preliminary split of cut to be proved by experiments but the risk to configure a wrong installation would decrease drastically.

5.3 Setup

For setting up the machine, an input for all machine parameters is needed. There is a more or less logical structure in which sequence the parameters are interdependent and must be determined. Starting with the end grit size of the abrasive, which is more or less a function of the substrates morphology respectively the grain or the desired roughness, the algorithms should take into consideration:

- Backing: needed flexibility or strength of the belt;
- Grain type: estimated forces respectively the density of the workpiece material, penetration of later coatings;
- Stiffness of the contact element: desired flatness or waviness of the raw workpiece;
- Length of the contact element, design of sanding unit: desired sanding surface pattern-oscillation marks;
- Sanding Pressure: danger to produce crushed cells under the surface layer, high abrasive wear;
- Feed speed: in most cases given by subsequent coating processes if machine in line operation;
- Cutting Speed: remaining factor to determine the needed stock removal rate.

Practitioners are often not clearly aware of the sequence of their intuitive decision tree. Further investigations are needed to come to an automatized algorithm by data bases and rule based artificial intelligence. Thus the decisions are not simple Boolean operations a fuzzy machine will be needed. Models to determine the stock removal rate out of main parameters are given; also computer based simulations are possible using one experimental input factor [1]. The stock removal rate is then the leading factor to appoint other important factors like removal of preceding cutting patterns respectively roughness. The resulting roughness can be roughly estimated by the used grit size, but there is at the moment no visible correlation between the sanding efficiency and the resulting roughness [7]. Anyway, a good starting point respectively default setting might be found by using decision trees combined with experimental process models and expert know-how. Other solutions are possible on the base of databases with experimental content, fitting default settings can there be found by decision trees or similarity search.

5.4 Monitor

Abrasives wear by adhesion and abrasion depending on the impact and forces on the belt and grits. The sanding process set up by defined parameters is therefore not static. Roughness and stock removal rate as the main process output parameters decrease over time but nonlinear [8] [1] [9] [7]. Sanding Process must be surveilled and the abrasive belt must be replaced if the stock removal rate is too small. The decision is nowadays made by the operator on the base of output parameters, time or feed length or on simple but ineffective customers standards “change per shift”. Several attempts have been made to support the operator in monitoring or even controlling the process automatically (see below). It is reported that in large scale operations like sanding of chipboards the operator gets an additional input by the ampere meter of the belt drive. Saloni [5] used acoustic emission to get additional signals to monitor, Heisel [10] for the same reason thermal cameras with limited success. In industry dark field illumination is used to enable the

operator to evaluate the surface quality safely and quicker [11]. Imaging systems are also used [12] but seem to have a too high a failure rate in pattern recognition or a too poor resolution for the standard quality characteristics.
A new proposal comes from [13]. He takes into consideration that in the past the control of the stock removal rate on the workpiece side was difficult and/or expensive. To get an integral result of the stock removal rate also the dust can be measured. He suggests to use microwaves dust concentrations measuring systems, which are not expensive and have a sufficient resolution. This needs, on the other hand, a stable and functioning suction system but would be another direction to try.

5.5 Control

Because sanding is a more or less unstable process and the abrasive wear passes in waves and not as a linear trend, it is obvious that automatic control might be a useful strategy. At the moment there are only few procedures in industry known to compensate and control the sanding process actively. The belts are just changed at the end of their lifetime or far beyond. Visual and haptic evaluation to control the changes in surface quality and to determine the end of the lifetime.
For closed loop controls a sensor, an actuator, and a control procedure is needed. As actuator the online changeable machine parameters can be used. Licher [14] developed a strategy for abrasive tool discs how and especially in what sequence to use the different parameters. Licher [4] refined that method further by the use of fuzzy logic algorithms. At the end, the missing component was at that time the right sensor to measure the stock removal rate in process. Acoustic emission and image processing were used by [5] as an input for an automatic control. In consequence of a loaded belt the system automatically used a cleaning technique for the belt. The experimental system was implemented in an industrial machine and worked.

6 MACHINE MODULES

As already explained for a closed loop control sensors, actuators and control algorithms are needed. Saloni [5] proposed a classical methodology to build up a closed loop control (Fig. 2).

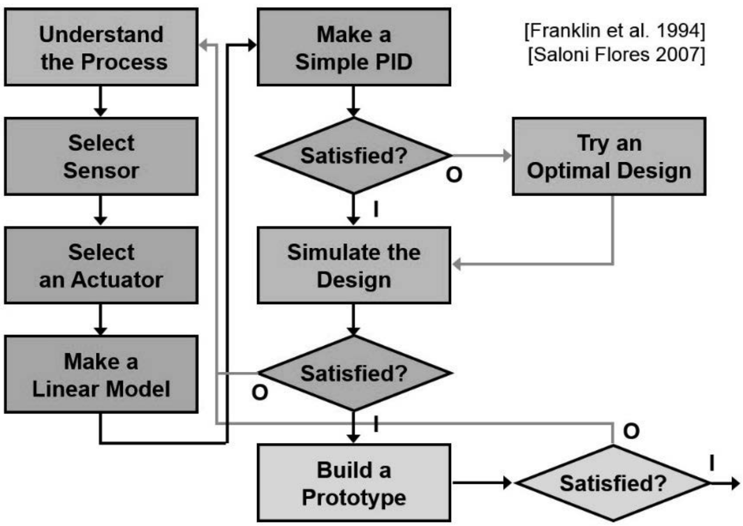

Figure 2: Control system methodology flowchart.

This is in relation to the complex process and task to simple and does not solve any task for autonomous sanding. Indeed it is the best solution to automatize a cleaning process in a sanding machine but cannot be enlarged for all tasks. In relation to the flowchart Fig. 3 shows names of scientists or companies who carried out investigations related to the listed blocks.
Figure 3 points out that the process understanding is poor in relation the process complexity, if the classical methodology should be applied. But even if all blocks are given for a closed loop control, not all tasks for autonomous sanding are taken into account. For the task of setting up the machine a database and a functional computation are required, most modern sanders should already offer the computing requirements, while using IPC's in combination with cloud computing or internet of things (e.g. Homag's "tapio" platform).

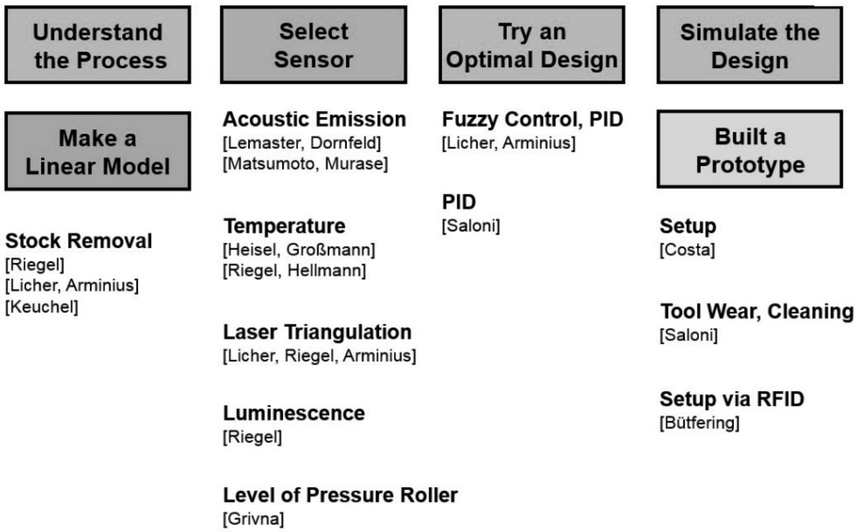

Figure 3: State of the art sanding control.

6.1 Sensors

In science and industry different sensor were used to measure directly or indirectly process or output parameters of the sanding process. A direct measurement of the cutting depth is used in chip or fibreboard production. Contact rollers from top and bottom side are linked with length measurement systems regular in four tracks over the width of the board before and after the sanding machine. These signals are used to control the sanding process and the chipboard press. If the depth of cut is differing the necessary changes are simply split on all aggregates of the machine. One problem is the accuracy of measuring. Depth of cuts is around 0.1 mm. Due to a high feed speed and adhesive wear of the rollers the measurement capability is not given in any case.

Due to the high price of these contact measuring devices there is a strong need to a more simple solution. Laser triangulation is widely used in industry to measure distances to a resolution up to 1 µm with no contact. The tracheid effect [15] might influence the possible resolution and therefore the usability in a small range.

Hellmann et al. [11] propose an almost complete equipment for a surface finishing sanding machine (Fig. 5). They respect the scientific results of Saloni [5] and Heisel [10]. The quality of the sensor signals is also here of high importance for the later autonomous process. Especially a noncontact measurement of the depth of cut would be of high interest. Systems are not available on the market.

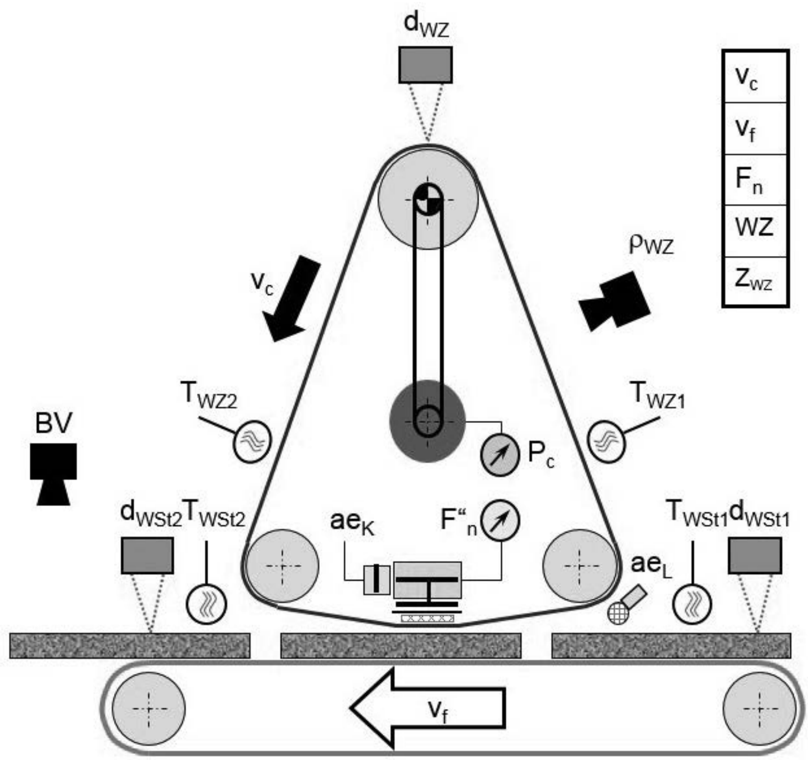

Figure 5: Equipment for autonomous sanding.

6.2 Actuators

All online adjustable parameters of the machine can be used as actuators. These are:

- Cutting speed;
- Feed speed;
- Sanding Pressure in the contact zone in relation to the workpiece;
- Running speed of additional felt rip bands;
- In limits oscillation of the wide belt;
- Cleaning operations.

There is a proposal to vary also the stiffness of the contact zone and length of the cutting zone [16], but this patented system was never introduced to the market. Another proposal was to introduce an extra adjustable high-frequency oscillation for the vacuum carpet [17], besides mechanical problems also this patent was not set to reality in industry. But anyway there are enough actuators to control the process autonomously. The major problem is the insufficient situation on the sensors side.

6.3 Computation

Today sanding machines are more or less controlled by simple PLC's. To improve the human machine interfaces in the past IPC's were introduced and would be able to run additional computations. Computations based on databases would need an access to a server via intra- or internet. This is state of the art. Due to remote diagnosis, which is not so customary in sanding, the connection is anyway existing. Computation is not the limiting factor.

7 DEPLOYMENT OF MODELS AND NEEDED INVESTIGATIONS

To realize autonomous sanding the sanding machine must be equipped with additional sensors and need computational models for set up and control. Riegel [1] pointed out that the in most cases indirect process parameter stock removal rate should be the target value for set up, monitor and control. Roughness parameters and other surface quality characteristics are not strongly correlated with the stock removal rate but sufficiently. Further, the stock removal rate is a necessary value for configuration and the split of cuts. [1] offers a mathematical model to describe the coherences based on few experimental results as an input. Many influencing parameters are not integrated but could be by the above mentioned logical sequence of questions and rules. This could be implemented by artificial intelligence algorithms and fuzzy logic. Some parameters can even be integrated in the model. E.g. it seems to be [18], the grit size according FEPA is approximately decreasing linear to the stock removal rate, but further experiments are needed. To replace the contact rollers to measure the thickness online further investigations must be made to. If the stock removal rate is the crucial factor to monitor and control the efforts must concentrate on reliable adequate sensors for this.

The big issue is the behavior of the abrasive over lifetime. Only in case of abrasive wear the stock removal rate and the roughness parameters are approximately linear decreasing [19]. If the belt is loaded the wear is often inhomogeneous of the area and the linear decrease is superposed by self-cleaning processes increasing the parameters inhomogeneous for a while [1] [7]. Most of the parameters directly influencing the wear are known in practice but there are no models in science at the moment. Saloni's [5] controlled cleaning process was a successful attempt to extend the lifetime of a single belt but not a contribution to a model to predict the lifetime. This is however the crucial duty in the tasks configuration, split of cuts and set up. Especially here more distinct experiments and models are needed. Currently, related experiments are carried out at the OWL University of Applied Sciences.

Besides [2] no investigations and models are known in literature how interlinked processes have to be taken into consideration by splitting up in cuts and in setting up. A model is needed to combine the removal of a pencil mark with different grit size – as a typical test in practice that all cutting marks of the preceding process are removed – with a distinct stock removal rate.

8 CONCLUSION

Autonomous sanding is not anymore a far vision. The computational capacity of the control units of the machine is indeed enough to base possible default values to set up the machine on distinct models also using fuzzy logic and simple rules. To control the process and especially the wear of the abrasive, adequate sensors must be additionally implemented.
The crucial question is the cost to benefit relation. Just to prove the innovativeness of a machine producer an autonomous sanding machine might be too expensive. If the at the moment very intense relations customer and the machine producer respectively the supplier of the abrasive could be reduced, savings high enough might be possible. Today all sanding machines need little supervision by a skilled operator during production. Here only low cost reduction is possible by an autonomous sanding machine.

REFERENCES

[1] Riegel, A. (1997) Holz- und Lackzwischenschliff - Beitrag zur Prozeßmodellierung. Diss. TU Dresden.
[2] Riegel, A., Schneider, B. (2010) Verfahrensintegration Kehlen-Schleifen – Prozessauslegung über ein Prozessmodell. Holztechnologie 51.
[3] Kortüm, C., Riegel, A. (2015) Networked Process Models for Production Chains. In: Proceedings of the 22th International Wood Machining Seminar. ed. Hernandez, R.; Caceres,. C.
[4] Licher, E. (1993) Optimierung von Zerspanprozessen mit veränderlichen Randbedingungen am beispiel der Formatbearbeitung. Diss. TU Braunschweig.
[5] Saloni, D.E. (2007) Process Monitoring and Control - System Design, Evaluation and Implementation of Abrasive Machining Processes. Dissertation North Carolina State University.
[6] Grivna, H. (2004) Principles of Widebelt Sanding & Data Reference Manual. Maple Grove: Sanding Systems Consulting.
[7] Miao, T., Li, L. (2014) Study on influencing factors of sanding efficiency of abrasive belts in wood materials sanding. Wood Research 2014 (59) p. 835-842.
[8] Pahlitzsch, G. (1970) Internationaler Stand der Forschung auf dem Gebiet des Schleifens von Holz. Holz als Roh- und Werkstoff 1970 (28) S. 329-343.

[9] Kalt, R. (2017) Einbeziehung von Verschleiß und Schleifbandtemperatur in die Prozessmodellierung beim Schleifen. Masterarbeit Biel: Berner Fachhochschule.
[10] Heisel, U. (2008) Beurteilung des Verschleißzustandes von Schleifbändern mittels thermographischer Methoden. Abschlußbericht Forschungsvorhaben 15020N-1 IfW Universität Stuttgart.
[11] Hellmann, T., Kortüm, Ch., Riegel, A. (2008) Reproduzierbare Gütebestimmung von Holzoberflächen als Basis für eine Prozessregelung beim Schleifen. Tagungsbreichtsband 2. Internationale Konferenz zur Automation in der Holzwirtschaft, Biel.
[12] Argos (2017) One system for all applications – grading system. (http://www.argossolutions.no/grading-system).
[13] Hausmann, J. (2017) Ansätze für intelligente Steuerungen von Breitbandschleifmaschinen. Bachelorarbeit Hochschule Ostwestfalen-Lippe.
[14] Licher, E. (1992) Adaptiver Regelkreis auf Basis eines Expertensystems für Mehraggregatschleifanlagen. Abschlußbericht, Mülheim: Zenit NRW.
[15] Riegel, A. (2013) A contribution to explain the tracheid effect. Holztechnologie 54 p. 52-54.
[16] Riegel, A. (2000) Schleifvorrichtung. Anmeldung Deutsches Patent- und Markenamt: 2000.
[17] Riegel, A. (2000) Schleifverfahren und Vorrichtung zur Durchführung. Anmeldung Deutsches Patent- und Markenamt: 2000.
[18] Riegel, A. (2006) Der Materialtyp entscheidet – Eigenschaften von bearbeitenten Oberflächen mitteldichter Fasderplatten im Hinblick auf eine 3D-Folienkaschierung. Teil 1 & 2. HOB Die Holzbearbeitung 53 10 & 53 11.
[19] Keuchel, K. (1986) Bandschleifen von Spanplatte – Zylindrische und ebene Eingriffsfläche. Diss. TU Braunschweig.

DURABILITY PREDICTION OF WOOD COATINGS

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Abstract
The aim of this study is to investigate the effects fast changes warm and cold checks cycles on wood finished surfaces. During the testing the influence of number of warm and cold check temperature cycles (1 hour -30°C, 1 hour 50°C) on the quality of finished surfaces and also on the tensile strength of tested coating films. In this contribution, there is also researched the correlation among the changing the quality of physical-mechanical and appearance properties of tested finished surfaces of samples and the changing the tensile strength of investigated coating films prepared from the same coating materials. The results can improve the possibility to predict the durability of coating materials and help the assessment the properties of finished surfaces.

Keywords:
Coating films tensile strength, Adhesion, Cold-check cycles, Roughness, Hardness

1 INTRODUCTION

Wood as the natural construction material in use needs the protection by coating films to keep its beauty, color and integrity. Wood movements due to swelling and shrinking and temperature changing induce stress to the surface coating. Results of this stress between the wood surfaces and coating films are the decreasing quality of physical-mechanical and appearance properties. The aim of the study is based on hypothesis that is the relation among the physical-mechanical properties and the tensile properties of lacquer films [1]. In this contribution, there are presented the results of the investigation of the influence of layers coats numbers on the physical-mechanical properties of furniture finished surfaces. Improving the durability and improving physical-mechanical properties of finished furniture surfaces is essential for the prolonging the life of the furniture [1] [2]. The conclusions of this study could have great influence, not only on the coating performance but also on the quality of wooden-based products. They can help to improve the physical-mechanical properties of finished surfaces of wood because it is supposed that the tensile strain of coating films has significant influence on the performance of finished surfaces. The tensile properties of coating films have not been assessed yet in correlation with physical-mechanical properties.

2 OBJECTIVES

The aim of this study was to identify the relationship between influence of the tensile strength during the tensile strains at break of tested lacquer coating films and the quality of mechanical-physical properties of the finished surfaces coating by the tested lacquers in dependence of number of cold-warm cycles and number of tested coats.

Polyurethane lacquer was tested for the evaluation of the influence of number of cold-warm cycles on the mechanical-physical properties. During one cycle there is changing temperature. One cycle consists of three steps:

1. Step - The samples are put into 50°C for one hour.
2. Step - The samples are taken out from 50°C and they are put into -30°C for one hour.
3. Step - The samples after taking them out from -30°C the sample must stay for 15 minutes in the room temperature 23°C.

After the third step the next cycle immediately continues.

3 MATERIALS, METHODS, EQUIPMENT

One lacquer was tested for the influence of different test parameters.

3.1 Used material

Coating materials: two-component solvent polyurethane lacquer U 1010, the producer Colorlak.

Substrates: chipboard veneered with alder veneer, the dimensions of samples: 250 mm x 150 mm x 18 mm, polytherephtalate foils.

3.2 Preparing the samples

Polyurethane finished surfaces of chipboard veneered with alder veneer

The tested polyurethane lacquer was applied to samples of chipboard veneered with alder veneer. The used way of samples finishing was spraying. The amount of wet coating lacquer varied from 127 g.m^{-2} to 133 g.m^{-2} (one wet layer of polyurethane lacquer) and from 259 g.m^{-2} to 265 g.m^{-2} (two wet layers of the polyurethane lacquer).

Table 1 shows the amount lacquers applied on the surface of the samples of chipboard veneered with alder veneer.

Free coated films of polyurethane lacquer

The tested lacquer was applied to on polytherephtalate foil by using the laboratory film applicator. The coatings were removed from the foil in controlled environmental conditions immediately after drying/curing took place. The tested films were carefully detached by hand. (using the scalpel).

The size of the samples of films was 50 mm x10 mm x 2 mm. The specimens were oriented longitudinally.

3.2 Used test methods and standards

Adhesion Paints and varnishes cross-cut standard ČSN EN ISO 2409
ČSN EN ISO 4287 Geometrical product specifications (GPS) - Surface texture: Profile method - Terms, definitions, and surface texture parameters;
ČSN 91 0282 Methods of determining the surface light resistance
BS 3962 part 6 The resistance of finished surfaces to mechanical damage - the impact tests;
ČSN EN ISO 2815 Bucholz indention tests
Tensile tests were performed using test devices of the company Instron 3365 Machine Serial Number Locator with measurement software Bluehills;
ČSN EN ISO 527-3 Determination of tensile properties Part 3 The conditions for films and foils;
ČSN EN ISO 527-1 Determination of tensile properties Part 1 General principles;
ČSN 673098 Determination of resistance to change of temperature.

3.3 Used equipment

Universal Testing Systems INSTRON, 3365, with software Bluehill 2
Laboratory coated applicator BYK,
Laboratory oven Venticell,
Laboratory freeze box,
Indentation Hardness Tester, Bareis,
Device for measurement of Surface roughness, Mitutoyo

4 RESULTS AND DISCUSSION

On the Figures 6, 7, 8 and 9 there are possible to observe the influence of number cold-check cycles on physical-mechanical properties of the tested finished surfaces of the chipboards veneered with Adler veneer. Tested properties hardness and roughness of finished surface were measured in longitudinal direction along fibers and across fibers. All results introduce the influence the number of cold-check cycles on surface roughness and hardness in comparison with changes of tested properties hardness and roughness of surface of the reference sample. The reference sample wasn´t exposed to temperature changes during the cold-check cycles.
The results of the investigation the influence of the cold-check cycles on the tensile stress at break are shown in the Figures 1, 2, 3, 4 and 5. The impact of the aplicate layers of coat could found in Table 2 and 3 and in Figure 5. The second layer of polyurethane lacquer decreasing the strain at break that means the second layer of coats declines the quality of free films. In Table 2 here issued results of measuring of the tensile strains at break in dependence of number cycles cold-check cycles and number of coat layers. The mean

values and standard deviations of assessed properties were determinate. The Figures 1, 2, 3 and 4 have been showing the behavior of the coating films during the tensile tests. The great differences in behavior of different samples have appeared during testing of tensile strain at break especially before starting the cold-check cycles. The cold-check cycles have an impact on the increasing of the quality of finished surfaces especially on roughness longitudinal direction of measurement along fibers.

Table 1: Amount of applicate wet polyurethane lacquer.

Amount of lacquer coating	1.layer $g.m^{-2}$	2.layer $g.m^{-2}$	1. + 2. layers $g.m^{-2}$
Average sample	130	132	262
Reference sample	128	125	253
Free coated film	140	117	257

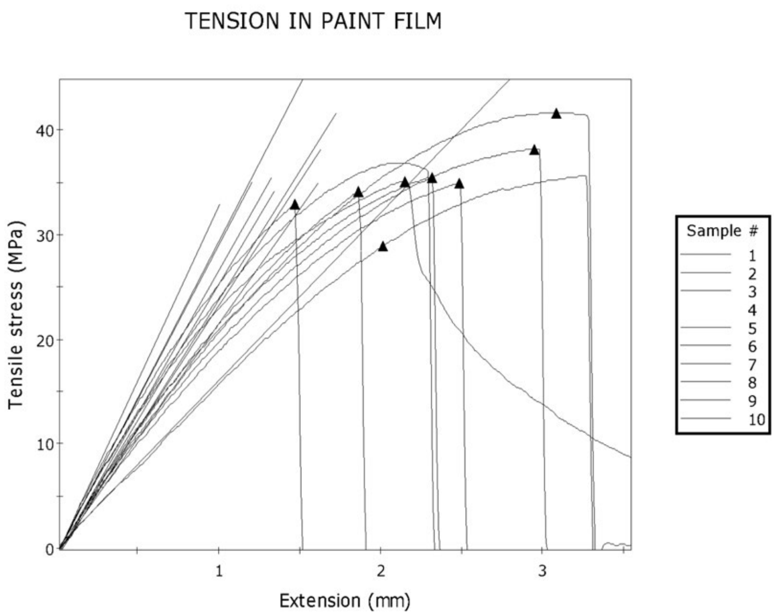

Figure 1: Tensile stress at break of free films, one layer and 0 cycles.

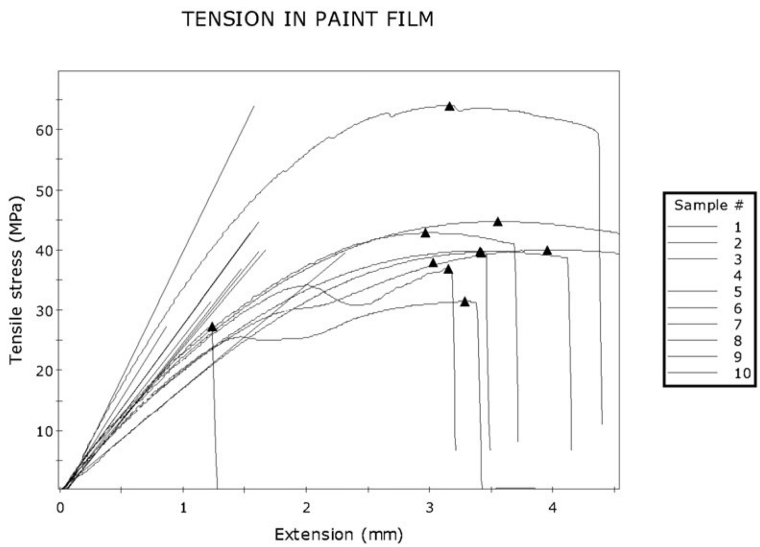

Figure 2: Tensile stress at break of free films, two layers and 0 cycles.

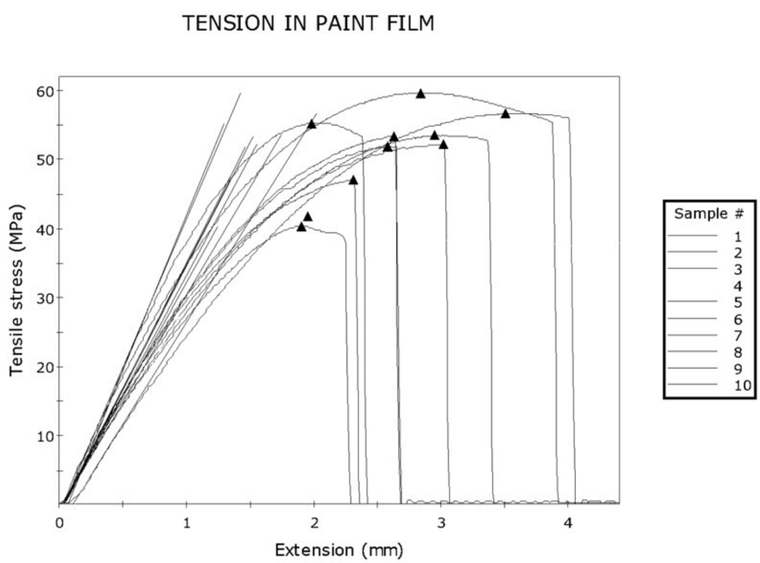

Figure 3: Tensile stress at break of free films, one layer and forty cycles.

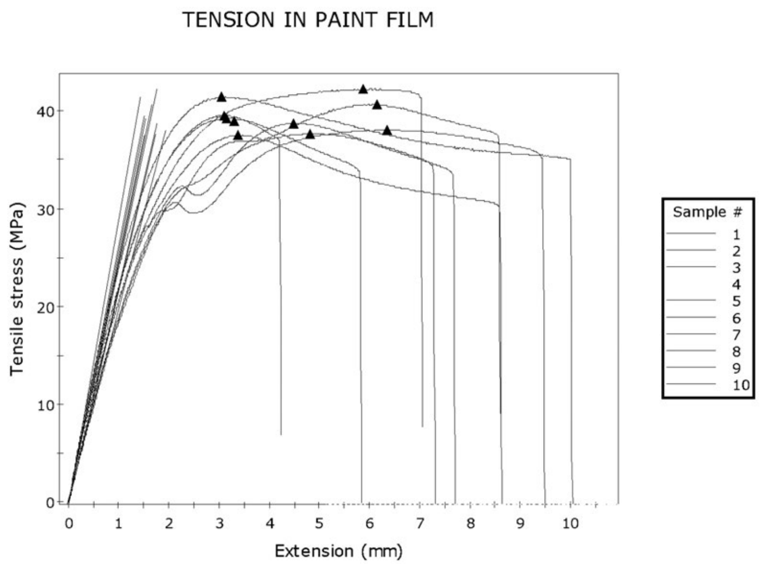

Figure 4: Tensile stress at break of free film, two layers and forty cycles.

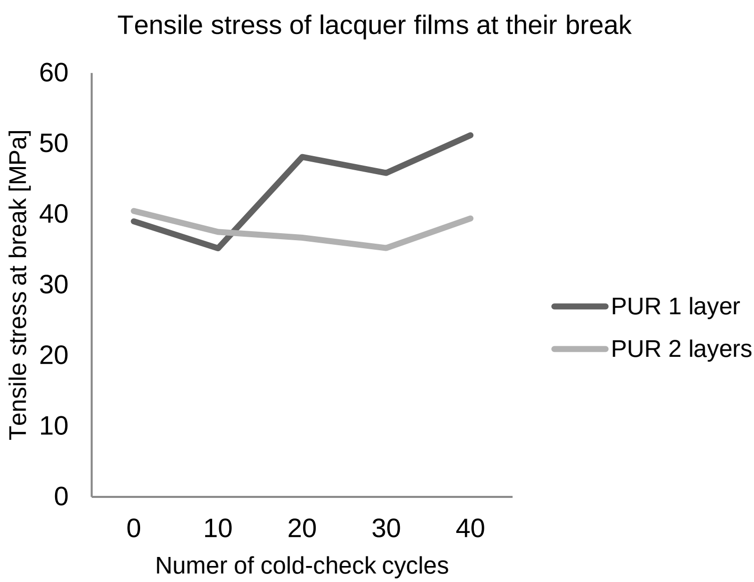

Figure 5: Tensile stress of lacquer films at their break.

Table 2: Tensile stress of lacquer film finished by one layer of polyurethane lacquer.

Number of cold-check cycles	σ_t [MPa] 0	σ_t [MPa] 10	σ_t [MPa] 20	σ_t [MPa] 30	σ_t [MPa] 40
Average	39,013	35,19	48,129	45,86	51,188
Maximum	56,959	38,652	56,793	50,766	59,69
Minimální	28,881	28,505	33,343	37,823	40,365
Standard deviation	8,3505	3,2108	6,6693	3,6409	5,934
Median	35,315	36,235	50,519	46,696	52,792

Table 3: Tensile stress of lacquer film finished by two layers of polyurethane lacquer.

Number of cold-check cycles	σ_t [MPa] 0	σ_t [MPa] 10	σ_t [MPa] 20	σ_t [MPa] 30	σ_t [MPa] 40
Average	40,4691	37,4962	36,6965	35,2242	39,4205
Maximum	64,049	42,715	41,471	39,172	42,257
Minimální	27,408	25,658	30,268	29,823	37,507
Standard deviation	9,2322	4,41572	3,51735	2,50394	1,51257
median Medián	39,69	37,924	37,2215	34,8615	39,148

Table 4: Surface hardness - direction of measurement along fibers.

	Hardness [mm] 0 cycle	Hardness [mm] 10 cycles	Hardness [mm] 20 cycles	Hardness [mm] 30 cycles	Hardness [mm] 40 cycles
Average value	-0,010	-0,010	-0,010	-0,012	-0,010
Reference sample	-0,013	-0,013	-0,012	-0,016	-0,015

Table 5: Surface hardness - direction of measurement across fibers.

	Hardness [mm] 0 cycle	Hardness [mm] 10 cycles	Hardness [mm] 20 cycles	Hardness [mm] 30 cycles	Hardness [mm] 40 cycles
Average value	-0,009	-0,010	-0,010	-0,010	-0,010
Reference Sample	-0,010	-0,010	-0,010	-0,011	-0,011

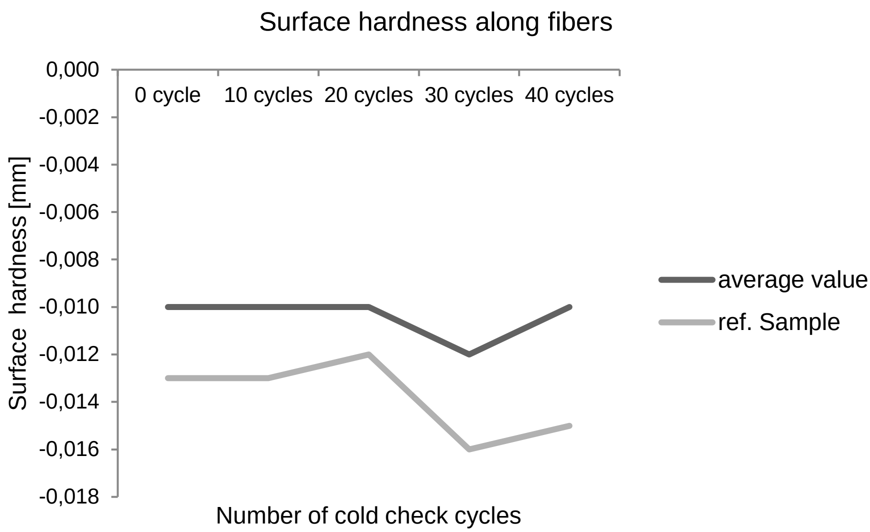

Figure 6: Changes of hardness tested surface - direction of measurement along fibers.

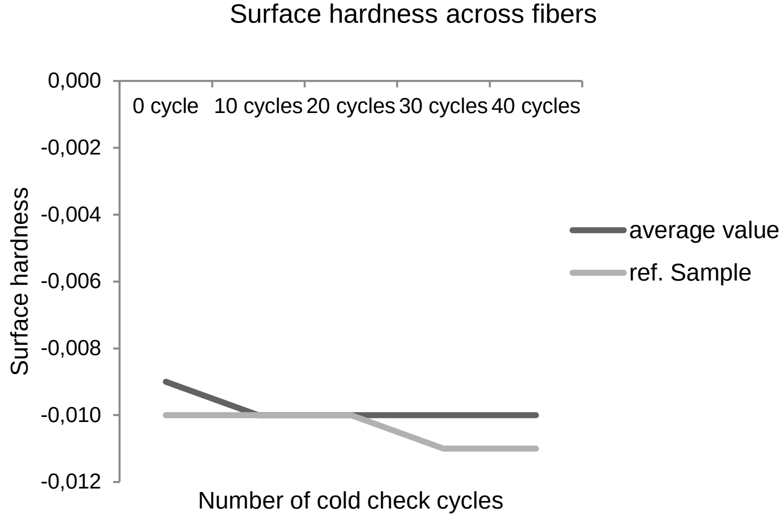

Figure 7: Changes of hardness tested surface - direction of measurement across fibers.

Table 6: Surface roughness - direction of measurement along the fibers.

	r_a [µm] 0 cycle	r_a [µm] 10 cycles	r_a [µm] 20 cycles	r_a [µm] 30 cycles	r_a [µm] 40 cycles
Average of roughness	0,898	0,6987	0,78667	1,0798	0,843
Reference sample	1,128	1,28	1,02	0,9	1,054

Table 7: Surface roughness - direction of measurement across the fibers.

	r_a [µm] 0 cycles	r_a [µm] 10 cycles	r_a [µm] 20 cycles	r_a [µm] 30 cycles	r_a [µm] 40 cycles
Average of roughness	1,044833	0,7785	0,921333	0,920333	0,9485
Reference sample	1,15	1,25	1,16	1,29	1,07

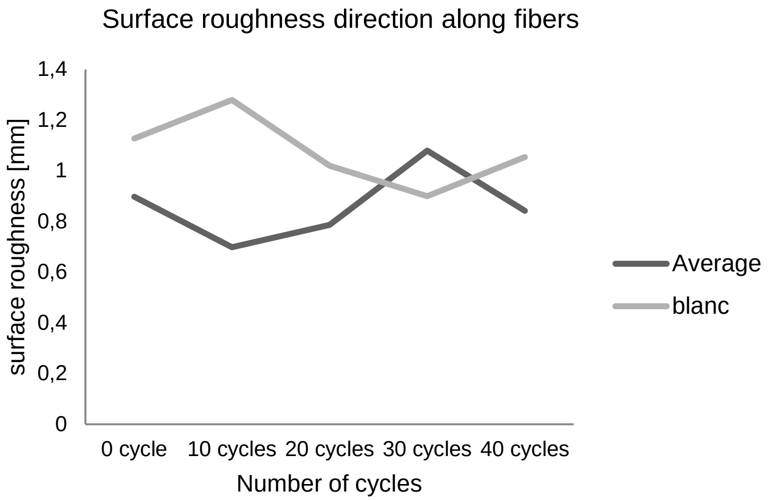

Figure 8: Changes of roughness tested surface - direction of measurement along fibers.

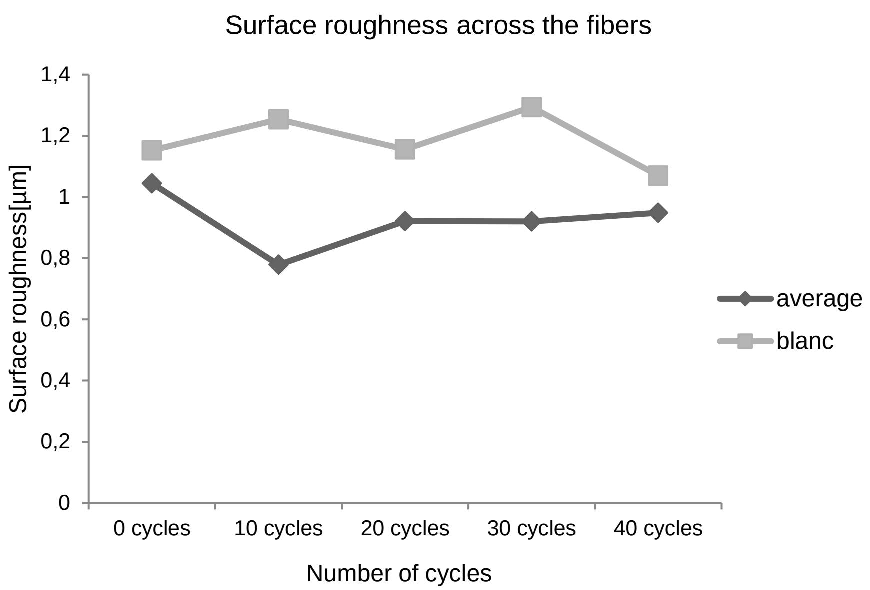

Figure 9: Changes of roughness tested surface - direction of measurement across the fibers.

5 CONCLUSION

The important results have been reached in this contribution. When the results of physical-mechanical properties (surface roughness and surface hardness) of finished surfaces after the exposure of forty cold-warm cycles were compared with the results of tensile stress at break of free lacquer films after the exposure of forty cold-warm cycles also the relationship between tensile stress at break of free films the correlation was found.
The results of surface hardness are summarized in Figures 6, 7, Tables 4, 5 and roughness of surface are expressed in Figures 8, 9, Tables 6, 7 and the forces at break of lacquer films are shown in Figure 5, Table 2 and 3. When all results were put together it was possible to compare them. These achieved and compared results confirmed our hypothesis about the relationship between the physical-mechanical properties of lacquers films and ultimate tensile stress of free coating films. The results of surface hardness and roughness especially in direction along the wood fibers are improving its properties in dependence of number of cycles. The improving of properties means the decreasing the value of roughness and the depth of the penetration into the surface during the measuring its hardness.
The results of the assessment of tensile stress at break of free coating films, expressed in Figure 5 and Table 2, proved improvements of the tensile stress at their break of free coating films in dependence of number of cold-warm cycles. The values of the tensile stress of free coating films are increasing with the higher number of cold-warm cycles. This dependence applies especially to a paint film consisting of only one layer of paint film. The second layers of lacquers have decreased the tensile stress at break that means, higher amount of coatings layers have reduced the quality of the finished surface.
The harmonization of the tensile test conditions for free wood coatings is mandatory before taking about threshold values or limit for mechanical properties. This study has showed it is very important to investigate the tensile stress of free coating films during the developing the coating materials.

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REFERENCES

[1] Podgorski, L., Meijer, M.D., Lanvin, J.D. (2016) Influence of coating formulation on mechanical properties and weathering performance 10th Wood coating congress, Amsterdam pp. 7,1.
[2] Schrip, C., Bausmstak, R. (2016) News about testing of films mechanics of exterior wood coatings-Parametrs, challendges and possibilities 10th Wood coating congress, Amsterdam pp. 3,3.

[3] Musche, N., Erdodi, G., Bird, J., Pourahmady, N. (2016) Unique self-crosslinking polyurethane for wood coatings 10th Wood coating congress, Amsterdam pp. 3,3.

[4] Huxol, A., Riegel, A., Dekomien, K. (2015) Development of an algorithm for measuring the quality of high gloss surfaces correlated to human perception, 5th International Conference on Production Engineering and Management, 99 – 110, Hochschule Ostwestfalen-Lippe and University of Applied Sciences, Universita degli studi di Trieste, ISBN978-3-9416445-11-0.

[5] Schulz, U. (2009) Accelerated testing: nature and artificial weathering in the coatings industry, in Hannover, Vincentz Network, ISBN 978-386630-908-1.

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The proceedings of the seventh International Conference on Production Engineering and Management, held between September 28 and 29, 2017 at the University of Trieste (Italy), collect the works carried out by professors, lecturers, researchers, graduates and students of the University of Trieste (Italy), the OWL University of Applied Sciences, Lemgo (Germany) as well as experts from other European universities and from industry. The main aim of the seventh edition of the conference has been to cover a broad range of topics and to bridge the gap between theory and practice in the field of Production Engineering and Management by offering an occasion where academia and industry could discuss practical and pressing questions. The topics of the conference therefore include not only production technologies and management in a narrower sense, but also new aspects of direct digital manufacturing, of lean management, of innovation techniques and methodologies, along with different topics of high interest for the wood processing and furniture production and addresses sustainable and revolutionary developments in modern industry.

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